

Herbal Plants and Their Applications in Cosmeceuticals: A Comprehensive Review

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15 July 2025: Received | 11 August 2025: Revised | 10 September 2025: Accepted | 04 October 2025: Available Online

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Citation: Sharik Khan, Sufyan Ahmed Ghawte, Sabila Ghawte, Ghazala Mulla, Nikhat Shaikh (2025). Herbal Plants and Their Applications in Cosmeceuticals: A Comprehensive Review. *Plant Science Review*.

DOI: <https://doi.org/10.51470/PSR.2025.06.02.44>

Abstract

Cosmeceuticals represent a rapidly evolving category bridging cosmetics and pharmaceuticals, incorporating biologically active ingredients for therapeutic skin benefits. Herbal plants provide rich sources of phytochemicals, including polyphenols, terpenoids, alkaloids, and vitamins that exhibit antioxidant, anti-inflammatory, antimicrobial, and anti-aging properties. This review comprehensively examines commonly used herbal species, their botanical classifications, bioactive components, and mechanisms of action in skin and hair care applications. Modern formulation strategies utilizing advanced extraction methods, nanotechnology-based delivery systems, and standardization protocols enhance efficacy and stability. Despite promising therapeutic potential, challenges persist regarding safety evaluations, regulatory compliance, quality control, and clinical validation. Future perspectives emphasize emerging botanicals, nanomedicine integration, and evidence-based research for sustainable cosmeceutical development.

Keywords: Cosmeceuticals, phytochemicals, photoprotection, Nanotechnology, Anti-aging.

Introduction

Cosmeceuticals represent a hybrid category of products that bridge the gap between cosmetics and pharmaceuticals, containing biologically active ingredients that provide therapeutic benefits beyond traditional cosmetic applications [1]. Unlike conventional cosmetics that merely enhance appearance, cosmeceuticals penetrate the skin's deeper layers to deliver physiological benefits such as anti-aging, skin whitening, and photoprotection [2]. The global cosmeceutical market has experienced exponential growth, driven by increasing consumer awareness about skin health and the demand for scientifically validated products with minimal side effects [3]. Herbal plants have emerged as invaluable resources in cosmeceutical formulations due to their rich phytochemical profiles, safety profiles, and multifunctional properties [4]. These botanical ingredients contain bioactive compounds such as polyphenols, flavonoids, terpenoids, and alkaloids that exhibit antioxidant, anti-inflammatory, antimicrobial, and anti-aging activities [5].

The shift toward natural ingredients reflects consumer preferences for sustainable, eco-friendly products with fewer synthetic chemicals and reduced environmental impact [19]. Herbal cosmeceuticals align with traditional medicine systems like Ayurveda and Traditional Chinese Medicine, which have utilized plant-based remedies for centuries [12]. This review aims to comprehensively examine the role of herbal plants in cosmeceutical applications, focusing on commonly used species, their botanical classifications, active components, and the evolution from traditional to modern cosmetic use. The scope encompasses the scientific validation of traditional knowledge and the integration of herbal ingredients into contemporary cosmeceutical formulations.

Herbal Plants Used in Cosmeceuticals Commonly Used Herbal Plants

Numerous herbal plants have demonstrated significant cosmeceutical potential. *Aloe vera* (*Aloe barbadensis*) is widely recognized for its moisturizing, wound-healing, and

anti-inflammatory properties attributed to polysaccharides and glycoproteins [1]. *Curcuma longa* (turmeric) contains curcumin, a potent antioxidant and anti-inflammatory agent used for skin brightening and anti-acne formulations [2]. *Camellia sinensis* (green tea) is rich in catechins, particularly epigallocatechin gallate (EGCG), which provides photoprotection and anti-aging benefits [3]. Other prominent herbs include *Glycyrrhiza glabra* (licorice) for skin lightening, *Centella asiatica* for wound healing and collagen synthesis, and *Azadirachta indica* (neem) for antibacterial and antifungal activities [4].

