

South American Botanical Terroir as a High-Bioactivity Source for Cutaneous Phytonutrition Protocols: Phytochemical Profile and the Co-Evolutionary Stress-Adaptation Hypothesis for Andean-Patagonian and Amazonian Species

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ABSTRACT

South American botanical species adapted to extreme environmental conditions — high ultraviolet irradiance in the Andean-Patagonian plateau and oxidative-flooding stress cycles in the Amazonian floodplain — have developed secondary metabolite profiles of exceptional antioxidant and anti-inflammatory potency. This paper proposes the **Stress-Adaptation Co-Evolutionary Hypothesis (SACE)**, which posits that the phytochemical superiority of these species relative to equivalent temperate-zone botanicals is not incidental but the direct result of evolutionary selection pressure operating on secondary metabolite biosynthetic pathways.

We systematically examine seven key species across two terroir lines — the Patagonian Line (*Aristotelia chilensis*, *Berberis microphylla*, *Rosa rubiginosa*) and the Amazonian Line (*Euterpe oleracea*, *Myrciaria dubia*, *Mauritia flexuosa*, *Copaifera* spp.) — characterizing their primary bioactive compounds, documented cutaneous mechanisms, and ORAC antioxidant indices. A comparative analysis against temperate equivalents demonstrates a 2–4× advantage in antioxidant capacity per unit mass of extract. We further propose the **ICDT (Index of Dermatotherapeutic Compatibility)** as a translational scoring framework mapping phytochemical profiles to individual systemic phenotypes, enabling evidence-grounded ingredient selection in personalized cutaneous phytonutrition. The SACE framework constitutes, to our knowledge, the first formal co-evolutionary rationale applied to botanical ingredient selection in dermatological personalized protocols.

Keywords: botanical terroir; South American phytochemistry; *Aristotelia chilensis*; *Myrciaria dubia*; *Copaifera*; cutaneous phytonutrition; antioxidant co-evolution; personalized dermatology; ICDT; Phytodermonutrition™

1. INTRODUCTION

The global botanical ingredient market for dermatology has been dominated by temperate-zone species — predominantly European and North American berries, Asian adaptogens, and Mediterranean herbs — despite substantial evidence suggesting that stress-adapted species from extreme ecological zones may offer superior bioactive compound profiles. South America, encompassing both the high-altitude ultraviolet environments of the Andean-Patagonian corridor and the oxidative-flooding cycles of the Amazonian várzea, constitutes one of the most botanically diverse and scientifically undercharacterized terroirs in dermocosmetic research.

The concept of *terroir*, well established in oenology to describe how geography, climate, and soil influence phytochemical expression, has been rarely applied in a rigorous scientific framework to dermatological ingredient selection. Yet the ecological rationale is compelling: secondary metabolites — particularly polyphenols, carotenoids, and terpenoids — are primarily biosynthesized as photoprotective, antimicrobial, and antioxidant shields against environmental stressors. Plants inhabiting zones of extreme UV irradiance, temperature oscillation, or oxidative stress are biologically incentivized to produce these compounds at higher densities and in more structurally diverse configurations than their temperate counterparts.

The present paper formalizes this rationale as the **Stress-Adaptation Co-Evolutionary Hypothesis (SACE)** and provides systematic evidence for its application to two South American terroir lines — Patagonian and Amazonian — within the emerging field of Phytodermonutrition™. We additionally introduce the ICDT (Index of Dermatotherapeutic Compatibility) as an operational translation framework connecting these phytochemical profiles to individual cutaneous-

systemic phenotypes.

2. THEORETICAL FRAMEWORK: THE SACE HYPOTHESIS

The Stress-Adaptation Co-Evolutionary Hypothesis (SACE) proposes that plants subjected to sustained high-intensity environmental stress develop secondary metabolite profiles characterized by:

- (a) **Higher polyphenolic density per unit of plant tissue mass**, driven by constitutive upregulation of the phenylpropanoid pathway in response to UV, oxidative, and thermal stressors.
- (b) **Greater structural diversity of anthocyanins and flavonoids**, produced through adaptive exploration of biosynthetic branch pathways, resulting in a broader spectrum of antioxidant mechanisms (radical scavenging, metal chelation, enzyme inhibition).
- (c) **Enhanced biocompatibility with human cutaneous biology**, on the basis that antioxidant compounds evolved to protect plant cells from ROS-generating stressors — UV, oxygen radical cascades, pathogen-induced oxidative bursts — operate via biochemical mechanisms directly relevant to human photooxidative skin damage, inflammatory cascades, and barrier dysfunction.

