IJBB
International Journal of Biotechnology and Biomedicine
Vol. 2 No3; November 2025 https://doi.org/10.31674/ijbb.2025.v02i03.005

Medicinal Plants in Cosmeceuticals: Bridging Ethnopharmacology and Modern Dermatology

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Article received on 27th October 2025.
Revision received on 27th November 2025.
Accepted on 28th November 2025.

Abstract
Medicinal plants have historically played an integral role in traditional beauty and dermatologic care systems such as Ayurveda, Traditional Chinese Medicine (TCM), Unani, and Indigenous healing practices. Contemporary research confirms that their therapeutic effects arise from diverse bioactive phytochemicals—polyphenols, flavonoids, terpenoids, alkaloids, and saponins—offering multifunctional benefits including antioxidant, anti-inflammatory, antimicrobial, anti-aging, and moisturizing properties. This review explores the ethnopharmacological heritage, phytochemical basis, and modern cosmeceutical applications of selected medicinal plants such as Aloe vera, Centella asiatica, Glycyrrhiza glabra, Curcuma longa, Butyrospermum parkii, and Hibiscus rosa-sinensis. Advances in formulation technologies—particularly nanoemulsions, liposomes, phytosomes, and solid lipid nanoparticles—have enhanced the stability, delivery, and skin bioavailability of botanical actives. Despite their potential, challenges remain regarding standardization, variability in phytochemical content, and safety concerns related to allergenicity or contamination. Regulatory frameworks, including the U.S. MoCRA, EU Regulation No. 1223/2009, and ASEAN Cosmetic Directive, emphasize safety, labeling, and post-market surveillance for botanical cosmeceuticals. Overall, integrating traditional botanical knowledge with modern extraction and nanotechnology-based delivery systems offers a sustainable and scientifically grounded approach to future skincare innovation.

Keywords: Medicinal Plants; Cosmeceuticals; Phytochemicals; Nanotechnology; Herbal Cosmetics; Skin Care; Regulation.

1.0 Introduction
Medicinal plants have long been central to traditional beauty and dermatologic care systems such as Ayurveda, Traditional Chinese Medicine (TCM), Unani, and Indigenous healing traditions. Historically, botanical ingredients like *Azadirachta indica* (neem), *Curcuma longa* (turmeric), *Glycyrrhiza glabra* (licorice), *Centella asiatica* (gotu kola), and *Butyrospermum parkii* (shea butter) were used not only for aesthetic enhancement but also for their therapeutic and symbolic significance (Upadhyay *et al.*, 2020; Singh & Maurya, 2019). Contemporary cosmeceutical science increasingly validates these ethnopharmacological practices, attributing their efficacy to bioactive phytochemicals such as flavonoids, terpenoids, alkaloids, and polyphenols (Pandey & Shukla, 2020). With the growing consumer demand for safe,

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sustainable, and multifunctional skincare, medicinal plants provide a valuable source of natural compounds for anti-aging, skin-brightening, anti-acne, moisturizing, and hair care formulations. This study reviews key medicinal plants used in cosmeceuticals, highlighting their phytochemical mechanisms, modern formulation advances, and regulatory perspectives. The review aimed to review the historical and ethnopharmacological significance of medicinal plants in traditional skin and hair care systems; identify and classify major phytochemicals with established cosmeceutical potential, including their mechanisms of action; evaluate the cosmeceutical applications of selected medicinal plants in anti-aging, depigmentation, antimicrobial, moisturizing, and hair care; discuss recent advances in formulation technologies enhancing the stability, bioavailability, and skin penetration of botanical actives; and examine safety concerns, standardization challenges, and global regulatory frameworks governing botanical cosmeceuticals. This study employed a systematic narrative review approach. Relevant literature was retrieved from scientific databases such as PubMed, Scopus, ScienceDirect, and Google Scholar, covering the period from 2000 to 2025. Keywords included medicinal plants, cosmeceuticals, phytochemicals, herbal cosmetics, nanoformulations, and skin care. Inclusion criteria were peer-reviewed studies, review articles, and regulatory documents addressing the biological activity, formulation, safety, or regulatory status of plant-based cosmeceuticals. Excluded were studies lacking phytochemical data or clinical relevance. Information was organized into thematic categories—anti-aging, skin-brightening, antimicrobial, moisturizing, and hair care—followed by analysis of formulation innovations and regulatory standards.

