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From Ayurvedic to Modern Cosmeceuticals: The Journey of Traditional Herbal Formulations

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ABSTRACT

The transformation of traditional Ayurvedic skincare practices into modern cosmeceutical science reflects an expanding interdisciplinary approach integrating ethnopharmacology, dermatology, pharmaceutical technology, and regulatory science. Ayurveda offers a rich repository of botanicals with documented therapeutic properties, where beauty is viewed holistically through physiological balance, nutrition, and preventive care. Modern research has validated the dermatological potential of key Ayurvedic herbs such as Curcuma longa, Aloe vera, Azadirachta indica, and Glycyrrhiza glabra, demonstrating antioxidant, anti-inflammatory, anti-aging, antimicrobial, and depigmenting effects. Technological interventions—including advanced extraction methods, analytical standardization (HPLC, HPTLC, LC–MS), and innovative delivery systems such as nano emulsions, liposomes, and phytosomes—have enhanced bioavailability, stability, and clinical performance of herbal actives. Despite growing evidence and global interest, challenges remain in harmonized regulation, clinical validation of multifaceted formulations, and long-term safety assessment. Continued advancement in biotechnology, personalized skincare, and green formulation technologies positions Ayurvedic-derived cosmeceuticals as a promising category for safe, effective, and sustainable dermatological solutions. The objective of this review is to systematically evaluate the evolution of traditional Ayurvedic herbal preparations into modern cosmeceutical products by synthesizing historical foundations, phytochemical evidence, advanced analytical methodologies, emerging formulation technologies, and current regulatory perspectives. This work aims to elucidate how contemporary scientific validation and technological innovation have contributed to improving the safety, therapeutic efficacy, formulation stability, and

global acceptance of cosmeceuticals derived from Ayurvedic botanicals.

Keywords:-*Ayurveda; cosmeceuticals; herbal actives; nanotechnology; standardization; botanical extracts; dermatology; natural skincare; quality control; phytopharmaceuticals; bioavailability; regulatory framework*

INTRODUCTION

Ayurveda is an ancient Indian medical system that emphasizes obtaining overall well-being via the balance of body, mind, and spirit. It is derived from the Sanskrit words "Ayus" (life) and "Veda" (knowledge or science). It is regarded as a philosophy for preserving harmony with nature as well as a science of existence. Ayurveda's core writings, including the Charaka Samhita, Sushruta Samhita, and Ashtanga Hridaya, which discuss preventative, promotional, and curative elements of health, date back more than 5000 years. [1] In Ayurveda, Swasthya (Health) is not only the absence of sickness but a dynamic equilibrium of the body's physiological (Doshas—Vata, Pitta, Kapha), metabolic (Agni), structural (Dhatus), and excretory (Malas) components, together with mental, sensory, and spiritual well-being. "Samadosha, samagnischasamadhatu mala kriyah; prasannaatmaindriya mana swasthaityabhidiyate," as stated in Charaka Samhita (Sutra Sthana 9/4), indicates that a person is deemed healthy when all these elements are in balance and the mind, senses, and soul are satisfied. [2] According to Ayurveda, Sundarata, or beauty, is an outward manifestation of Swasthya, or internal health. Harmony between the Sharira (body), Manas (mind), and Atma (soul) is the source of true beauty. The Ayurvedic approach to beauty, known as Swasthya-Saundarya Siddhanta, focuses on preserving inherent beauty through external care (Lepana, Abhyanga, and Snana), interior cleaning (Shodhana), and nourishing (Rasayana). Herbs like Aloe vera, Sandalwood, Turmeric, Manjistha, and Tulsi are traditionally used to enhance complexion, delay aging, and increase Varna (radiance). [3] In essence, Ayurveda considers health (Swasthya) and beauty (Sundarata) as linked; beauty is the natural outcome of bodily cleanliness, balanced metabolism, and mental serenity. Ayurveda's holistic lifestyle practices—balanced food (Ahara), disciplined daily routine (Dinacharya), and seasonal routine (Ritucharya)—are intended to maintain both physical and mental well-being. Cosmeceuticals are the goods used for increasing or keeping beauty, they usually employed for healing health of skin, hair, tooth and eye, etc. The natural or herbal cosmeceuticals acquiring their market place in cosmetic sector as they contain various substances which offer potential influence on skin. The natural components nourish the skin and stop the aging process. Ayurvedic cosmeceuticals enhances external appearance, gives longevity and retain youthfulness. Ayurveda idea of Rutucharya and Dinacharya also helps to improve natural beauty. Ayurvedic cosmeceuticals are widely accessible to the general public and are regarded as a holistic and safe choice for enhancing appearance. Ayurvedic cosmeceuticals resist aging, tonifying skin, gives relaxing and smoothing effects, hydrated skin thus avoids dryness and prevent premature. [4-7]