Botanical Classification and Active Components

Herbal cosmeceuticals derive from diverse botanical families, each contributing unique phytochemical profiles. The Zingiberaceae family includes *Curcuma longa*, whose curcuminoids exhibit tyrosinase inhibition for hyperpigmentation treatment [5]. The Fabaceae family contributes *Glycyrrhiza glabra*, containing glabridin and liquiritin that interfere with melanogenesis [6]. *Centella asiatica* from the Apiaceae family contains triterpenoid saponins (asiaticoside, madecassoside) that stimulate collagen production and accelerate wound healing [7]. The Theaceae family's *Camellia sinensis* provides polyphenolic catechins with free radical scavenging capabilities [8].

Traditional vs. Modern Use in Cosmetics

Traditional cosmetic practices have utilized herbal plants for millennia across various cultures. Ancient Egyptian, Indian, and Chinese civilizations employed plant-based preparations for skin care, hair treatment, and beautification rituals [9]. However, traditional use often lacked standardization and scientific validation regarding efficacy and safety. Modern cosmeceuticals have revolutionized herbal applications through advanced extraction techniques, standardization of active ingredients, and rigorous clinical trials [10]. Contemporary formulations incorporate nanotechnology, microencapsulation, and delivery systems to enhance bioavailability and stability of herbal actives [11]. While traditional knowledge provides the foundation, modern cosmeceutical science validates mechanisms of action, optimizes concentrations, and ensures product consistency and regulatory compliance.

Bioactive Phytochemicals in Herbal Cosmeceuticals

Polyphenols and Flavonoids

Polyphenols and flavonoids constitute the most abundant phytochemicals in herbal cosmeceuticals, exhibiting potent antioxidant, anti-inflammatory, and photoprotective properties [12]. Green tea polyphenols, particularly epigallocatechin-3-gallate (EGCG), demonstrate remarkable free radical scavenging activity and inhibit matrix metalloproteinases (MMPs) responsible for collagen degradation [13]. Resveratrol from *Vitis vinifera* (grape) activates sirtuins and suppresses nuclear factor-kappa B (NF- κ B) signalling, providing anti-aging benefits [14].

Quercetin, kaempferol, and rutin, found in various botanical sources, exhibit tyrosinase inhibition for hyperpigmentation management and enhance skin barrier function [15].

Terpenoids and Essential Oils

Terpenoids represent diverse phytochemicals with significant cosmeceutical applications. Triterpenoids from *Centella asiatica*, including asiaticoside and madecassoside, stimulate fibroblast proliferation and collagen synthesis, accelerating wound healing [16]. Ursolic acid and oleanolic acid demonstrate anti-inflammatory and antimicrobial activities beneficial for acne treatment [17]. Essential oils containing monoterpenes and sesquiterpenes, such as tea tree oil (*Melaleuca alternifolia*) and lavender oil (*Lavandula angustifolia*), provide antimicrobial, anti-inflammatory, and aromatherapeutic benefits [18]. Limonene and linalool contribute to skin penetration enhancement and sensory properties in formulations [19].

Alkaloids and Saponins

Alkaloids, though less common in cosmeceuticals, offer specific therapeutic benefits. Berberine from *Berberis* species exhibits antimicrobial and anti-inflammatory properties useful for acne and seborrheic conditions [20]. Saponins, glycosidic compounds found in *Panax ginseng* and *Glycyrrhiza glabra*, demonstrate emulsifying, foaming, and biological activities [21]. Ginsenosides enhance skin microcirculation, promote collagen synthesis, and provide anti-wrinkle effects [22]. Glycyrrhizin and its metabolite glycyrrhetic acid exhibit anti-inflammatory and skin-lightening properties through tyrosinase inhibition [23].

Vitamins and Minerals

Herbal sources provide essential vitamins and minerals crucial for skin health. Vitamin C from *Rosa canina* (rosehip) and citrus fruits acts as a cofactor for collagen hydroxylation and provides antioxidant protection [23]. Vitamin E (tocopherols) from wheat germ and vegetable oils protects cell membranes from lipid peroxidation [24]. Provitamin A (β -carotene) from carrots and algae converts to retinol, promoting cell turnover and collagen production [25]. Minerals, including zinc, selenium, and copper from botanical sources, support enzymatic processes, wound healing, and antioxidant defense systems [26]. The mechanism of Action of some Herbal Bioactive in Cosmeceuticals is given in table 1.