This framework differentiates SACE from simple claims of "natural ingredient superiority" by grounding ingredient selection in evolutionary biology, phytochemistry, and cutaneous biochemical homology.

3. THE PATAGONIAN TERROIR LINE

3.1 Maqui Berry (*Aristotelia chilensis*)

Native to the Andean-Patagonian corridor of Chile and Argentina, *Aristotelia chilensis* thrives at elevations where UV irradiance is substantially elevated relative to sea-level equivalents. The fruit exhibits the highest documented anthocyanin concentration among commonly characterized superfruits, with delphinidin-3-sambubioside-5-glucoside and delphinidin-3-galactoside as the predominant pigments.¹

Antioxidant capacity, measured across five ROS species (hydroxyl radical, peroxy radical, peroxynitrite, singlet oxygen, superoxide anion) by the Brunswick Laboratories Multi-Radical ORAC protocol, yields a composite ORAC value documented at approximately 27,600 $\mu\text{mol TE}/100\text{g}$ — approximately 2–4 $\times$ the values recorded for cultivated blueberry (*Vaccinium corymbosum*) under equivalent measurement conditions.²

Documented cutaneous mechanisms include: photoprotective activity against UVB-induced DNA damage in normal human skin fibroblasts (NHFs), with restoration of SOD, catalase, and glutathione antioxidant systems;³ anti-inflammatory inhibition of TNF- α , iNOS and IL-6 in adipocyte-macrophage co-culture;⁴ antimicrobial activity against *Propionibacterium acnes* and *Staphylococcus aureus*; and MMP inhibition relevant to collagen preservation.

3.2 Calafate (*Berberis microphylla* / *buxifolia*)

Endemic to Patagonian steppe and subantarctic forests, *Berberis microphylla* exhibits total polyphenol content of 1,344–6,553 mg GAE/100g dry weight — comparable to maqui and substantially superior to blueberry in anthocyanin density. Principal anthocyanins include delphinidin-3-glucoside, petunidin, and malvidin glycosides.

Recent evidence (2025) documents significant reductions in circulating systemic inflammatory biomarkers following calafate extract supplementation: thrombomodulin (–24%), soluble E-selectin (–34%), sICAM-1 (–24%), and proMMP-9 (–31%).⁵ These vascular and inflammatory endpoints have direct dermatological relevance: sICAM-1 and E-selectin are markers of endothelial activation underlying erythema and couperose, while MMP-9 is a primary collagen-degrading enzyme in photoaged skin. Calafate's documented vasodilatory and antioxidant cellular activity further supports its role in improving dermal microcirculation and reducing subclinical cutaneous inflammation.⁶

3.3 Patagonian Rosehip (*Rosa rubiginosa* / *eglanteria*)

Cultivated since pre-Columbian times in the Andean foothills, *Rosa rubiginosa* (syn. *R. eglanteria*, commonly known as *rosa mosqueta*) yields a seed oil of unique dermatological significance. The oil's fatty acid composition is characterized by unsaturated fatty acid content exceeding 92% of total lipids, with polyunsaturated fatty acids (PUFAs) exceeding 77% — primarily linoleic acid (omega-6, ~54%) and alpha-linolenic acid (omega-3, ~19%).⁷

Critically, *Rosa rubiginosa* seed oil contains measurable concentrations of all-*trans*-retinoic acid (tretinoin), a naturally occurring first-generation retinoid. Cold-pressed and supercritical CO₂ extractions have documented tretinoin concentrations above 0.3% in the cold-pressed fraction.⁸ This renders *R. rubiginosa* the only botanical fruit known to contain a pharmacologically active retinoid, directly binding retinoic acid receptors (RARs) to promote keratinocyte differentiation, collagen synthesis, and MMP suppression. A 2024 systematic review confirmed the plausibility of rosehip oil's mechanism for scar improvement and reported positive clinical outcomes in two controlled trials.⁹

4. THE AMAZONIAN TERROIR LINE

4.1 Açaí (*Euterpe oleracea*)

Native to the Amazonian várzea floodplain, *Euterpe oleracea* fruit pulp and peel exhibits ORAC values among the highest recorded for edible fruits — approximately 102,700 µmol TE/100g for the combined pulp-peel fraction — driven primarily by cyanidin-3-glucoside and cyanidin-3-rutinoside as dominant anthocyanins. The extreme oxidative challenge of várzea ecology (cyclic flooding, high irradiance, pathogen load) provides a compelling SACE-consistent rationale for this exceptional antioxidant density.

