



Review

# Mortiño (*Vaccinium floribundum* Kunth): An Underutilized Superplant from the Andes

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**Abstract:** Mortiño is a member of the Ericaceae family native to the Andes that has been used by local communities for centuries. This species has shown potential in the areas of medicine, agronomy, and green technology. We used a multidisciplinary approach to review aspects related to the ecology, horticulture, composition and potential biotechnological applications of mortiño. As interest in this species grows, care must be taken to identify opportunities that justify its sustainable use while emphasizing the development of local communities. Mapping the wide variety of potential uses and the current state of conservation and utilization of this berry will help researchers to better target mortiño's potential.

**Keywords:** ecology; genetic diversity; domestication attempts; polyphenols; anthocyanins; medicinal plant; antioxidant; antimicrobial; green technology

## 1. Introduction

*Vaccinium* spp. generally produce sweet berries with a very pleasant flavor [1] that are usually consumed fresh as well as in jams, drinks, and desserts. The berries of *Vaccinium* spp., such as blueberries (*Vaccinium corymbosum*) and cranberries (*Vaccinium macrocarpon*), are rich in phenolic acids, flavonoids, proanthocyanidins, coumarins, hydrolyzable tannins, carotenoids, and anthocyanins [2]. Moreover, they are considered “superfruits” due to their antioxidant capacity and potential health benefits [3,4]. The traditional uses and cultural values as well as the bioactive components of *Vaccinium* berries have promoted the cultivation and the study of potential applications of these species in pharmacy, nutrition, and health [5].

In Ecuador, three species of *Vaccinium* are registered, including *Vaccinium distichum*, *Vaccinium crenatum*, and *Vaccinium floribundum*, the last being the most common [4]. Mortiño

(*Vaccinium floribundum* Kunth)—also known as Andean blueberry—is native to the tropical Andes of Ecuador, Colombia, and Peru [6]. The interest on mortiño as an alternative crop in tropical Andean countries benefited from the popularity of the other *Vaccinium* berries promoted as superfruits [4]. As a result, production and consumption of various *Vaccinium* berries have almost quintupled in the last 15 years [7]. However, domestication of mortiño has not been accomplished, and the use of this berry still relies on fruit harvesting from wild plants [3], which can potentially affect the conservation of the species and the balance of those ecosystems. Therefore, the analysis of new applications for mortiño should be accompanied by a holistic approach integrating ecological, horticultural, and cultural aspects associated with the growth of this plant.

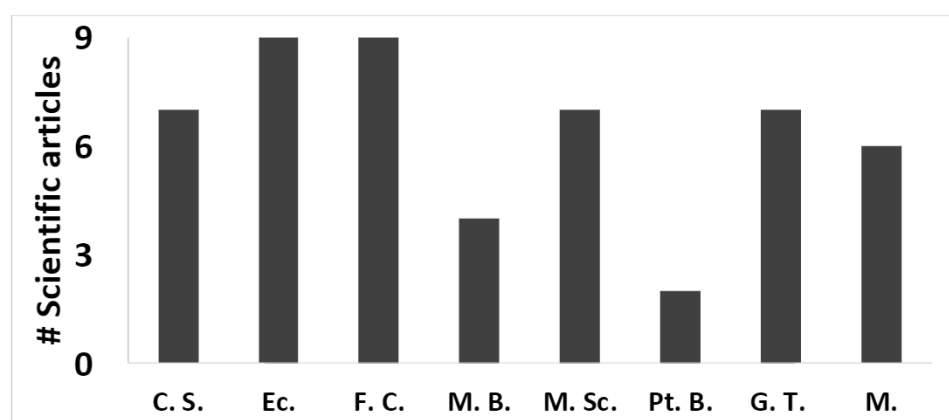
The sustainable applications of mortiño in pharmacy, nutrition, and health have the potential to support the development of local communities and promote human health [8]. The objective of this work was to review the horticultural and biochemical aspects of mortiño and promote the development of new knowledge that could lead to fair and sustainable use of this species from the tropical Andes.

## 2. Literature Search and Systematic Analysis

The PubMed, Elsevier, NCBI, Scopus, and Google scholar databases were used to search for articles on the genus *Vaccinium* and—more specifically—on *V. floribundum*. Keywords such as polyphenols, anthocyanins, antioxidant, antimicrobial, medicinal property, in vitro propagation, ethnobotany, genetics, green technology, and pharmacological activity of mortiño were used.

Studies in areas classified as cultivation strategies, ethnobotany and ecophysiology, chemical characterization, molecular characterization, antimicrobial characterization, medicinal properties, and green technology were taken into account.