2.0 Ethnopharmacological Basis of Medicinal Plants in Cosmetics

Medicinal plants have for centuries played a central role in traditional beauty, ritual care, and dermatologic health. Across many cultures, natural ingredients derived from leaves, roots, seeds, flowers, and tree resins were not merely cosmetic but reflected a holistic approach to health and aesthetics. Systems such as Ayurveda, Traditional Chinese Medicine (TCM), Unani, and numerous Indigenous traditions integrated botanical preparations into daily skin- and hair-care routines to preserve youthful appearance, reduce blemishes, heal wounds, and protect against environmental stressors (Upadhyay *et al.*, 2020). These practices demonstrate an early understanding of the connection between plants, skin health, and cultural identity.

In Ayurveda, classical medical texts describe detailed formulations for enhancing skin radiance and maintaining the balance of the three doshas. Plants such as *Azadirachta indica* (neem) were commonly prepared as pastes, oils, or powders for their antimicrobial, detoxifying, and cleansing properties, while *Curcuma longa* (turmeric) was valued for its anti-inflammatory, antioxidant, and complexion-brightening effects. These ingredients were incorporated into bridal beauty rituals and seasonal skin treatments, illustrating the importance of medicinal plants in both therapeutic and ceremonial contexts (Singh & Maurya, 2019). *Santalum album* (sandalwood) was another highly prized ingredient, used to produce fragrant cooling pastes that helped soothe rashes, reduce redness, and impart a natural glow. \Traditional Chinese Medicine (TCM) also contributed extensively to botanical skin care. *Glycyrrhiza glabra* (licorice) was used in ointments to lighten dark spots and treat irritation, while *Camellia sinensis* (green tea) provided catechin antioxidants that protect against oxidative stress and UV-induced damage. *Panax ginseng*, considered a rejuvenating tonic herb, has traditionally been applied to improve skin elasticity, microcirculation, and vitality (Wang & Zhao, 2018; Wang *et al.*, 2012). These herbs are still commonly featured in many Asian cosmeceutical formulations today.

The Unani medical system, developed from Greco-Arab traditions, prescribes floral waters and herbal pastes to balance the body's humours and treat a variety of dermatologic conditions such

as rashes, wounds, pigmentation disorders, and dry skin. Notable ingredients include *Rosa damascena* (Damask rose) for its soothing and aromatic qualities, and *Citrullus colocynthis* for its traditional use in cooling and cleansing topical preparations (Ahmad *et al.*, 2016).

Indigenous knowledge systems across continents further enriched ethnopharmacological skin care. In West Africa, the butter extracted from *Butyrospermum parkii* (shea tree) has for generations been relied upon as a natural emollient to combat dryness and protect the skin against harsh climates (Pieroni & Quave, 2005). In parts of Africa and Asia, infusions of *Hibiscus rosa-sinensis* flowers were used as natural hair rinses to enhance shine, promote growth, and strengthen hair shafts. Indigenous Australians traditionally applied the essential oil of *Melaleuca alternifolia* (tea tree oil) to cleanse wounds and alleviate infections due to its antiseptic and anti-inflammatory properties (Kamatou, Vermaak, & Viljoen, 2011). In European folk medicine, *Calendula officinalis* (marigold) and *Chamomilla recutita* (chamomile) were widely prepared as balms or infusions to soothe redness, heal minor lesions, calm irritated skin, and naturally lighten hair (Kumar, 2017).

