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Perspective

Chilean Wild Berries and the Chemical Cost of Domestication: A New Path for Functional Foods?

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Abstract: Chilean native berries such as *Ugni molinae*, *Aristotelia chilensis*, *Berberis darwinii*, and *Berberis microphylla* offer significant potential as sources of bioactive ingredients due to their complex profiles of secondary metabolites. Unlike fully domesticated crops, these species are in an early stage of domestication, preserving chemical defense traits and diverse phytochemical profiles that are typically reduced during breeding processes focused on yield and palatability. This early domestication phase maintains a functional balance between growth and defense, promoting the accumulation of phenolic compounds, volatile organic compounds, and other defense-related phytochemicals. These compounds not only enhance the nutritional and functional properties of the fruits but also play key roles in ecological interactions, such as pollination, herbivore resistance, and pathogen defense. Additionally, they influence sensory attributes like aroma, astringency, and color, which are crucial for consumer acceptance and perceived quality. We propose that these underutilized native berries present a strategic opportunity for developing sustainable, health-oriented food systems. By harnessing their unique phytochemical richness and ecological resilience, it is possible to cultivate these wild species as high-value crops without compromising their functional integrity. Understanding the trade-offs between growth and defense is essential to inform future breeding and valorization strategies. In doing so, Chilean native berries can transition from traditional roles to becoming central components in innovative food and nutraceutical formulations that meet the global demand for natural, functional ingredients.

Keywords: phytochemical diversity; incipient domestication; functional food; Chilean native berries; growth-defense trade-off

1. From Wildness to Wellness: Rethinking Domestication and Phytochemical Resilience in Chilean Native Berries

In recent decades, there has been growing global interest in functional foods and bioactive compounds, increasing efforts to identify and valorize plant species with rich phytochemical profiles [1–3]. Chilean native berries, such as *Ugni molinae* (murtilla), *Aristotelia chilensis* (maqui), *Berberis darwinii* (michay), and *Berberis microphylla* (calafate), have emerged as promising candidates for developing health-promoting food products [4–7]. These species, largely undomesticated, retain their natural defense mechanisms, including high concentrations of phenolic compounds, essential micronutrients, and volatile compounds, such as monoterpenes, sesquiterpenes, and esters, that are involved in ecological interactions. “Unlike fully domesticated crops, where selection for yield, sweetness, and uniformity often reduces secondary metabolites, Chilean wild berries offer a unique opportunity to develop novel ingredients that retain high levels of bioactive compounds while also exhibiting desirable sensory attributes such as elevated °Brix and natural palatability [8,9]”.

The trade-off between growth and defense, well-established in domestication biology, suggests that reducing chemical defenses to favor productivity can diminish nutritional density, alter sensory characteristics, and increase vulnerability to pests [10]. However, for species undergoing incipient domestication, such as murtilla, this trade-off has not fully manifested, allowing both agronomic improvement and the preservation of valuable phytochemicals [11–13]. Domestication has historically prioritized traits such as yield, sweetness, and visual appeal, often at the expense of a plant's innate chemical defenses [14,15]. This metabolic reallocation from secondary to primary metabolism has led to a marked reduction in phytochemical richness, including (i) phenolic compounds, (ii) essential micronutrients, and (iii) soluble solids [10,16]. For example, Rodríguez-Saona et al. [17] reported that domesticated blueberry varieties exhibited a significant decrease in phenolic content (from 400 to 200 mg/100 g), copper concentrations (from 7.15 to 2.88 mg/kg), and °Brix values (from 15 to 12), respectively. These declines not only compromise nutritional density but also undermine the fruit's ecological resilience and functional potential. Moreover, domestication has traditionally prioritized attributes such as uniformity and shelf stability, traits aligned with industrial agriculture and global food distribution [18,19]. These changes may remain unnoticed by consumers accustomed to highly processed foods, but they pose significant concerns for public health and the functional food industry.

Reduced levels of bioactive compounds, especially phenolics, alkaloids, and terpenes, affect antioxidant, antimicrobial, and anti-inflammatory properties [11–13,20]. In particular, decreases in phenolic content can lead to blander flavor profiles, lower antioxidant capacity, and reduced resistance to microbial spoilage, affecting both food safety and sensory appeal [21]. The underlying dilemma, whether to grow or to defend, emerges as a central tension in modern agriculture [22]. Can we continue to favor productivity without compromising phytochemical richness and functionality?