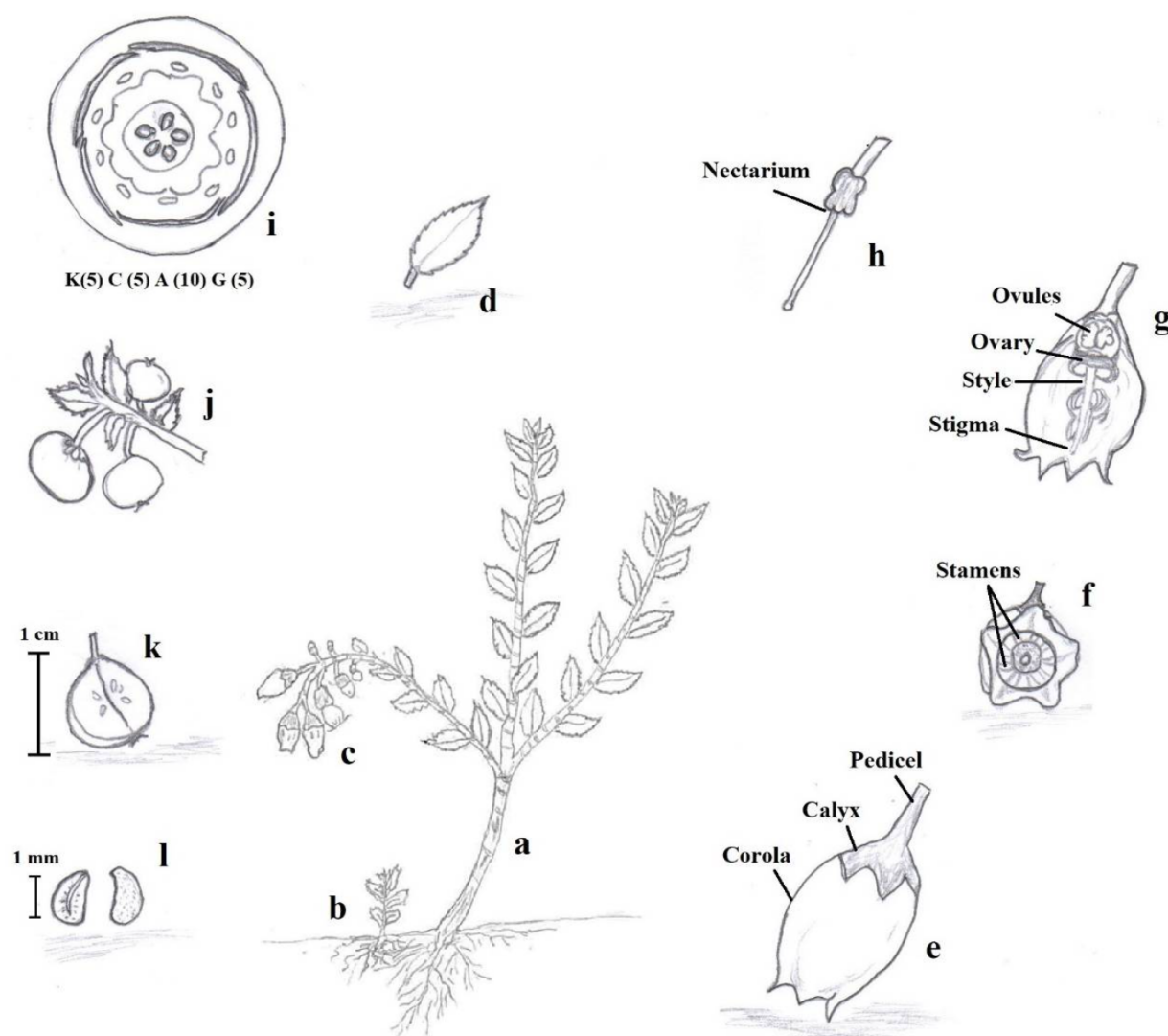
More than 200 articles on the genus *Vaccinium* were reviewed, including scientific articles as well as undergraduate and graduate theses, but only 65 were selected to be referenced in this review, of which 48 talked about *V. floribundum*. It should be noted that 17.5% of the scientific articles belonged to institutions in the United States and Europe, whose research focused mainly on the medicinal properties of mortiño [9] including chemopreventive properties [5], inhibition of adipogenesis, and inflammation [10], among other topics. On the other hand, the articles from other countries such as Ecuador focused on cultivation strategies as well as food chemistry and molecular biology of mortiño, in which European and US universities also participated. The most studied scientific areas of *V. floribundum* in Andean countries were ecology followed by food chemistry, green technology, and cultivation strategies (Figure 1).



**Figure 1.** Different studies on *Vaccinium floribundum* published around the world on topics such as cultivation strategies (C.S.), ecology (Ec), food chemistry (F.C.), molecular biology (M.B.), medicinal properties (M.Sc.), berry pretreatment (Pt. B.), green technology (G.T.), and manufacturing (M).

### 3. Origin, History, and Botany of Mortiño

Native to the tropical Andes of Colombia, Ecuador, and Perú [6,11], mortiño is commonly found at high altitudes on the edges of cold and humid paramos [12]. Mortiño commonly grows at temperatures between 7 and 18 °C [6], on rocky surfaces as a shrub reaching 2.5 m height, often prostrate or scandent [13]. It is one of the first species to grow back from root sprouts after fires in the paramos, playing a key ecological role in the regeneration of the ecosystem [14]. Mortiño leaves are small, coriaceous, elliptic, and ovate to ovate–lanceolate (Figure 2). The flowers are white to pink or red developed on racemes of 6–10 flowers, while the fruits are small (5–8 mm diameter) blue-black glabrous spherical berries at maturity [15] (Figure 3).



**Figure 2.** Description of *Vaccinium floribundum* Kunth: Semi-woody stem that can measure up to 2.5 m in height (a), Roots with their root hairs that, when they come to the surface, give rise to a seedling (b), White to lilac flowers in racemes of 6 to 10 (c), Elliptical, oval, or oval–lanceolate leathery leaves, with crenate-serrated edge, cuneate or round base, and slightly rounded acuminate apex (d), Corolla and Calyx (e), Vertical view of stamens (f), Gynoecium (g), Nectaries (h), Floral diagram of the Ericaceae (i), Round bittersweet berries of bluish to black color (j), Fruit in longitudinal section (k), Recalcitrant seeds of approximately 1 mm in size (l). Source: Herbarium of the Interpretation Center of the Protective Forest “La Prosperina” (BPP—Ar001E), of the Escuela Superior Politécnica del Litoral (ESPOL), Guayaquil—Ecuador, by Botanist Jaime Naranjo (Co-author).