Documented cutaneous mechanisms include NF-κB inhibition with downstream reduction of IL-6, IL-1β, and TNF-α. Topical application of açaí-containing formulations has shown reduction of transepidermal water loss (TEWL) and improvement in elasticity in ex vivo skin models, supporting barrier-restorative application particularly for high-pollution urban exposomes.

4.2 Camu-Camu (*Myrciaria dubia*)

Myrciaria dubia, native to blackwater rivers and flooded forests of the Amazonian basin, contains the highest documented natural concentration of vitamin C (ascorbic acid) of any known fruit — 2,000–3,000 mg per 100g of fresh pulp, approximately 60× the concentration found in citrus. This extraordinary accumulation, consistent with SACE, reflects adaptive response to high oxidative stress in the blackwater river ecosystem.

Beyond ascorbic acid, camu-camu contains ellagitannins (castalagin, vescalagin) whose antioxidant potency exceeds that of isolated ascorbic acid in DPPH and FRAP assays. Tyrosinase inhibition activity has been documented, providing a mechanistic basis for hyperpigmentation treatment applications. The vitamin C content serves a critical cofactor function in cutaneous collagen biosynthesis: ascorbic acid is the obligate cofactor for prolyl and lysyl hydroxylases, enzymes essential for the post-translational hydroxylation of procollagen type I and III — the structural backbone of dermal connective tissue.

4.3 Buriti (*Mauritia flexuosa*)

The buriti palm, endemic to Amazonian and Cerrado gallery forests, produces a fruit pulp with one of the highest beta-carotene concentrations among known botanical sources — up to 3,000 µg/g of pulp — contributing solar-protective activity through both direct UV absorption and pro-vitamin A biological activity. The fruit oil is characterized by oleic acid (60–70% of fatty acids), providing exceptional emollient biocompatibility with the skin's lipid barrier. High tocopherol (vitamin E) concentrations additionally protect unsaturated fatty acids from oxidative degradation during formulation and cutaneous residence.

Indigenous ribeirão communities along Amazonian waterways have employed buriti oil for photoprotection, hydration, and skin repair for millennia, providing ethnopharmacological validation extending well beyond the modern evidence base. This traditional use, combined with the phytochemical data, positions buriti as a key component of barrier-restorative cutaneous protocols for high UV-exposure phenotypes.

4.4 Copaiba (*Copaifera* spp.)

The oleoresin of *Copaifera* species (principally *C. multijuga*, *C. langsdorffii*, and *C. paupera*) extracted from Amazonian tree trunks contains β-caryophyllene (BCP) as its dominant sesquiterpene. BCP is a selective agonist of the cannabinoid receptor type 2 (CB2), a G-protein coupled receptor expressed in hair follicles, sebaceous glands, keratinocytes, immune cells, and the dermal vasculature — making it the primary endocannabinoid receptor of cutaneous immunoregulation.¹⁰

CB2 activation by BCP suppresses NF-κB and MAPK inflammatory signaling, reduces pro-inflammatory cytokine release (IL-1β, IL-6, TNF-α, COX-2), and promotes re-epithelialization and collagen remodeling in wound and inflammatory models.^{11,12} A 2025 systematic review covering PubMed, Embase, and Web of Science confirmed BCP's coherent CB2-

mediated anti-inflammatory, antipruritic, antioxidant, and barrier-restorative actions across in vitro and in vivo models.¹³ Critically, BCP activates CB2 without any CB1-mediated psychoactivity, rendering it a legally and clinically unencumbered cannabinoid-pathway modulator for topical dermatological use. Its documented activity against *P. acnes* further supports its role in inflammatory acne protocols and cutaneous microbiome dysbiosis management.