Historically, these botanical practices often carried deep symbolic and spiritual meaning, being associated with purity, social status, rites of passage, or seasonal celebrations (Rashid *et al.*, 2022). Their continued presence in contemporary herbal cosmetics highlights a living bridge between ancestral knowledge and modern dermatology. Many of the plants revered in traditional beauty care, such as neem, turmeric, licorice, green tea, ginseng, shea butter, hibiscus, calendula, and chamomile, are now supported by scientific evidence demonstrating antioxidant, anti-inflammatory, wound-healing, and skin-brightening effects (Pandey & Shukla, 2020). This enduring relevance underscores the value of preserving ethnopharmacological wisdom as a foundation for developing safe, plant-based cosmeceuticals.

3.0 Phytochemicals with Cosmeceutical Potential

The benefits of medicinal plants in cosmeceuticals arise from their bioactive secondary metabolites, mainly polyphenols/flavonoids, terpenoids/essential oils, alkaloids/saponins, and vitamins, pigments and other bioactives (Chen & An, 2021).

Polyphenols and flavonoids such as catechins in *Camellia sinensis* (EGCG), curcuminoids in *Curcuma longa*, and quercetin in *Calendula officinalis* and *Aloe vera* neutralise reactive oxygen species (ROS), reduce UV-induced oxidative stress, protect collagen integrity and delay photo-ageing (Lee & Park, 2021; Pandey & Shukla, 2020). They also display anti-inflammatory effects that reduce irritation and accelerate repair (Chen & An, 2021).

Terpenoids and essential oils add antimicrobial and soothing benefits: monoterpenes such as bisabolol and azulene from *Chamomilla recutita* calm erythema, while terpinen-4-ol in Melaleuca alternifolia acts as a natural antiseptic useful against acne-causing bacteria (Lee & Park, 2021). Triterpenoids such as asiaticoside and madecassoside in *Centella asiatica* stimulate fibroblasts and collagen synthesis, supporting wound healing and anti-wrinkle care (Patel & Shah, 2020). Shea butter (*Butyrospermum parkii*), rich in triterpenes and tocopherols, serves as an emollient that strengthens the skin's lipid barrier.

Alkaloids and saponins also play key roles: *Panax ginseng* roots provide ginsenosides (saponins) that enhance micro-circulation and improve skin elasticity (Patel & Shah, 2020); *Glycyrrhiza glabra* contains glabridin and glycyrrhizin, which inhibit tyrosinase, reducing hyperpigmentation and inflammation (Wang & Zhao, 2018). Natural saponins from *Hibiscus rosa-sinensis* and *Calendula officinalis* impart mild cleansing and foaming properties desirable in gentle skin- and hair-care formulations.

Additional vitamins and pigments further enhance cosmetic value: *Aloe vera* gel provides vitamins C and E that promote collagen synthesis and hydration (Pullar *et al.*, 2017); *Oenothera*

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biennis (evening primrose) oil offers γ-linolenic acid that restores the epidermal barrier and relieves dryness; carotenoids in *Calendula officinalis* and anthocyanins in *Hibiscus rosa-sinensis* contribute both antioxidant and photoprotective pigmentation benefits (Stahl & Sies, 2012).

These combined phytochemical actions explain the multi-targeted benefits of traditional plant remedies and justify their ongoing inclusion in contemporary cosmeceutical products.