**Figure 3.** Mortiño plant (*Vaccinium floribundum* Kunth) with its floral primordia (A), A small bunch of flowers with some pigmentation (B), Serrated leaves and its ripe berries (C). Source: This article.

During its development, the fruit color transitions from green to white-pink, to pink, and finally to blue-black [16]. Fruit development after anthesis takes roughly between 60 and 100 days under natural conditions [17]. Taxonomically, *V. floribundum* has traditionally been classified within the Pyxothamnus section in the genus *Vaccinium* along with *V. consanguineum* and *V. ovatum*. However, phylogenetic analysis of tribe Vaccineae suggested *Vaccinium* is not monophyletic with *V. floribundum*, forming a clade along with *V. consanguineum* and *V. meridionale*, separate from other *Vaccinium* spp. [17].

Since it was first described in 1825 by Kunth as *Vaccinium floribundum* from the collections of Bonpland, the taxonomy of mortiño has varied little over the years. However, some common synonyms for the species have been reported, including: *V. crenulatum*, *V. marginatum*, *V. ramosissimum*, *V. polystachium*, *V. mortinia*, *V. moritzianum*, *V. dasygynum*, *Metagonia crenulate*, and *M. marginata* [12]. Common names for *V. floribundum* are many and often used ambiguously to identify other related species such as *V. meridionale*, *Thibaudia floribunda*, or *Macleania rupestris*. For instance, in Ecuador, mortiño is the most used vernacular name for the species; however, it is also known as uva de los Andes (grape from the Andes), manzanilla del cerro (chamomile from the hill), raspadura quemada (burnt panela), and uva de monte (mountain grape). In Peru, it is known as pushgay, uvitas, congama, and macha macha, whereas in Colombia it is also known as mortiño, agraz, agracejo, and chivaco; nonetheless, here, the name mortiño is more often associated with *V. meridionale* [6].

The consumption of this fruit was common in the Andean region before the arrival of the Europeans; later, it was assimilated into criollo traditions associated with the All Souls' day, which continues to this day [6]. Currently, the species is mainly found in the wild, but it is also often present in smallholder farms [18].

#### 4. Ecology and Genetic Diversity

Like many other neotropical Ericaceae, *V. floribundum* predominates in belts of moist and cool montane forest preceding the transition towards the colder Paramo (cold and moist ecosystem typical of the high mountain in the Andes between the treeline and the snowline) between 3000 and 4500 m.a.s.l. [19,20]. On the slopes of the Rumiñahui volcano,

near Quito (Ecuador), *V. floribundum* has commonly been observed in landscapes dominated by *Calamagrostis intermedia* and *Carex jamesonii*, although many other species, mostly dicots including other Ericaceae such as *Pernettya prostrata*, have been found growing in close spatial association to *V. floribundum* [21].

*V. floribundum* typically thrives in cold, nutrient-poor, moist though well-drained, shallow, and acidic soils [14]. The shrubs show remarkable adaptations to these conditions, such as shallow and almost horizontal root systems as well as profuse sprouting from roots and other vegetative tissues. These characteristics make *V. floribundum* one of the first species to regenerate damaged paramo ecosystems [14], drawing attention to ecosystem restoration programs in the Andes. Furthermore, *V. floribundum* has been reported as one of the species more often visited by a variety of bird and insect pollinators [22,23]. Adaptation to these environmental conditions is probably aided by association with specific soil microorganisms, as evidence of interactions between the *V. floribundum* rhizospheric microbiome and soil chemical properties has been reported [24]. Similarly, ericoid mycorrhiza forming fungi have been reported in *V. floribundum* roots, potentially contributing to the development of the species in nutrient-limited soils [21].

Currently, the conservation status of *V. floribundum* populations remains unknown. However, in Ecuador, mortiño is considered highly diverse—a typical characteristic of wild populations—and has shown both geographical and altitudinal patterns of diversification [25]. Still, concerns about the conservation of the species in scenarios of increasing demand of the berry and unsuccessful domestication efforts could pose risks, both to the species and to the paramos where it grows. For these reasons, interest in developing propagation techniques amenable for commercial cultivation has been recently growing in Colombia, Ecuador, and Peru [8].

## 5. Domestication Attempts

Mortiño berries have been extracted from wild populations since pre-Columbian times, when the fruit was reportedly used by the Quitu-Cara people in preparations for the celebration of their deceased [26]. After the arrival of the Spaniards, this tradition was assimilated in the emerging *criollo* culture in the form of “colada morada”, a traditional drink still consumed today around All Soul’s Day in Ecuador [6,27]. Coinciding with these festivities, peak production for mortiño berries occurs between October and November in Ecuador, although the fruit can be found in lower quantities throughout the year [27]. Relationships between environmental factors and flower/fruit development in mortiño have not been explored, and further research is needed to better understand the effect of climate on fruit production of *V. floribundum*. Other uses of mortiño by local people span from medicinal uses (allegedly as an ailment for rheumatism, fevers, colics, common colds, hangover, and liver and kidney problems), to ornamental (mainly for the color of its foliage and to form hedges), to uses as dye, fodder, or firewood [27].