As consumer demand shifts toward nutrient-dense, health-promoting products, re-evaluating the metabolic consequences of domestication becomes not only relevant but urgent. Chilean native berries, still largely unaltered by domestication, offer an ideal model to explore how preserving defense traits may enhance, rather than hinder, food quality in next-generation crop systems. Could these overlooked traits, often discarded through conventional breeding, become key to meeting the demand for resilient, health-oriented crops in the face of global change? By integrating insights from plant defense ecology, metabolomics, and agroecological resilience, we propose a vision where native berries transition "from wild to valuable," offering strategic resources in functional food design and sustainable agri-food systems.

2. Floral Chemistry, Pollinators, and the Lost Flavors of Cultivated Foods

While secondary metabolites are often discussed in the context of plant defense, their ecological roles extend far beyond [22]. In flowering species, these compounds are integral to plant-pollinator communication, influencing floral scent, nectar palatability, and pollen chemistry [24]. Such traits are vital not only for pollination success but also directly impact the bioactive and sensory properties of edible floral derivatives, such as honey, infusions, and fruits [25]. However, the process of domestication frequently simplifies floral chemistry, favoring uniformity and productivity over ecological function. This reduction in floral volatile organic compounds (VOCs) and phenolic diversity may impair pollinator attraction and efficiency while simultaneously diminishing the aromatic complexity and bioactive richness of plant-based foods [13]. For instance, wild blueberries contain phenolic compounds like 4-O-caffeoylshikimic acid, quercetin, and kaempferol in nectar and pollen, molecules often absent or reduced in cultivated varieties [26]. Likewise, VOCs such as limonene and α-pinene, key to floral scent and flavor, tend to decline with domestication [13]. These changes are not trivial. The transition from wild to cultivated forms may represent not only a reduction in ecological resilience but also a loss of food sensory identity [27]. As interest grows in flavor-rich, health-promoting foods, could these overlooked floral chemistries represent a new frontier in functional ingredient innovation? Chilean native berries, still bearing the complex phytochemical signatures shaped by their ecological interactions, offer a living model of what has been lost, and what can be reclaimed, in the shift toward more sustainable and flavorful food systems.

3. From Pests to Plates: How Defense Compounds Shape Food Safety and Functionality

Plant-pest interactions not only challenge crop production but also shape the chemical identity of the foods we consume [28]. Under natural herbivory pressure, plants synthesize a range of defense-related secondary metabolites, many of which possess health-promoting properties for humans [29]. However, domestication often diminishes these traits, prioritizing yield and palatability over chemical defenses. This reduction can have a twofold cost: decreased pest resistance and a decline in the functional quality of food products [13,27]. Phenolic compounds such as rutin and quercetin exemplify this duality [11]. While bitter and deterrent to insects, they also act as potent antioxidants, benefiting cardiovascular and metabolic health. In cultivated varieties, their reduction may not only increase reliance on synthetic pesticides, raising food safety concerns, but also diminish the nutraceutical value of the final product [29]. Similarly, volatile compounds like citral and linalool—known for their antimicrobial properties against pathogens such as *Escherichia coli*, *Listeria monocytogenes,* and *Botrytis cinerea*, as well as for their flavor-enhancing qualities—are often underrepresented in domesticated crops [30]. A clear example is *U. molinae*, a Chilean native berry in the early stages of domestication [11–13]. Wild ecotypes exhibit higher resistance to *Chilesia rudis*, a polyphagous moth, whereas cultivated genotypes are more readily consumed by larvae [11]. This pattern likely stems from decreased phenolic concentrations—particularly flavonoids such as quercetin and anthocyanins like delphinidin derivatives, affecting not only pest management but also the antioxidant capacity, shelf life, and food safety of murtilla-derived products. As demand for cleaner labels and functional foods increases, could revaluing natural defense chemistry offer a pathway to safer, more resilient, and health-enhancing food systems?