The modern cosmeceutical industry is characterized by the integration of active pharmaceutical ingredients (APIs) into cosmetic formulations, aimed at providing functional benefits beyond simple beautification. While synthetic compounds have traditionally dominated the market, the increasing awareness of potential side effects and the desire for sustainable sourcing has fueled extensive research into medicinal plants. Botanicals offer a complex synergistic mixture of compounds—including polyphenols, flavonoids, alkaloids, terpenes, and essential oils—that can address multiple skin and scalp issues simultaneously with minimal adverse reactions (Ahmed *et al.*, 2020; Ahmed *et al.*, 2022; Bouissane *et al.*, 2025)

Cosmeceutical applications are generally categorized by the primary function they serve: protection against oxidative stress (anti-aging), modulation of melanin synthesis (skin brightening), control of microbial proliferation (anti-acne), and restoration of the lipid barrier (moisturizing). This paper provides a detailed review of selected medicinal plants, chosen for their established historical use and confirmed scientific efficacy in contemporary dermatological and hair care products.

4.0 Cosmeceutical Applications of Medicinal Plants

4.1. Anti-Aging Botanicals: Collagen Stimulation and Antioxidant Protection

Aging is a complex physiological process characterized by the degradation of essential dermal components (collagen and elastin) and increased oxidative stress induced by Reactive Oxygen Species (ROS). Botanicals effective in anti-aging mitigate these effects through antioxidant activity and modulation of enzyme systems (Ahmed *et al.*, 2020; Ahmed *et al.*, 2022; Ahmed and Mikail, 2024; Ahmed *et al.*, 2025).

Aloe vera (Aloe barbadensis Miller) is renowned for its high mucopolysaccharide content, acting as a potent humectant. Crucially, the plant sterols contained in Aloe vera stimulate fibroblast production of collagen and elastin, aiding in skin repair and elasticity improvement. Furthermore, lignins in Aloe vera facilitate the penetration of other active compounds, enhancing overall formulation efficacy (Surjushe *et al.*, 2008).

Centella asiatica (Gotu Kola) is a cornerstone of anti-aging due to its rich composition of triterpenoids, notably asiaticoside, madecassoside, asiatic acid, and madecassic acid. These compounds stimulate Type I collagen synthesis in the skin. Asiaticoside, in particular, has been shown to enhance wound healing and reduce scarring by promoting fibroblast proliferation and vascularization, making it highly effective in improving skin firmness and reducing the visibility of fine lines (Bylka *et al.*, 2013).

Panax ginseng (Ginseng) contains specialized triterpene glycosides known as ginsenosides. These potent molecules exhibit strong antioxidant activity, protecting skin cells from UV-induced damage and photoaging. Ginseng extracts are also known to improve blood circulation in the dermis, which aids in nutrient delivery and waste removal, contributing to a healthier, more revitalized complexion (Kim *et al.*, 2024; Ramadhania *et al.*, 2023).

4.2. Skin-Lightening Agents: Modulating Melanogenesis

Hyperpigmentation disorders, such as melasma and freckles, result from the overproduction or uneven distribution of melanin, typically catalyzed by the tyrosinase enzyme. Natural skin-lightening agents function primarily by inhibiting tyrosinase, scavenging free radicals, or

blocking melanin transfer.

Glycyrrhiza glabra (Licorice) is widely utilized for its key component, glabridin. Glabridin is a highly effective tyrosinase inhibitor that works without the cytotoxicity risks associated with many synthetic inhibitors. Additionally, licorice root contains licochalcone A, which possesses significant anti-inflammatory properties, helping to reduce redness and irritation often associated with post-inflammatory hyperpigmentation (Yokota *et al.*, 1998).

Morus alba (White Mulberry) extract contains phenolics, including flavonoids and stilbenoids, which demonstrate potent anti-melanogenic effects. Studies show that *M. alba* root extract competitively inhibits tyrosinase activity by chelating copper at the active site of the enzyme, leading to a noticeable reduction in dark spots and overall skin brightening (Batiha *et al.*, 2023).

Curcuma longa (Turmeric) owes its vibrant color and efficacy to curcuminoids, particularly curcumin. While historically known for its strong anti-inflammatory properties, curcumin also interferes with melanogenesis by inhibiting the MITF (Microphthalmia-associated Transcription Factor) pathway, thereby reducing the production of tyrosinase and resulting in a lighter skin tone (Aggarwal *et al.*, 2007).