In recent years, the discovery of potential health promoting properties and the growth of the market demand for berries have fueled interest in domesticating the species, a task that, to this day, remains challenging. For instance, the *in vitro* propagation of the species has been affected by the presence of detrimental microorganisms in the wild explants of mortiño. Those microorganisms have been particularly difficult to eliminate with simple disinfection methods, so the use of methyl *N*-[1H-benzimidazol-2-yl) carbamate has been proposed for disinfection of the cuttings in micropropagation studies of *V. floribundum* [28].

Propagation by seed is likely the main form of dispersion of the species in the wild, although it is not considered a convenient method for commercial uses. Germination of mortiño seeds has been reported to be high and fast, reaching 64 to 76% germination 40 days after seeding on tissue paper and 95% germination in agar [29]. However, development of the seedlings after germination is rather slow, at 2 cm/month or slower [13]. As in other Ericaceae species [30], light has been reported to enhance the germination of *V. floribundum* [31].

Wild populations of mortiño in Ecuador showed high diversity, suggesting random crossing of this species [25]. Such high diversity, while ecologically advantageous, could be difficult to manage in commercial plantations where some degree of homogeneity in the plant biology is desirable. Nevertheless, being a diploid [32,33], high diversity of mortiño, derived from adaptations to different environmental conditions [16], might provide a rich gene pool for launching selection and breeding programs to develop locally adapted materials [25,34].

Most commercial *Vaccinium* berries are clonally propagated either by stem cuttings or using in vitro techniques [26]. Both methods have also been tested for the propagation of mortiño, with varying degrees of success. Studies have tested both cuttings and micro cuttings on different substrates and rooting agents, with very low success [26]. Differences in the degree of rooting have been reported between young (25 to 47% rooting) and semi-hard (8.1 to 24% rooting) wood cuttings from *V. floribundum*; in both cases, rooting was still considered very low [16]. On the other hand, better rooting was reported when using lignocellulosic residues such as rice husks and pine sawdust in contrast to more compact substrates such as peat or sand. However, rooting still remained below 50%, which was inefficient to support commercial propagation [26].

Similarly, in vitro propagation has been assayed with moderate success in mortiño. The in vitro establishment of axillary buds required high initial concentrations of cytokinins (TZR) and the acclimatization showed a low yield [31]. A complete regeneration of mortiño plants through axillary bud culture has been reported using 6-( $\gamma,\gamma$ -Dimethylallylamino) purine (2iP) instead of TZR to successfully induce sprouting [35]. Survival rate after transfer to a peat plus vermiculite substrate was above 75% in all the treatments; additionally, the average growth rate in the 14 weeks after transfer to the substrate ranged between 1.67 and 2.16 cm/week. However, after a second transfer to paramo soil, the overall survival rate fell to 46.6% due to fungal infection, while growth was arrested in some of the plants [35]. Studies that follow the fate of these plants after establishment under field conditions are still needed to assess the feasibility of domesticating mortiño from micropropagated plants. The increased availability of micropropagated plants could allow horticultural evaluation of mortiño production systems to begin, an activity that can benefit from the current knowledge attained from similar *Vaccinium* berries, such as blueberries.

In nature, the rhizosphere of *Vaccinium* spp. has coexisted with specialized fungal communities such as ericoid mycorrhizal fungi and dark septate endophytes [36], including *Leotia lubrica*, *Leotia viscosa*, *Arbutus menziesii*, *Arctostaphylos uva-ursi*, *Rhizoscyphus ericae*, and *Acephala applanata*, among others [32,37]. These symbiotic fungi can play a fundamental role in the adaptation and acclimatization of mortiño seedlings obtained from in vitro culture since this fungal species can mitigate different types of stress by promoting a greater tolerance to harmful elements and facilitate access to nutrients [33,38]. Researching symbiont candidates to improve the establishment of mortiño plants in substrates and field conditions remains an underexplored field of research.

## 6. Chemical Composition of Mortiño

The berries from *Vaccinium* spp. are known for their substantial amounts of sugars, polyphenols, vitamins B and C, minerals, and anthocyanins [39]. Table 1 shows the bromatological parameters and Table 2 describes works on mortiño phytochemistry.

**Table 1.** Physical and bromatological parameters of the *Vaccinium floribundum* berry.

Parameter/Units	Value	Reference
Soluble solids g/100 g	10.9	[40]
Ash g/100 g	0.4	[40]
	0.4	[41]
Protein g/100 g	0.6	[40]
	0.7	[41]

Table 1. Cont.

Parameter/Units	Value	Reference
Carbohydrates g/100 g	14.5	[40]
	16.9	[41]
	18.1	[42]
Fat g/100 g	0.6	[40]
	1	[41]
Calories kcal/100 g FW *	84	
	75	[42]
Water %	80	[41]
Fiber %	7.6	[41]
	2.9	[42]
pH	3.8	[42]
Fe (mg/100 g FW)	0.64 ± 0.2	[41]
K (mg/100 g FW)	607 ± 73	[41]
Ca (mg/100 g FW)	17.0 ± 2.3	[41]
Mg (mg/100 g FW)	10.2 ± 1.1	[41]
Cu (mg/100 g FW)	0.12 ± 0.02	[41]
Zn (mg/100 g FW)	0.13 ± 0.02	[41]

\* FW = Fresh Weight.