4. Domestication of Chilean Wild Berries: Implications for Food Quality

Chilean wild berries like murtilla, maqui, and michay are undergoing an Incipient Domestication Process (IDP), providing a unique opportunity to examine how domestication influences bioactive compounds and food quality [11–13,31,32]. These species are rich in bioactive molecules, including phenolic compounds, anthocyanins, and VOCs, which contribute to their antioxidant, anti-inflammatory, and antimicrobial properties [11–13,31,33]. However, as domestication progresses, there is a shift in the balance between growth traits and the production of defense compounds, which affects both plant resilience and fruit nutritional value. Murtilla, the most domesticated, has shown significant reductions in bioactive compounds. For instance, flavonols decreased from 350 mg/L to 280 mg/L, with quercetin and kaempferol levels dropping by 17.5% and 96%, respectively. Additionally, a 33% decrease in α-pinene, a compound linked to flavor and antimicrobial activity, has been observed [11–13]. These reductions could impact both flavor complexity and food safety [27]. Maqui, now cultivated with new clones, provides an opportunity to study how domestication affects secondary metabolites like anthocyanins, particularly delphinidin and petunidin, which are central to its antioxidant properties [34,35]. This has important implications for the health benefits of maqui in food products as its global popularity increases. Michay, though less studied, has high anthocyanin content and a distinctive VOC profile that may attract more native pollinators compared to traditional berries [31]. *Berberis darwinii* has been found to produce pharmacologically active isoquinoline alkaloids like berberine and palmatine, which have antioxidant, anti-inflammatory, and cardioprotective properties [31]. Early selection strategies focus on high-yielding genotypes based on alkaloid content, suggesting that domestication may prioritize both bioactive and agronomic traits.

These shifts in bioactive profiles during domestication raise concerns about the potential loss of functional food value. Balancing productivity with the preservation of these health-promoting compounds is essential to ensure the nutritional and therapeutic value of domesticated varieties.

5. Toward a New Path for the Domestication of Functional Berries

The decline in phytochemical complexity observed during fruit domestication results from the interplay between both genetic and environmental factors. On the genetic side, artificial selection for traits such as fruit size, sweetness, and yield often involves pleiotropic effects or linkage drag, where loci associated with primary metabolism are favored at the expense of those controlling secondary metabolism [36,37]. Moreover, internal resource allocation may shift away from the production of defense-related compounds (e.g., phenolics and volatiles) toward accelerated growth and reproduction [38]. From an ecological perspective, wild plants typically evolve in highly complex environments, rich in biotic and abiotic stressors, where the production of secondary metabolites confers adaptive advantages [38]. In contrast, under managed agricultural conditions, characterized by nutrient abundance, reduced herbivory, and environmental uniformity, the selective pressure to maintain costly phytochemicals diminishes [39,40]. When wild berry species are transitioned from complex native habitats to agricultural settings, they often experience reduced interspecific and intraspecific competition for light, nutrients, and water. This relaxation of environmental constraints typically leads to enhanced photosynthetic performance, increased biomass accumulation, and faster fruit development. However, such resource-rich conditions also reduce the ecological need to sustain energetically costly secondary metabolites used for defense or environmental adaptation. As a result, both natural and artificial selection in human-managed environments tend to favor genotypes that maximize primary metabolism, potentially at the expense of phytochemical diversity. As a result, both natural and artificial selection may drive a metabolic reallocation that reduces key bioactive compounds such as volatiles, flavonoids, or terpenes, with consequences for flavor, microbial resistance, and functional food value [41].

These dynamics may explain apparent contradictions in breeding goals. For instance, while breeders have prioritized traits like firmness, uniformity, and shelf life [41], this selection may inadvertently reduce levels of bioactive compounds involved in microbial resistance and sensory complexity [36]. Similarly, some domesticated cultivars have shown reduced pollinator attraction or pollination efficiency, possibly due to unintended changes in floral volatile emissions or morphology, even if yield was the primary target [38]. In addition to these physiological trade-offs, a key mechanism behind the loss of phytochemical diversity is the accidental loss of genetic variation during domestication. Strong directional selection for visible traits (e.g., yield or sweetness) often creates genetic bottlenecks that eliminate alleles associated with other valuable traits, such as nutritional compounds, defense chemicals, or pollinator cues [42,43]. Many of these traits remain invisible to breeders either because they are not prioritized or because they are too costly or time-consuming to measure [44]. Genetic correlations, including physical linkage or pleiotropic effects, can also lead to unintended changes, even without direct selection [45]. However, since linkage can be broken and rare alleles recovered, these dynamics do not represent strict trade-offs and offer opportunities to reintegrate beneficial metabolic traits without compromising agronomic performance [41,44].