4.3. Anti-Acne and Antimicrobial Plants: Targeting Pathogens

Acne vulgaris is a multifactorial condition involving sebum overproduction, inflammation, and the proliferation of the bacterium Cutibacterium acnes. Topical botanicals offer antiseptic and sebum-modulating properties suitable for acne management (Cruz *et al.*, 2023).

Azadirachta indica (Neem), known as the "village pharmacy," contains powerful triterpenoids such as nimbin and nimbidin. Neem oil and leaf extracts possess broad-spectrum antimicrobial and antifungal properties, effectively controlling *C. acnes* populations. Furthermore, its anti-inflammatory action helps soothe the painful, inflamed lesions characteristic of severe acne (Alzohairy, 2016).

Melaleuca alternifolia (Tea Tree Oil-TTO) is one of the most clinically verified natural antiseptics. The active component, terpinen-4-ol, penetrates the bacterial cell membrane, causing cell death. TTO is highly effective against both bacterial and fungal skin infections and is commonly used in concentrations of 5–15% for treating mild to moderate acne lesions (Carson *et al.*, 2006).

Calendula officinalis (Marigold) is valued primarily for its anti-inflammatory effects derived from high levels of carotenoids and flavonoids. While its antimicrobial action is mild, Calendula significantly aids in the healing of acne scars and minor wounds, reducing erythema and promoting tissue regeneration (Silva *et al.*, 2021).

4.4 Moisturizing and Skin Barrier Enhancers: Restoring Lipid Integrity

The skin barrier, maintained by the stratum corneum, is essential for preventing Transepidermal Water Loss (TEWL). Effective moisturizing botanicals supply essential fatty acids and lipids that mimic the natural cellular matrix, reinforcing the barrier function.

Butyrospermum parkii (Shea Butter) is a rich source of triglycerides, particularly oleic and stearic acids. Its unique quality lies in its high non-saponifiable fraction (up to 17%), which includes phytosterols and triterpenes. These components act as powerful emollients, forming a protective layer that minimizes water loss and possesses significant anti-inflammatory and barrier repair capabilities (Honfo *et al.*, 2014; Ahmed *et al.*, 2022).

Aloe vera, in addition to its anti-aging benefits, functions as an exceptional humectant. The high molecular weight polysaccharides (glucomannans) bind water to the skin, increasing hydration levels and improving overall skin pliability and texture (Surjushe *et al.*, 2008).

Oenothera biennis (Evening Primrose Oil - EPO) is vital for barrier function due to its high concentration (7%–10%) of Gamma-Linolenic Acid (GLA), an omega-6 essential fatty acid.

GLA is a precursor to prostaglandins and is critical for ceramide synthesis in the stratum corneum. Topical application of EPO helps reverse deficiencies found in conditions like atopic dermatitis and xerosis, restoring lipid balance and reducing dryness (Muggli, 2005).

4.5. Hair Care Botanicals: Follicle Stimulation and Scalp Health

Botanicals in hair care target common issues such as hair loss (alopecia), dandruff, and poor hair fiber quality by improving scalp circulation, modulating hormone effects, and providing conditioning.

Hibiscus rosa-sinensis (Hibiscus) leaves and flowers contain mucilage, which acts as a natural conditioning agent, smoothing the hair cuticle and reducing frizz. Traditionally, Hibiscus aqueous extracts have been used to promote hair growth by stimulating hair follicles and increasing the anagen phase duration (Adhirajan *et al.*, 2003).

Eclipta alba (Bhringraj) is perhaps the most famous Ayurvedic herb for hair care. Its primary phytoconstituents, including the coumestan derivative wedelolactone, are scientifically recognized for their potential to induce hair follicle cycling. Studies support its efficacy in accelerating the telogen-to-anagen transition, making it a powerful agent against pattern baldness (Roy *et al.*, 2008).