Table 2. Bioactive compounds from *Vaccinium floribundum*.

Compounds/Analysis Technique/Units *		Reference
Total polyphenols By the Folin-Ciocalteu method (mg GAE/100 g)	Fresh: 524.4 ± 4.5	Powder: 495.6 ± 9.1
	204.01 ± 12.50	
	882 ± 38	
	2167 ± 835	
	7254.62 ± 1209.17	
	Chimborazo Province: 107.4 ± 6.7	Pichincha Province: 146.1 ± 13.4
Total phenols By spectrophotometry:		
Total phenols (mg GAE/100 mg)	608.05	[41]
Total phenols (mgPgEq/g)	1.9 ± 0.7	[45]
Total phenols (mg GAE/g)	9.3 ± 1.4	[45]
<b>Anthocyanins</b>		
Total anthocyanin (pH differential) mg/100 g	Chimborazo Province: 89.9 ± 0.6	Pichincha Province: 1095.4 ± 19.2
Anthocyanin mg/g; (C3G equivalent)	10.6	
Total anthocyanin (%)	Fresh: 11.1 ± 0.5	Powder: 2.3 ± 0.6
Anthocyanin (mg cyanidin/100 g)	345	
Anthocyanin mg/100 g	376.2 ± 49.9	
Proanthocyanidin mg/g dry weight (epicatechin equivalent)	5.2	
Proanthocyanidin (%)	Fresh: 5.3 ± 0.5	Powder: 4.6 ± 0.3
Flavonoids (Spectrophotometry):		
Total flavonoids (mg EC/g)	6.5 ± 0.7	[45]
Flavonols total content mg/100 g	41.6 ± 10.2	[5]
Flavonols glycosides	38	[41]

Table 2. Cont.

Compounds/Analysis Technique/Units *		Reference
<b>Other compounds (By spectrophotometry)</b>		
Total tannins (mg TAEq/g)	4.2 ± 0.8	
Vit C mg/100 g	45.9 ± 6.7	[45]
Carotenes (µg/100 g):		
-B-carotene	70.6 ± 2.0	
-Lutein	866.6 ± 7.5	
Neochlorogenic acid	1.5 ± 0.5	[5]
Chlorogenic acid	9.5 ± 2.9	
Quercetin and myricetin	-3-O-hexosides, -3-O-pentosides and -3-O-deoxyhexosides	[41]
Hydroxycinnamic acids	Predominance of acids: chlorogenic, neochlorogenic and derivatives of caffeic/ferulic acid	

\* GAE = Gallic acid equivalent; C3G = cyanidin-3-glucoside; TAEq = tannic acid equivalent.

*V. floribundum* berries have shown high amounts of polyphenols, with levels reaching up to  $7254.62 \pm 10.86$  mg GAE/100 g [44]. The most representative phenolic acids and flavonols reported in mortiño were quercetin-3-O-arabinofuranoside, chlorogenic acid, and quercetin-3-O-galactoside [5].

In comparative studies, other superfruits such as *Prunus serotina* showed lower levels of polyphenols than those found in mortiño, with reported concentrations of  $1494 \pm 385$  and  $2167 \pm 835$  mg GAE/100 g for each species, respectively [43]. Similarly, a higher content of phenolic acids and flavonols was observed in *V. floribundum* ( $41.6 \pm 10.2$  mg/100 g FW) when compared to *V. myrtillus* ( $13.7 \pm 0.2$  mg/100 g FW) [5]. In another study, the content of total soluble phenolic of mortiño ( $882 \pm 38$  mg GAE/100 g FW) was almost double that of guava (462 mg GAE/100 g FW) and plum (440 mg GAE/100 g FW); furthermore, it was four times higher than the values observed in strawberry (238 mg GAE/100 g FW) but less than half the content in the Andean blackberry (2167 mg GAE/100 g FW) [41].

Anthocyanins are other important components in *V. floribundum* berries, accounting for up to 67% of their total phenolic compounds [41]. Delphinidin-3-arabinose and cyanidin-3-arabinose have been reported as the most abundant anthocyanins in mortiño [10]. Values from  $376.2 \pm 49.9$  [5] to 1095.39 mg/100 g FW [3] of anthocyanin content in blueberry have been reported, exceeding that observed in *V. myrtillus* ( $568.8 \pm 8.8$  mg/100 g FW) [5]. However, sample processing can reduce the levels of anthocyanins, as commercial mortiño powder showed lower levels of these bioactive compounds compared to fresh berries [10]. On the other hand, the levels of proanthocyanidins observed in *V. floribundum* (5.2 mg/g dry weight epicatechin equivalent) were higher than those in *Aristotelia chilensis* berries (4.0 mg/g DW EE) but lower than the values observed in *V. myrtillus* (13.7 mg/g DW EE) [10].

Lastly, it is also very important to know the content of P, Mn, Se, and I of mortiño berries. Unfortunately, to date there are no studies that provide this information. Further research is needed to assess the mineral content of mortiño berries.

## 7. Factors Influencing the Chemical Composition and Genotype of Mortiño

The variability observed in the chemical composition and genotype of *V. floribundum* has been related to climatic and geographic influences [3,12]. A geographic pattern has been associated with the genetic diversity of *V. floribundum* [12]; in addition, the influence of geoclimatic factors on the genetic and chemical composition of mortiño has been proposed [3]. These observations differ from the negligible effect of the growing location on the fruit composition observed in other *Vaccinium* species [47,48]. Further research is needed to understand the factors that influence the nutraceutical quality of the mortiño berries.