5. COMPARATIVE PHYTOCHEMICAL PROFILE

Species	Terroir Line	Primary Bioactives	ORAC (μmol TE/100g)	Key Cutaneous Mechanism	Evidence Level
Aristotelia chilensis (Maqui)	Patagonian	Delphinidin glycosides, quercetin, myricetin	~27,600	UVB photoprotection, MMP inhibition, NF-κB suppression	B (strong preclinical + human fibroblast)
Berberis microphylla (Calafate)	Patagonian	Delphinidin-3-glucoside, petunidin, malvidin	~18,500 (est.)	Vascular anti-inflammation, MMP-9 reduction, microcirculation	B (2025 human biomarker data)
Rosa rubiginosa (Rosehip)	Patagonian	All-trans-retinoic acid, linoleic acid, alpha-linolenic acid, ascorbic acid	~10,000 (est.)	RAR activation, collagen synthesis, barrier repair, scar remodeling	B (clinical trials for scar, wrinkle)
Euterpe oleracea (Açaí)	Amazonian	Cyanidin-3-glucoside, cyanidin-3-rutinoside	~102,700	NF-κB inhibition, TEWL reduction, barrier restoration	B (preclinical + ex vivo)
Myrciaria dubia (Camu-Camu)	Amazonian	Ascorbic acid (2,000–3,000 mg/100g), castalagin, vescalagin	~15,200	Collagen cofactor (prolyl/lysyl hydroxylase), tyrosinase inhibition	B (in vitro mechanistic + nutricosmetic)
Mauritia flexuosa (Buriti)	Amazonian	Beta-carotene (≤3,000 μg/g), oleic acid, tocopherols	~8,800 (est.)	Solar photoprotection, barrier emolliency, pro-vitamin A activity	C + D (in vitro + ethnopharmacological)
Copaifera spp. (Copaiba)	Amazonian	β-Caryophyllene (BCP), sesquiterpenes	N/A (terpenoid)	CB2 agonism → NF-κB/MAPK suppression, barrier repair, antimicrobial	B (systematic review 2025)

Evidence levels: A = RCT human; B = strong preclinical/human biomarker data; C = in vitro mechanistic; D = traditional/ethnopharmacological use. ORAC values: documented from Brunswick Laboratories and peer-reviewed sources; estimates flagged accordingly.

6. SACE COMPARATIVE ANALYSIS: SOUTH AMERICAN VS. TEMPERATE EQUIVALENTS

The SACE hypothesis predicts that South American stress-adapted species will exhibit measurably superior antioxidant indices compared to functionally similar temperate-zone species. Available data support this prediction across the Patagonian line:

South American Species	ORAC (μmol TE/100g)	Temperate Equivalent	Temperate ORAC	Advantage Ratio
Aristotelia chilensis (Maqui)	~27,600	Vaccinium corymbosum (Blueberry)	~6,552	~4.2×
Euterpe oleracea (Açaí, pulp+skin)	~102,700	Vaccinium corymbosum (Blueberry)	~6,552	~15.7×
Myrciaria dubia (Camu-Camu, Vit C)	2,000–3,000 mg/100g	Citrus sinensis (Orange)	50–70 mg/100g	~40–60×

While ORAC comparisons require methodological standardization for formal equivalence testing, the magnitude of

observed differences across independently validated measurement protocols exceeds plausible measurement variance and is consistent with the SACE framework’s prediction of systematic phytochemical upregulation in stress-adapted ecotypes.

7. THE ICDT: A TRANSLATION FRAMEWORK FOR PERSONALIZED INGREDIENT SELECTION

The translational gap between phytochemical characterization and clinical ingredient selection remains one of the primary limitations of evidence-based phytocosmetics. A given botanical with documented antioxidant activity may not produce equivalent clinical outcomes across all cutaneous phenotypes; individual variation in barrier integrity, inflammatory tone, gut-skin axis status, and photoexposure history modulates the effective biocompatibility of any given phytochemical intervention.

We propose the **Index of Dermotherapeutic Compatibility (ICDT)** as a composite scoring function that maps a botanical ingredient’s phytochemical profile to an individual’s assessed cutaneous-systemic phenotype:

ICDT FORMULA — VERSION 1.0

ICDT(ingredient, individual) =
w₁ · Score_{PhytoDermo} (cutaneous inflammatory phenotype)
+ w₂ · Score_{GutSkin} (gut-skin axis status; SPOI™)
+ w₃ · Score_{Inflammatory} (systemic inflammatory load; PSS-4 + HRV)
+ w₄ · Score_{Exposome} (UV/pollution exposure; ICE-8™)
+ w₅ · Score_{NutriGastro} (nutritional status axis)

Weights (v1.0): w₁=0.35, w₂=0.20, w₃=0.20, w₄=0.15, w₅=0.10

ICDT Range: 0–100
≥70 → High compatibility: prescribed as primary protocol ingredient
40–69 → Moderate compatibility: prescribed as supportive ingredient
<40 → Low compatibility: excluded from current protocol cycle

The ICDT operates at the intersection of the SACE framework (characterizing ingredient phytochemical profiles) and personalized phenotyping (characterizing individual cutaneous-systemic status). It is designed as a dynamic index — weights are intended for empirical calibration through prospective cohort data correlating ICDT scores with clinical outcomes at 12 weeks (ΔBSPI, the Bloomsync Skin Phenotype Index) — not as a fixed formula. This approach reflects the epistemological commitment of Phytodermonutrition™ to translational evidence generation rather than static protocol prescription.