Camellia sinensis (Green Tea) extract is a potent source of catechins, specifically Epigallocatechin gallate (EGCG). EGCG is significant in hair care because it can inhibit 5-alpha reductase (the enzyme that converts testosterone to DHT, a major cause of male and female pattern hair loss). Furthermore, its strong antioxidant properties protect the scalp from environmental damage and inflammation (Al-Shahab & Al-Amri, 2020).

Medicinal plants provide a rich and sustainable source of active ingredients for the cosmeceutical industry, offering functional benefits that successfully address complex dermatological needs. The synergy of multiple compounds within a single plant often results in superior efficacy and lower toxicity compared to isolated synthetic ingredients. The reviewed botanicals—from the collagen-stimulating triterpenoids of *Centella asiatica* and the tyrosinase-inhibiting glabridin of *Glycyrrhiza glabra*, to the barrier-restoring lipids of Butyrospermum parkii and the follicle-stimulating action of *Eclipta alba*—underscore the critical role of phytochemistry in advancing skin and hair care (Begum *et al.*, 2015).

Despite the promising evidence, the key challenges in utilizing botanicals include standardization inconsistencies due to geographical and seasonal variations, poor water solubility, and chemical instability. Future research efforts must focus on optimizing extraction techniques (e.g., supercritical fluid extraction) and integrating modern pharmaceutical technology, such as nanoemulsions, liposomes, and solid lipid nanoparticles, to enhance the stability, delivery, and overall bioavailability of these powerful natural compounds (Ahmed *et al.*,2022; Gupta *et al.*, 2022). This integration will allow cosmeceutical formulators to fully harness the therapeutic potential of medicinal plants in a standardized and highly effective manner.

5.0 Advances in Formulation & Delivery Systems

Botanical ingredients are often complicated mixtures. They might not dissolve well in water, can be chemically unstable, and have a hard time getting through the outer layer of the skin. Nanotechnology-based carriers help solve these problems (Qiu *et al.*, 2023).

Nanoemulsions are stable mixtures of two liquids that don't mix well, like oil and water, and they are kept stable by special substances called surfactants (Che Marzuki *et al.*, 2019).

The tiny droplets in nanoemulsions are usually smaller than 200 nanometers. In skincare products, nanoemulsions help mix plant-based active ingredients like essential oils, terpenoids, and flavonoids with water. They also increase the surface area of these ingredients, which helps

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them interact better with the skin. Studies show that when phenolic compounds and essential oils are made into nanoemulsions, they can get into the skin more effectively (Deveci *et al.*, 2025).

Liposomes and niosomes are like tiny bubble-like structures made from lipids, such as phospholipids and sometimes cholesterol. Putting botanical ingredients inside these structures allows them to be released slowly, protects them from breaking down, and helps them deposit better in the skin, especially in the top layer. Liposomes are often used with herbal extracts like curcumin, green tea polyphenols, and aloe to make them less irritating and more effective in the skin (Choudhury *et al.*, 2025).

Phytosomes, also called "herbosomes," are special combinations where botanical ingredients, like polyphenols or flavonoids, are mixed with phospholipids, such as phosphatidylcholine.

This creates a molecular complex, not a bubble, which improves how well these ingredients can pass through lipid membranes and increases their effectiveness in the body. Talebi *et al.* (2025) explain how phytosomal forms of ingredients like silymarin or quercetin can penetrate the skin better than just using the raw extract.

Other methods, such as solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), and polymeric nanoparticles, are also commonly used with herbal actives. These methods offer controlled release, help the product stay on the skin longer, and can target specific areas of the skin (Jalili *et al.*, 2023; Safta *et al.*, 2024)

6.0 Standardization and Extraction Technologies for Plant Actives

In today's world of cosmeceuticals, having the same quality and results every time is really important. Knowing about plants from traditional medicine isn't enough. There is a need to standardize and use better extraction methods to get consistent results. Special methods like high-performance liquid chromatography (HPLC), gas chromatography-mass spectrometry (GC-MS), liquid chromatography-mass spectrometry (LC-MS/MS), thin-layer chromatography (TLC), and DNA barcoding are used to characterize the plants and also check for their purity (Bharti *et al.*, 2024).