Applications in Skin Care

Anti-aging and Wrinkle Reduction

Herbal cosmeceuticals combat skin aging through multiple mechanisms. Retinol-like compounds from rosehip stimulate collagen synthesis and reduce fine lines [27]. Ginseng extract increases dermal density and elasticity by upregulating procollagen gene expression [28]. Bakuchiol from *Psoralea corylifolia* functions as a natural retinol alternative, improving photoaging signs without associated irritation [29].

Pomegranate extract rich in punicalagin protects against UV-induced collagen degradation and elastin breakdown [30].

Aloe vera polysaccharides promote fibroblast proliferation, collagen deposition, and accelerate wound closure [40].

Skin Whitening and Brightening

Herbal ingredients effectively address hyperpigmentation through tyrosinase inhibition and melanogenesis suppression. Arbutin from *Arctostaphylos uva-ursi* competitively inhibits tyrosinase, reducing melanin production [31]. Kojic acid from *Aspergillus* species chelates copper ions essential for tyrosinase activity [32]. Licorice extract containing glabridin disperses melanin and inhibits tyrosinase [33]. Niacinamide from yeast extract reduces melanosome transfer from melanocytes to keratinocytes [34].

Anti-inflammatory and Soothing Effects

Botanical anti-inflammatory agents alleviate various dermatological conditions. Chamomile (*Matricaria chamomilla*), containing bisabolol and apigenin, inhibits prostaglandin synthesis and calms sensitive skin [35]. Calendula (*Calendula officinalis*) flavonoids reduce inflammatory cytokines and accelerate epithelialization [36]. Colloidal oatmeal (*Avena sativa*) provides relief from pruritus and irritation through avenanthramide content [37].

Acne and Wound Healing

Herbal antimicrobials and wound-healing agents effectively manage acne and skin injuries. Tea tree oil demonstrates bactericidal activity against *Propionibacterium acnes* comparable to benzoyl peroxide with fewer side effects [38]. Neem (*Azadirachta indica*) compounds inhibit bacterial growth and reduce sebum secretion [39].

Applications in Hair Care

Hair Growth Promotion

Several herbal extracts stimulate hair follicle activity and promote growth. Ginseng ginsenosides prolong the anagen phase and prevent premature catagen transition [40]. Saw palmetto (*Serenoa repens*) inhibits 5 α -reductase, reducing dihydrotestosterone (DHT) levels implicated in androgenetic alopecia [41]. Pumpkin seed oil increases hair count and thickness through similar mechanisms [42]. Rosemary extract enhances microcirculation and demonstrates efficacy comparable to minoxidil [43].

Anti-dandruff and Scalp Health

Herbal ingredients combat *Malassezia* species and seborrheic dermatitis. Tea tree oil exhibits fungicidal activity and reduces dandruff severity [44]. Neem oil's antifungal properties effectively manage scalp conditions [45]. Zinc pyrithione from botanical sources demonstrates cytostatic effects on fungal proliferation [46].

Hair Conditioning and Strengthening

Plant proteins and oils improve hair mechanical properties. Hydrolyzed wheat protein penetrates the hair shaft, strengthening and repairing damage [47]. Coconut oil reduces protein loss and prevents hygral fatigue [48]. Argan oil (*Argania spinosa*), rich in vitamin E and fatty acids, improves elasticity and shine [49]. The mechanism of Action of some Herbal Bioactives in Cosmeceuticals is given in Table 1.