8. TERROIR SELECTION LOGIC: PATAGONIAN VS. AMAZONIAN LINE

Patagonian Line (Maqui, Calafate, Rosehip) is indicated as primary for phenotypes characterized by:

- High photooxidative load (ICE-8™ ≥ 67, UV-dominant exposome)
- Inflammatory or reactive cutaneous phenotype (acne, rosacea, couperose, photoaging)
- Compromised skin barrier (elevated TEWL, dry-reactive skin profile)
- Hyperpigmentation or post-inflammatory marks

Amazonian Line (Açaí, Camu-Camu, Buriti, Copaiba) is indicated as primary for phenotypes characterized by:

- Urban pollution exposome (ICE-8™ ≥ 67, PM_{2.5}-dominant)
- Gut-skin axis dysbiosis (high SPOI™ score)
- Collagen deficiency phenotype (reduced turgor, deep static lines)
- Inflammatory acne with suspected microbiome involvement
- Chronic solar exposure with moderate-to-high UV fototipo

9. DISCUSSION

The formalization of SACE provides a scientific foundation for what has historically been treated as a narrative or marketing concept in botanical cosmetics — the idea that geographic origin of ingredients matters for clinical efficacy. The presented data suggest that this concept is not merely intuitive but mechanistically grounded: the same biosynthetic pathways that

produce antioxidant compounds in plants as an adaptive response to environmental stressors are the pathways whose end products intervene in human cutaneous ROS damage, inflammatory cascades, and barrier disruption.

This creates a compelling hypothesis — not yet fully tested in controlled human trials — that stress-adapted botanical species from extreme environments may offer phytochemically superior clinical substrates for cutaneous protocols. The SACE framework does not claim therapeutic equivalence to pharmaceutical interventions; it positions South American botanical terroir within a rigorous ethnopharmacological and phytochemical rationale that can and should be subjected to prospective clinical validation.

The ICDT translation framework addresses a critical gap: even if the SACE hypothesis is correct at the phytochemical level, individual-to-individual variation in biological response means that ingredient-to-phenotype matching is necessary for optimal protocol design. The five-axis ICDT model — weighting cutaneous phenotype, gut-skin axis, inflammatory load, exposome, and nutritional status — reflects the multidimensional nature of skin health as conceptualized within Phytodermonutrition™.

Important limitations must be acknowledged. ORAC comparisons across studies carry methodological heterogeneity. Clinical evidence for several Amazonian species (particularly buriti and calafate) remains limited to preclinical and ethnopharmacological data. The ICDT weights (v1.0) are literature-derived, not empirically calibrated, and are designed to evolve through prospective beta-cohort data. Future work should prioritize randomized controlled comparisons of protocol outcomes across terroir lines stratified by ICDT compatibility scores, as well as standardized phytochemical characterization of SACE-predicted species under controlled cultivation conditions.

10. CONCLUSIONS

South American botanical species from the Andean-Patagonian and Amazonian terroirs exhibit systematically superior antioxidant and anti-inflammatory phytochemical profiles relative to temperate-zone equivalents, consistent with the proposed Stress-Adaptation Co-Evolutionary Hypothesis (SACE). The seven species reviewed — maqui, calafate, patagonian rosehip, açai, camu-camu, buriti, and copaiba — span a mechanistically complementary range of cutaneous actions: photoprotection, collagen support, barrier restoration, endocannabinoid-mediated anti-inflammation, and microbiome modulation.

The ICDT framework provides an operational bridge between phytochemical characterization and personalized ingredient selection, enabling systematic matching of terroir-derived bioactives to individual cutaneous-systemic phenotypes. Together, SACE and ICDT constitute foundational elements of a scientifically defensible approach to botanical ingredient selection in personalized phytodermonutrition — one that honors the biological intelligence embedded in extreme ecological adaptation while demanding rigorous clinical validation of its translational claims.

DECLARATIONS

Author Contributions: Willer de Souza — conceptualization, theoretical framework (SACE, ICDT), systematic literature review, writing (original draft, revision), and submission.

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Ethics: Not applicable (theoretical/review paper; no human or animal subjects).

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