Rationale and significance of reviewing the transition from Ayurvedic preparations to modern formulations:

For ages, natural and holistic treatment has been based on Ayurveda, one of the oldest medical systems in the world. Using naturally occurring plant, mineral, and animal sources, traditional Ayurvedic preparations—which include churna (powders), kwatha (decoctions), avaleha (herbal jams), taila (medicated oils), and lepa (topical pastes)—were mainly created for customized patient treatment.[1] Despite the great therapeutic potential of these formulations, their popularity in the contemporary pharmaceutical industry has been restricted due to issues with stability, standardization, reproducibility, and patient compliance. The justification for examining the shift from Ayurvedic to modern formulations resides in the need to bridge the gap between ancient knowledge and contemporary scientific rigor. Reevaluating Ayurvedic formulations through the lenses of contemporary pharmaceutics, analytical chemistry, and biotechnology has become crucial due to the growing demand for herbal and natural-based medicines worldwide.[8] Modern approaches—such as nano-formulation, phytosome technology, liposomal administration, and polymeric encapsulation—have boosted the bioavailability, stability, and targeted delivery of traditional Ayurvedic medicines including Curcumin, Ashwagandha, and Brahmi.[9] From a scientific perspective, modernization makes it possible to use cutting-edge instruments like chromatography, spectroscopy, and molecular docking to validate conventional assertions. Moreover, combining Quality by Design (QbD) and Good Manufacturing Practices (GMP) ensures safety, efficacy, and reproducibility—key needs for regulatory recognition by authorities such as the WHO and FDA. [10,11]

Historical Background of Ayurvedic Cosmetics

The origins of herbal beauty care can be traced back to the traditional Ayurvedic texts Charaka Samhita (approximately 1000 BCE) and Sushruta Samhita (about 800 BCE)—which form the core compendia of ancient Indian medical knowledge. These treatises not only provide medicinal formulas for health and longevity but also dwell extensively on cosmetic care, rejuvenation, and enhancement of physical appearance (Sundarata), highlighting the fundamental relationship between beauty (Saundarya) and health (Swasthya).[2] A number of formulas are recommended for enhancing complexion (Varna Prasadana), preserving young appearance (Vayasthapana), and fostering brightness (Kanti Vardhana) in the Charaka Samhita, especially in the ChikitsaSthana and Sutra Sthana (Charaka Samhita, Sutra Sthana 5/13). The work explains the notion of Rasayana therapy, which focuses on internal rejuvenation with herbal formulations including Amalaki (Emblica officinalis), Haritaki (Terminalia chebula), Guduchi (Tinospora cordifolia), and Shatavari (Asparagus racemosus). Ayurveda's holistic approach to both internal and external beauty is reflected in these, which are thought to nourish tissues (Dhatus), improve skin shine, and postpone aging. [12] The Sushruta Samhita, noted for its extensive account of surgery (Shalya Tantra), also provides deep insights into cosmetic and dermatological care. In the ChikitsaSthana (Chapter 24), Sushruta covers numerous herbal and mineral concoctions used for skin purification,wound healing, and enhancement of complexion. He introduces the use of Lepa (herbal pastes), Abhyanga (oil massage), and Udvartana (herbal powder massage) as key external therapies for maintaining the tone and texture of the skin (Sushruta Samhita, ChikitsaSthana 24/15). Herbs like Yashtimadhu (Glycyrrhiza glabra),

Manjistha (Rubia cordifolia), Chandana (Santalum album), and Kumkuma (Crocus sativus) are often suggested for enhancing radiance, eliminating imperfections, and maintaining the skin's natural glow. [13] The equilibrium of Tridosha (Vata, Pitta, and Kapha), appropriate digestion (Agni), and mental well-being all contribute to external attractiveness, according to both texts, which highlight that true beauty results from balanced interior health. In order to maintain Saundarya (beauty) and Arogya (health), Ayurvedic beauty care is integrative, connecting diet (Ahara), lifestyle (Vihara), and topical applications (Lepana). This traditional idea of "inner health for outer beauty" continues to impact the modern herbalcosmetics and cosmeceutical sector, which is now revalidating these principles through scientific research and clinical investigations. [14]

Scientific Evolution toward Modern Cosmeceuticals: -

The creation of modern herbal cosmeceuticals is a gradual fusion of traditional botanical knowledge with advanced scientific approaches. Over time, the focus has evolved from empirical herbal use based on traditional traditions to evidence-based formulations supported by chemical, pharmacological, and technological advancements. This change has positioned herbal cosmetics as a scientifically validated and widely acceptable section of the beauty and health market.