It has been observed that the levels of polyphenols and other bioactive compounds can vary significantly according to the geographical location of the mortiño plants, as well as the growing conditions influenced by radiation, altitude, and temperature [3]. In the



same way, fruit development and ripening along with the processing of the samples for analysis can cause the observed variations in the levels of polyphenols, ranging from 100 to 5000 [44] or even up to 7254.62 [44] mg GAE/100 g.

Only few studies have attempted to characterize the effect of the genotype on the composition of *V. floribundum*. Some studies on other *Vaccinium* species showed that biometric and nutritional parameters were not affected by the cultivar or the cultivation altitude. Still, the fresh mass and volume of the fruit, as well as the crude protein and crude fat, varied significantly between cultivars, although their dry mass and energy content were similar in the samples tested in a previous report [47]. Furthermore, the levels of bioactive compounds were affected by the genotype, and the manipulation of varieties through traditional breeding or advanced biotechnological methods has been suggested as a tool to modify the patterns and composition of *Vaccinium* species [49]. Another study showed that the antioxidant capacity of different *Vaccinium* species ranged from 13.9 to 45.9  $\mu\text{mol TE/g}$  of fresh berries and 63.2 to 282.3  $\mu\text{mol TE/g}$  of dry matter, and rose as fruit ripeness increased at harvest. Anthocyanins and the total phenolic contents also increased as the fruit ripened, but the growing location did not affect the levels of these bioactive compounds in the berries [48].

## 8. Biological Activities of Mortiño

Due to the high amounts of polyphenols, anthocyanins, and antioxidants, mortiño has shown various bioactive properties. Table 3 shows some of the antimicrobial and medicinal properties of mortiño. Several studies have shown the antimicrobial capacity of *Vaccinium* spp. For example, *V. corymbosum* extracts inhibited the growth of various pathogens such as *Salmonella* spp. [50] and *Listeria monocytogenes* [51], while *V. macrocarpon* prevented the growth of *Bacillus cereus* and *Micrococcus luteus* [52]. Similarly, two studies have reported the antimicrobial capacity of mortiño. In one study, mortiño extracts obtained from lyophilized fruits or leaves in 70% ethanol inhibited the growth of 12 species of human pathogens, with inhibition halos ranging from  $4.3 \pm 0.3$  to  $39.7 \pm 0.2$  mm. The reported inhibition halos were greater than those observed when the antibiotic ampicillin was used [3]. Similarly, aqueous pulp and peel extracts of mortiño inhibited the growth of *Streptococcus mutans* ATCC35668 [46].

Various medicinal properties have been attributed to *V. floribundum*, including potential applications in managing the symptoms of diabetes [9] and protection against oxidative stress [45]. Additionally, anti-inflammatory properties of mortiño have been suggested, as phenolic extracts of this species decreased the production of inflammatory mediators such as nitric oxide (NO), prostaglandin E2, and cyclooxygenase-2 in lipopolysaccharide-stimulated RAW 264.7 macrophages [10]. Similarly, mortiño has been proposed as an inhibitor of adipogenesis, since proanthocyanidin-rich extracts of *V. floribundum* significantly prevented lipid accumulation in adipocytes and increased the expression of the preadipocyte factor 1 (Pref-1) by 4% in preadipocytes, a value higher than the 2.2% reached by *A. chilensis* but similar to the 5.9% achieved by epigallocatechin gallate used as a positive control (5.9%) [10]. Likewise, proanthocyanidins from mortiño successfully inhibited the enzymes  $\alpha$ -glucosidase and  $\alpha$ -amylase in vitro, with a 50% inhibition concentrations ( $\text{IC}_{50}$ ) of 35 and 25  $\mu\text{g/mL}$ , respectively, suggesting a potential use of this berry for diabetes therapy [9].

The berries of *V. floribundum* have also shown a high antioxidant capacity ranging from  $0.339 \pm 0.01$  g/mL to  $0.69 \pm 0.03$  g/mL [8,10], comparable to that of *V. myrtillus* ( $0.42 \pm 0.01$  g/mL) [5]. Through the Trolox Equivalent Antioxidant Capacity test,  $250.01 \pm 2.0$   $\mu\text{mol TE/g FW}$  was reported in mortiño, which was higher than the  $1.52 \pm 3.1$   $\mu\text{mol TE/g FW}$  observed in the berries of *Rubus glaucus* [45]. Due to its high antioxidant capacity, mortiño has the potential to protect human cells against oxidative stress. Crude extracts of *V. floribundum* attenuated the damage to Human Dermal Fibroblasts (HDFa) caused by oxidative stress, providing better protection than *Rubus glaucus* extracts [45]. However, no chemopreventive activity of mortiño was observed in mu-

tagenicity and genotoxicity tests against 4-nitroquinoline-1-oxide (4-NQO) using SOS Chromotests [5]. Further research is needed to assess the potential antioxidant and radical scavenging applications of *V. floribundum*. In vivo studies, either in clinics or other controlled environments, are still needed to confirm the health benefits of mortiño.