In light of this complexity, we propose metabolomics-assisted selection as a transformative tool. Unlike traditional phenotype-based breeding, metabolomics offers a comprehensive and quantitative snapshot of the fruit's biochemical landscape, enabling breeders to track, preserve, and restore compounds such as flavonoids, volatiles, and micronutrients [46,47]. Even when trade-offs seem apparent between yield and phytochemical richness, metabolomics can help identify exceptional genotypes that combine productivity with nutritional or ecological value [48]. Moreover, metabolomics data can guide context-specific breeding strategies, adjusting selection to match environments where traits like pest resistance or pollinator attraction are critical. Rather than assuming a universal conflict between yield and quality, this approach reveals that many such trade-offs may stem from historical blind spots in breeding or a lack of relevant data. Thus, metabolomics not only expands the breeding toolkit, but also reorients fruit improvement around integrative goals that bridge agronomic, ecological, and nutritional priorities. In parallel, we advocate for participatory selection with rural communities as a powerful and complementary approach. While non-scientists may not measure antioxidant or vitamin content directly, they often favor traits that align with phytochemical richness, such as intense flavor, aroma, acidity, or color [49,50]. Research has shown that preference for "wild" or rustic berries correlates with high levels of anthocyanins, terpenes, and organic acids, which are often diminished during domestication. Engaging communities in early stages of selection can broaden the set of preferred traits beyond yield and sweetness, incorporating cultural and ecological values that reflect functional quality. When paired with metabolomic profiling, participatory breeding enables co-identification of genotypes that meet both agronomic and phytochemical goals. This co-creative strategy is especially suitable for underutilized native species like *Ugni molinae*, where no dominant market ideotype yet exists, and where the domestication pathway can still be shaped jointly by scientific and local knowledge systems [51]. In this sense, the future of functional fruit domestication lies not in abandoning wild traits, but in strategically integrating them through high-throughput tools and participatory processes. Only by doing so can we develop fruits that are productive, resilient, culturally meaningful, and nutritionally rich.

6. Future Perspectives on Native Chilean Berries: Bioactive Compounds and Sustainable Food Systems

Native Chilean berries, such as murtilla, maqui, and michay, show great potential as sources of bioactive compounds with health-promoting properties. These fruits, still in the early stages of domestication, preserve a unique genetic diversity that distinguishes them from fully cultivated crops. This diversity contributes to rich profiles of phenolic compounds, flavonoids, and anthocyanins, phytochemicals known for their antioxidant, anti-inflammatory, and anticancer activities. However, as domestication advances, the challenge of balancing increased productivity with the preservation of these bioactive traits becomes more pressing. Historically, domestication has prioritized traits like yield and fruit size over phytochemical content, and a similar trend is being observed in these native berries. For example, during murtilla domestication, reductions in key flavonols like quercetin (17.5%) and kaempferol (96%) have been reported. These compounds are crucial not only for human health but also for plant defense, suggesting that their reduction could have broader ecological and agronomic consequences. To address this challenge, future domestication efforts must focus on sustainable cultivation practices and advanced breeding strategies. Selecting genotypes that maintain high levels of health-promoting compounds while also ensuring desirable agronomic traits will be essential for their success in the food and nutraceutical industries. With growing demand for functional foods, native Chilean berries present a valuable alternative to conventional bioactive sources, which often involve environmentally intensive extraction processes.

In light of climate change, these berries' resilience under harsh conditions makes them even more valuable, contributing to food security and a stable supply of bioactive ingredients. Balancing productivity with ecological resilience will be crucial for ensuring that these native species fulfill their potential in the future food landscape. Native Chilean berries not only have significant nutritional potential but also embody a genetic and cultural heritage that should be actively protected. Prioritizing these species in national research agendas could position Chile as a global leader in resilient and health-promoting crops. We propose that future breeding programs for native berries incorporate metabolomics-assisted selection to maintain or enhance bioactive compound diversity. Furthermore, participatory selection with local communities could align agronomic improvements with cultural and nutritional values, fostering both resilience and identity in functional food development.

Author Contributions

M.C.-F. Conceptualization, Visualization, Writing-original draft preparation, Writing-review and editing, and Project administration. M.C.-F. Writing-original draft preparation M.C.-F. and M.O.-N. Writing-review and editing. All authors have read and agreed to the published version of the manuscript.

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Not applicable.

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Conflicts of Interest

The authors declare no competing financial interest.

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