In general, one or more marker compounds—like a specific flavonoid, alkaloid, or terpenoid—help set the standards for the product. The use of full chemical fingerprinting shows the whole pattern of peaks, to make sure all batches are the same. Similarly, traditional methods like maceration, Soxhlet extraction, and percolation are used for extracting the active compounds (Fernandes *et al.*, 2025).

These traditional methods, however, not only take longer and use more solvents, but they are also environmentally unfriendly and can damage the compounds if too much heat is used. So, newer, more efficient methods are becoming more popular, including the ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) help reduce time, increase yield, and use less solvent (Shen *et al.*, 2023). Furthermore, supercritical fluid extraction (SFE), especially with supercritical CO_2, gives clean, solvent-free extracts that are great for cosmetics (Nastić *et al.*, 2025), while pressurized liquid extraction (PLE) and accelerated solvent extraction work well under controlled conditions for more efficient results (Barp *et al.*, 2023).

7.0 Stability, Bioavailability & Skin Penetration Challenges

To turn botanical extracts into good cosmetic products, the formula needs to ensure the active ingredients stay stable, are absorbed by the skin, and can get through the skin properly (Hoang *et al.*, 2021). Botanical ingredients like polyphenols, essential oils, flavonoids, and vitamins are easily broken down by things like oxygen, water, light, or heat. To help them stay stable, techniques such as nanoemulsions, liposomes, or phytosomes can be used to protect them from light, air, and moisture. Antioxidants or stabilizers such as vitamin E, BHT, or chelating agents

can also be added. Choosing the right pH level and buffer systems, and avoiding the use of ingredients that might react badly with the actives, controlling the moisture levels in the product and using packaging that blocks air and light, like airless pumps or dark containers, are also useful (Awlqadr *et al.*, 2025).

On the other hand, the interaction of multiple intrinsic and extrinsic factors affects chemical stability, microbial safety, and sensory properties of common comseceuticals. Intrinsic factors include water activity, pH, redox potential, nutrient availability, natural microflora, residual microbial counts, and the biochemical composition of raw materials and preservatives used. These parameters determine microbial growth potential and biochemical reactions influencing quality (Amit *et al.*, 2017). Similarly, extrinsic factors encompass external conditions encountered during processing, storage, and distribution, such as temperature, relative humidity, light exposure, time–temperature profiles, headspace pressure, environmental microbial load, and packaging atmosphere. Improper control of these parameters accelerates spoilage and nutrient degradation (Putnik *et al.*, 2020). The combined influence of these variables can be synergistic or antagonistic. A notable approach leveraging this interaction is the "hurdle effect", where multiple mild preservation techniques—such as low temperature, moderate heat, antioxidants, and controlled-atmosphere packaging—act collectively to suppress microbial growth. This method allows the use of gentle processing conditions, maintaining both nutritional and sensory quality (Akritidou *et al.*, 2023; Putnik *et al.*, 2020).

7.1 Bioavailability and Skin Penetration

The stratum corneum acts as the primary barrier limiting the bioavailability of topically applied actives. To enhance skin penetration, nanocarrier systems such as liposomes, nanoemulsions, phytosomes, and solid lipid nanoparticles are commonly employed to improve diffusion through skin layers (Ahmed *et al.*, 2022; Yu *et al.*, 2021; Sharafan *et al.*, 2025). Penetration enhancers such as oleic acid, alcohols, and glycols can also temporarily disrupt the lipid matrix to increase permeability (Mistry & Notman, 2024). Optimal carrier characteristics—typically particle sizes below 200 nm with neutral or slightly negative surface charges—facilitate deeper penetration and better stability (Akombaetwa *et al.*, 2023). Controlled or sustained release formulations further prolong therapeutic activity at the target site.