**Table 3.** Medicinal properties of *Vaccinium floribundum*.

Biological Activity	Main Findings	References
Modulatory capacity of adipogenesis	<ul style="list-style-type: none"> <li>- Phenolic extracts inhibited lipid accumulation by 10.8% to 37.9%</li> <li>- Proanthocyanidin increased Pref-1 expression in preadipocytes</li> </ul>	[10]
Anti-inflammatory capacity	<ul style="list-style-type: none"> <li>- Phenolic extracts decreased NO production by 25.5%; inducible NO synthase expression by 55.5%; prostaglandin E2 (ng/mL) by 20.1%; and chloxygenase-2 conversion by 62.0%</li> </ul>	
Diabetes therapy potential	<ul style="list-style-type: none"> <li>- Proanthocyanidins inhibited <math>\alpha</math>-glucosidase with <math>IC_{50} = 35 \mu\text{g/mL}</math> and <math>\alpha</math>-amilase with <math>IC_{50} = 25 \mu\text{g/mL}</math></li> </ul>	[9]
Chemopreventive activity	<ul style="list-style-type: none"> <li>- No significant antimutagenicity and antigenotoxicity activity was observed</li> </ul>	[5]
Protection against oxidative stress	<ul style="list-style-type: none"> <li>- Crude extracts attenuated the oxidative damage in HDFa caused by the stressor 2,2'-azobis(2-amidinopropane) dihydrochloride (AAPH) and improved the oxidative damage markers compared to the control.</li> </ul>	[45]
Antimicrobial capacity	<ul style="list-style-type: none"> <li>- Fruit and leaf extracts significantly inhibited the growth of 8 Gram-negative and 3 Gram-positive bacterial strains</li> </ul>	[3]
	<ul style="list-style-type: none"> <li>- The pulp and peel extracts of the mortiño inhibited the growth of <i>S. mutans</i> at the in vitro level</li> </ul>	[46]

## 9. Other Uses of Mortiño

There is a growing interest on plant antioxidants for green technology applications. For this reason, mortiño has been used in the synthesis of nanoparticles and solar cells.

The synthesis of nanoparticles commonly requires the use of toxic chemicals that serve as reducing agents. As a result of its high antioxidant capacity, mortiño has the potential to replace hazardous molecules for green production of nanoparticles. Mortiño extracts with high antioxidant capacity have been used for the green synthesis of graphene and functionalization of this material, with silver nanoparticles yielding a highly efficient photocatalyst [53]. Similarly, mortiño extracts were applied as a reducing and stabilizing agent for multicomponent nanoparticles (MCNPs) [54] and zero-valent iron nanoparticles (nZVIs) for bioremediation studies [40,55]. The resulting MCNPs showed >99% removal efficiency of toxic metals in water [54], whereas the zVIs removed at least 80% of total petroleum hydrocarbons (TPH) in contaminated water and soil [55]. The researchers indicated that the efficient formation and stabilization of the nZVIs was probably related to the -OH and -COOH groups from the berry polyphenols.

Additionally, mortiño extracts have also served as sensitizers for dye-sensitized solar cells, yielding efficiencies between 0.18 and 0.26% [56]. Table 4 shows some of the applications of mortiño.

**Table 4.** Other applications of *Vaccinium floribundum*.

Applications	Main Findings	Reference
Synthesis of zero-valent iron nanoparticles (nZVIs) for environmental remediation	- <i>V. floribundum</i> was used as a reducing and stabilizing agent yielding nZVIs of $13.2 \pm 5.9$ nm diameter	[43]
	- <i>V. floribundum</i> was used as a reducing and stabilizing agent yielding nZVIs of 5 to 10 nm diameter - Removal of 88.3% of TPH from water (94.20 mg/L) - Removal of 81.9% of TPH from the soil (5000 mg/kg)	[55]
Production of multicomponent nanoparticles (MCNPs) for removal/immobilization of heavy metals from water and in soils	- <i>V. floribundum</i> was used as a reducing and stabilizing agent yielding MCNPs of 12 nm diameter - MCNPs made from mortiño removed or immobilized heavy metals from water and soils with >95% efficiency	[54]
Synthesis of silver–graphene nanocomposites with photocatalytic activity	- <i>V. floribundum</i> was used as a reducing agent. - The nanocomposites showed high photocatalytic degradation of methylene blue (92%; $k = 0.0163283 \text{ min}^{-1}$ ) and methylene orange (84%; $k = 0.0140985 \text{ min}^{-1}$ )	[53]
Biosynthesis of silver nanoparticles with photocatalytic activity	- <i>V. floribundum</i> was used as a reducing agent yielding nanoparticles of $20.5 \pm 1.5$ nm diameter - The nanoparticles showed high photocatalytic activity against 5 mg/L methylene blue with $k = 0.00707788 \text{ min}^{-1}$	[57]
Elaboration of dye-sensitized solar cells (DSSCs)	- <i>V. floribundum</i> was used as a photosensitizer in DSSCs showing a power conversion efficiency of 0.33%, open circuit voltages of 0.520 V, and short-circuit photocurrent densities of $1.014 \text{ mA cm}^{-2}$	[58]
	- <i>V. floribundum</i> was used as a photosensitizer in DSSCs showing an energy conversion efficiency of 0.18–0.26%	[56]