Table 1: Mechanisms of Action of Herbal Bioactives in Cosmeceuticals

Mechanism	Herbal Source	Active Component	Molecular Target	Cosmeceutical Application
Antioxidant Activity	<i>Camellia sinensis</i>	EGCG	ROS neutralization, SOD/catalase upregulation	Anti-aging, photoprotection
Tyrosinase Inhibition	<i>Glycyrrhiza glabra</i>	Glabridin	Tyrosinase enzyme, melanogenesis pathway	Skin whitening, hyperpigmentation
MMP Inhibition	<i>Vitis vinifera</i>	Resveratrol	MMP-1, MMP-3, NF- κ Bsignaling	Collagen preservation, wrinkle reduction
Collagen Synthesis	<i>Centella asiatica</i>	Asiaticoside	Fibroblast proliferation, procollagen gene expression	Wound healing, anti-aging
5 α -Reductase Inhibition	<i>Serenoa repens</i>	Fatty acids, phytosterols	DHT synthesis pathway	Hair growth, androgenetic alopecia
Antimicrobial Action	<i>Melaleuca alternifolia</i>	Terpinen-4-ol	Bacterial cell membrane disruption	Acne treatment, scalp health
UV Protection	<i>Curcuma longa</i>	Curcumin	UV-induced DNA damage, inflammatory mediators	Photoprotection, anti-inflammatory
Anti-inflammatory	<i>Matricaria chamomilla</i>	Bisabolol, apigenin	Prostaglandin synthesis, cytokine reduction	Sensitive skin, dermatitis

Mechanisms of Action

Antioxidant Activity

Herbal antioxidants neutralize reactive oxygen species (ROS) through electron donation and metal chelation. Polyphenols scavenge free radicals and upregulate endogenous antioxidant enzymes, including superoxide dismutase and catalase [50]. This activity prevents oxidative damage to lipids, proteins, and DNA implicated in photoaging and inflammation.

Anti-microbial Properties

Phytochemicals disrupt microbial membranes, inhibit biofilm formation, and interfere with bacterial quorum sensing. Essential oils damage cell membrane integrity, causing cytoplasm leakage [51]. Alkaloids interfere with DNA synthesis and protein production in pathogenic organisms.

Enzyme Inhibition and Collagen Synthesis

Herbal actives modulate key enzymes regulating skin homeostasis. MMP inhibition by EGCG prevents collagen and elastin degradation [52]. Tyrosinase inhibitors reduce melanogenesis for hyperpigmentation control [53]. Procollagen peptidase activators enhance collagen maturation and dermal architecture [54].

UV Protection and Photoprotection

Botanical compounds absorb UV radiation and mitigate photodamage. Polyphenols absorb UVB and attenuate UV-induced erythema and DNA damage [55]. Flavonoids reduce sunburn cell formation and suppress inflammatory mediators following UV exposure [56]. Molecular Mechanisms of Herbal Cosmeceuticals in Skin Health are depicted in the Figure 1.

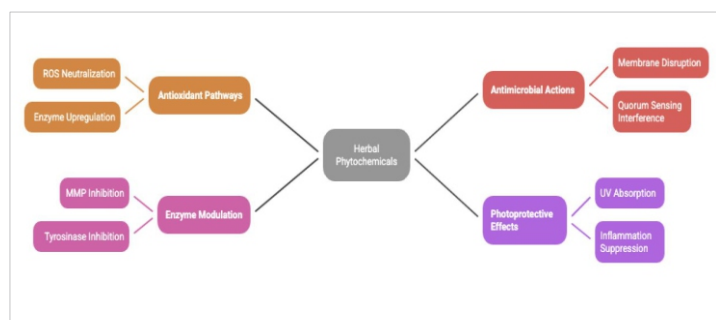


Figure 1: Molecular Mechanisms of Herbal Cosmeceuticals in Skin Health

Formulation Aspects of Herbal Cosmeceuticals

Extraction Methods and Standardization

Extraction methodology critically influences phytochemical yield and activity. Conventional techniques include maceration, percolation, and Soxhlet extraction, while modern methods employ supercritical fluid extraction (SFE), ultrasound-assisted extraction (UAE), and microwave-assisted extraction (MAE) for enhanced efficiency [57]. Standardization ensures consistent bioactive content through chromatographic techniques (HPLC, GC-MS), quantifying marker compounds [58].

Stability and Shelf-life Considerations

Phytochemicals' susceptibility to degradation necessitates stability optimization. Antioxidants like ascorbic acid and polyphenols oxidize upon light and oxygen exposure [59]. pH optimization, chelating agents, and inert packaging enhance stability. Accelerated stability studies predict shelf-life under various storage conditions (ICH guidelines).

Delivery Systems

Advanced delivery systems improve herbal bioavailability and efficacy. Liposomes and niosomes encapsulate hydrophilic and lipophilic actives, enhancing skin penetration [60]. Nanoemulsions increase surface area and permeation rates [61], provide sustained release and cooling effects suitable for sensitive skin [62]. Selection depends on active physicochemical properties and the target application site.