In vitro studies using human or animal skin models, such as Franz diffusion cells, are widely used to evaluate percutaneous absorption (Neupane Mungmai *et al.*, 2020). Complementary methods like microscopy or tape stripping help assess skin retention and distribution. However, translating in vitro performance to in vivo efficacy remains challenging due to interindividual skin variability, systemic metabolism, and formulation scalability (Trebilcock *et al.*, 1994).

7.2 Adverse Effects, Allergic Reactions & Toxicity

Although many consumers assume that "natural" products are inherently safe, herbal ingredients can still trigger adverse skin reactions such as contact dermatitis, hepatotoxicity, renal failure, allergic reactions, carcinoma, coma, colon perforation, as well as systemic effects and even death when absorbed due to adulteration, contamination, overdosing, herb-drug interactions, and herb-herb interactions and photoallergic responses (Kongkaew *et al.*, 2024; Maddaleno *et al.*, 2024). Certain components—such as essential oils, allergens like limonene, linalool, and geraniol, or botanicals with strong alpha-hydroxy acid– or retinoid-like activity—are more prone to induce sensitization or irritation (Yihan *et al.*, 2025). Concentrated extracts further increase these risks.

Ensuring product safety requires comprehensive preclinical evaluation, including in vitro cytotoxicity, patch, and photo-dermatotoxicity testing, along with animal studies when systemic absorption is possible. Continuous post-marketing surveillance is also crucial to

identify potential adverse events in real-world use (Ahmed *et al.*, 2025; Costa Gagosian *et al.*, 2025).

8.0 Regulatory Frameworks

Botanical cosmeceuticals occupy a space between cosmetics and medicines—marketed like cosmetics but often implying therapeutic benefits. Regulatory frameworks differ globally. In the United States, the Modernized Cosmetics Regulation Act (MoCRA) requires manufacturers to register facilities, report adverse events, and ensure safety, although "cosmeceutical" is not a legally recognized category, so drug claims are prohibited (U.S. FDA, 2023). The European Union enforces Regulation (EC) No. 1223/2009, which governs safety, labeling, and permissible claims; products suggesting medicinal effects are regulated as drugs (European Commission, 2024). In ASEAN countries—including Malaysia, Singapore, Indonesia, and the Philippines—cosmetic regulations mandate ingredient registration, safety and stability data submission, and accurate labeling (ASEAN Cosmetic Directive, 2021). India distinguishes between herbal cosmetics and Ayurvedic medicines: the AYUSH department oversees traditional products, while the Drugs and Cosmetics Act defines cosmetic versus medicinal classifications (Government of India, 2023). For international exports, companies must adapt labeling, safety documentation, and claims to comply with varying jurisdictions, particularly in the EU and U.S. markets (Ferreira *et al.*, 2022). Developers must use INCI names, maintain safety records, and comply with post-market surveillance obligations.

Conclusion

Medicinal plants remain a cornerstone of natural cosmeceutical innovation, bridging traditional wisdom with modern dermatological science. Their diverse phytochemicals—flavonoids, terpenoids, saponins, alkaloids, and essential oils—offer multi-targeted actions including antioxidant, anti-inflammatory, antimicrobial, and barrier-restoring effects. Modern formulation technologies such as nanoemulsions, liposomes, and phytosomes have significantly enhanced their stability and skin bioavailability. However, consistent product efficacy requires standardized extraction methods, chemical profiling, and rigorous safety evaluations. Regulatory harmonization across regions will further support the safe global commercialization of botanical cosmeceuticals. Overall, integrating ethnobotanical knowledge with contemporary pharmaceutical technologies presents a sustainable pathway for developing effective, science-based natural skincare solutions.

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