Mortiño has also been used in the wine industry [59,60], baking [61], and even in the production of mortiño gummies [62]. The bioactive compounds of mortiño have attracted much interest in various sectors, which is why several methods have been proposed for the conservation and long-term storage of this berry, including short exposure to UV-C [63] and drying pretreatments [64] (Table 5). In a study, it was shown that after a storage period of 21 days, UV-C-treated ( $12.5 \text{ kJ m}^{-2}$ ) mortiño retained 90% of the original anthocyanin levels compared to 76.85% of the untreated berries. However, the concentration of polyphenols was similar in both UV-C-treated and untreated berries [63]. Surprisingly, dry mortiño retained 93% of the anthocyanins and all the polyphenols in a storage period of 8 weeks [64]. However, other food processing technologies have been detrimental for the bioactive compounds of mortiño. Compared to lyophilization, heating in a sand bath to obtain a commercial mortiño powder yielded significantly lower levels of bioactive compounds such as anthocyanins ( $2.3 \pm 0.6$  vs.  $11.1 \pm 0.5\%$ ), proanthocyanidins ( $4.6 \pm 0.3$  vs.  $5.3 \pm 0.5\%$ ), total phenols ( $495.6 \pm 9.1$  vs.  $524.4 \pm 4.5 \text{ mg/g}$ ), and antioxidant capacity ( $3.3 \pm 0.1$  vs.  $8.3 \pm 0.4 \text{ mmol/g}$  Trolox equivalents estimated by Oxygen Radical Absorbance Capacity (ORAC)) [10] (Table 5). In general, the processing of berries can degrade the anthocyanins naturally present in the fruits [65] (Table 3). Therefore, the pre-treatment of mortiño using UV-C represents a non-chemical approach to complement the treatment for low temperature storage, especially to maintain the anthocyanin concentration. Table 5 shows some of the preservation studies carried out on mortiño.

**Table 5.** Berry quality preservation studies.

Application	Main Findings	References
UV-C treatments for quality preservation of <i>V. floribundum</i> berries	<ul style="list-style-type: none"> <li>- The exposure to UV-C prior to storage improved the antioxidant capacity (AC) retention of the berry</li> <li>- Retained 90% of the anthocyanins compared to 76.85% of the control</li> </ul>	[63]
Drying pretreatment for <i>V. floribundum</i>	<ul style="list-style-type: none"> <li>- Best drying conditions: 40 °C, airflow of 0.24 m<sup>3</sup>/s, immersion bath concentration of 1.55% K<sub>2</sub>CO<sub>3</sub> (<i>w/w</i>)—1.25% of ethyl oleate (<i>v/v</i>), concentration of SO<sub>2</sub> 2000 ppm and sulfidation per 2 h</li> <li>- The dried product retained 98.2% of anthocyanins and 99.7% of polyphenols</li> <li>- The mortiño dried by a solar dryer hybrid retained 88.5% of anthocyanins and 99.7% of polyphenols</li> </ul>	[64]
Winemaking	<ul style="list-style-type: none"> <li>- Andean berries are a suitable raw material to produce wines with antioxidant capacity comparable to red grape wines</li> </ul>	[1]

## 10. Future Prospect of Mortiño

Today, berries are common cash crops of global demand due to the excellent quality of the fruits and their potential health benefits and have historically been used for medicinal purposes [9]. Local communities in Ecuador have traditionally used the plant to treat various medical conditions, including diabetes and inflammation. In addition to the pharmaceutical potential, the cosmetic potential of mortiño has also been proposed due to the intense color of the pigments in this berry [9].

With the advancement in food processing technologies, commercial mortiño is now available in the markets in different presentations: powder, capsules, and wines, known as Wine of the Andes [1]. These are all indicators of the growing popularity of this plant. Even so, mortiño has not been marketed yet as a functional drink, and uses of the by-products from this plant have rarely been proposed. To make a functional drink from mortiño, it is necessary to investigate its nutraceutical and quality parameters such as color, minerals, phytochemicals, and antioxidant capacity as well as its biological activities, such as the inhibitory effects of  $\alpha$ -glucosidase and lipase in the final product, with due scientific rigor [66]. Similarly, mortiño by-products could be used to provide added value to cereals and other nutritional snacks, minimizing the cost of waste management for the agro-industrial area [67]. Both consumers and the scientific community expect more exciting results from superfruit products in the upcoming years [4].

Mortiño pigments showed the potential to replace the toxic chemicals commonly used as reducing agents for the synthesis of nanoparticles for the production of solar cells [53] and removal of hydrocarbons [55], among others. Therefore, applications of *V. floribundum* in green nanotechnology should continue to be explored.

Experts indicate that the demand for berries of the various domesticated *Vaccinium* species will continue to grow in the near future [68]. However, mortiño is still generated exclusively through traditional reproduction. Methods such as hybridization and controlled selection as well as in vitro reproduction are still needed. Nevertheless, studies on genetic markers continue to fill the genomic databases of *Vaccinium* and results that will contribute to improve efficiency of mortiño multiplication are beginning to emerge [25]. Even so, more genetic studies are still needed.

## 11. Conclusions

Superfruits that have exceptional nutrients and a high content of phytochemicals—particularly phenolic acids and flavonoids—with remarkable antioxidant activity and enormous nutraceutical potential, such as mortiño, are being increasingly used. Research has shown that many of the active principles in both berries and leaves of mortiño are

highly desirable for the nutraceutical, food, wine, and pharmaceutical industry, as well as for green technology processes in the synthesis of nanoparticles for the sensitization of solar cells and the elimination of petroleum hydrocarbons or heavy metals. Despite its great potential and ethnobotanical history among indigenous communities, mortiño remains a wild species vulnerable to extinction due to the destruction of its habitat. Therefore, the achievement of an effective in vitro reproduction methodology should also be prioritized to promote the conservation and sustainable use of this natural resource.

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