Safety, Toxicity, and Regulatory Aspects

Safety Evaluations and Adverse Effects

Despite the perception of herbal products as inherently safe, comprehensive safety evaluations remain essential. Allergic contact dermatitis represents the most common adverse effect, with botanical allergens including sesquiterpene lactones from the Compositae family and primin from the *Primula* species [63]. Essential oils, particularly tea tree and lavender, may cause irritant or allergic reactions at high concentrations [64]. Phototoxicity occurs with certain herbal ingredients like bergamot oil containing furocoumarins [65]. Systematic toxicological studies, including patch testing, repeated insult patch tests (RIPT), and photoallergenicity assessments, ensure consumer safety [66].

Quality Control and Regulatory Status

Herbal cosmeceutical quality control faces significant challenges due to botanical variability, inconsistent standardization, and adulteration risks [67]. Regulatory frameworks vary globally; the FDA classifies cosmeceuticals as cosmetics without requiring premarket approval, while the European Union enforces stricter safety assessments under Cosmetics Regulation (EC) No 1223/2009 [68]. Good Manufacturing Practices (GMP), authenticated raw materials, standardized extraction protocols, and analytical verification using HPLC and mass spectrometry ensure product consistency [69]. Heavy metal contamination, microbial limits, and pesticide residues require rigorous monitoring per pharmacopeial standards [70].

Challenges in Commercialization

Commercialization obstacles include batch-to-batch variation, limited shelf-life, complex regulatory landscapes, intellectual property protection difficulties, and insufficient clinical evidence [71]. Consumer skepticism regarding efficacy claims and price competitiveness with synthetic alternatives further complicates market penetration. Sustainable sourcing, ethical wildcrafting, and environmental conservation represent additional considerations for responsible commercialization [72].

Future Perspectives and Research Directions

Emerging Herbal Ingredients

Novel botanical sources continue emerging with promising cosmeceutical potential. Bakuchiol from *Psoralea corylifolia* demonstrates retinol-like benefits without associated

irritation, gaining significant attention [7]. Marine botanicals, including algae and seaweed, provide unique phytochemicals with antioxidant and anti-aging properties [43]. Adaptogenic herbs like ashwagandha (*Withaniasomnifera*) and rhodiola offer stress-protective benefits for skin homeostasis [13]. Extremophile plants from harsh environments contain specialized metabolites with enhanced stability and bioactivity [55].

Nanotechnology and Herbal Cosmeceuticals

Nanotechnology revolutionizes herbal cosmeceutical delivery through enhanced penetration, targeted delivery, and improved stability [12]. Nanostructured lipid carriers (NLCs), solid lipid nanoparticles (SLNs), and polymeric nanoparticles encapsulate hydrophobic phytochemicals, increasing bioavailability [15]. Nanoencapsulation protects sensitive compounds from degradation and enables controlled release [17]. Ethosomes and transfersomes facilitate transdermal delivery of polar herbal actives across the stratum corneum [19]. However, safety concerns regarding nanoparticle penetration and potential toxicity necessitate thorough investigation [9].

Clinical Trials and Evidence-based Validation

Rigorous clinical validation establishes herbal cosmeceutical credibility and differentiates efficacious products from marketing claims. Randomized controlled trials (RCTs) with appropriate controls, standardized outcome measures, and statistical power provide robust evidence [18]. Instrumental assessments, including corneometry, mexametry, profilometry, and spectrophotometry, objectively quantify efficacy parameters [21]. Mechanistic studies elucidating molecular pathways validate traditional uses and guide formulation optimization [34]. Biomarker identification enables personalized cosmeceutical approaches targeting individual skin characteristics and concerns.

Conclusion

Herbal cosmeceuticals represent a promising intersection of traditional botanical knowledge and modern dermatological science, offering multifunctional therapeutic benefits through diverse phytochemical mechanisms. Advanced formulation technologies and nanotechnology-based delivery systems enhance bioavailability and efficacy. However, rigorous clinical validation, standardization protocols, comprehensive safety assessments, and harmonized regulatory frameworks remain essential for sustainable market growth and consumer confidence.

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