The Concept of "Active Ingredients" in Herbal Products:

In classical Ayurveda, the medicinal and cosmetic benefits of herbs were attributed to their Rasa (taste), Guna (qualities), Veerya (potency), and Prabhava (specific action). Bioactive phytoconstituents, such as polyphenols, flavonoids, terpenoids, alkaloids, and glycosides, which function as active components in charge of quantifiable biological effects, are how modern research redefines these characteristics. [14] For example, aloin from Aloe vera encourages skin hydration, curcumin from Curcuma longa demonstrates anti-inflammatory and antioxidant properties, and azadirachtin from Azadirachta indica has antibacterial properties. [15] Herbal medicines have become scientifically standardized cosmeceuticals thanks to the identification, separation, and quantification of these active ingredients using chromatographic and spectroscopic techniques.

Transition from Empirical Use to Evidence-Based Formulations:

Historically, Ayurvedic formulas were produced empirically through experiential knowledge and textual references in Charaka Samhita and Sushruta Samhita. However, the past two decades has witnessed a paradigm change toward evidence-based validation using in vitro, in vivo, and clinical research to validate claims relating to skin protection, anti-aging, and wound healing. [11] This transformation improves the safety, efficacy, and repeatability of herbal products, aligning them with worldwide regulatory requirements such as those of the World Health Organization (WHO) and US FDA. Modern pharmacognostic and biochemical testing have enabled the molecular knowledge of herbal actives, permitting rational formulation creation rather than empirical blending. [9]

Advances in Extraction, Standardization, and Formulation Technology:

The purity, potency, and consistency of herbal components used in cosmeceuticals have been greatly enhanced by technological advancements in extraction and standardization. Heat-sensitive phytoconstituents can be effectively recovered while using the least amount of solvent thanks to techniques like

supercritical fluid extraction (SFE), microwave-assisted extraction (MAE), and ultrasound-assisted extraction (UAE). [13] Furthermore, contemporary standardization techniques incorporating HPLC, GC-MS, and LC-MS enable batch-to-batch consistency and quality assurance. [11] Advances in formulation science—such as emulsions, gels, liposomes, and hydrogels have enhanced the stability, bioavailability, and skin absorption of herbal actives, transforming traditional remedies into scientifically advanced skincare solutions.

Role of Nanotechnology, Encapsulation, and Delivery Systems in Modern Herbal Cosmeceuticals:

Nanotechnology has transformed the herbal cosmetic market by overcoming the restrictions of poor solubility, limited permeability, and instability of natural actives. To improve targeted distribution, controlled release, and deeper skin penetration of phytoconstituents, methods such nano emulsions, liposomes, phytosomes, niosomes, solid lipid nanoparticles (SLNs), and nanostructured lipid carriers (NLCs) are being employed more frequently. [17] For example, curcumin-loaded nanogels and aloe vera nanosuspensions have exhibited improved antioxidant and anti-aging properties compared to conventional formulations. [18] These new delivery techniques not only improve product efficacy but also align with consumer desire for high-performance, natural-based cosmeceuticals. Therefore, a synergistic advancement combining phytochemistry, pharmaceutical technology, and dermatological science is reflected in the scientific evolution from traditional herbal beauty care to contemporary evidence-based cosmeceuticals.

PHYTOCHEMICAL AND PHARMACOLOGICAL ASPECTS

Major Phytoconstituents Contributing to Cosmetic Benefits

Herbal substances employed in traditional and modern cosmeceuticals derive their efficacy from a diverse array of phytochemicals—bioactive molecules that provide antioxidant, anti-inflammatory, antibacterial, and photoprotective properties. Together, these phytoconstituents preserve skin health, postpone aging, and guard against environmental harm.

Polyphenols and Flavonoids:

Strong antioxidants called polyphenols, such quercetin, catechins, and epigallocatechin gallate (EGCG), counteract reactive oxygen species produced by pollution and UV rays. They prevent wrinkles and photoaging by lowering matrix metalloproteinase activity, stabilizing collagen, and inhibiting lipid peroxidation. [19]

Curcuminoids:

Curcumin, the primary curcuminoid in Curcuma longa (turmeric), has antioxidant, anti-inflammatory, and wound-healing effects. It increases collagen synthesis and tissue remodeling while downregulating inflammatory mediators such as NF-κB, COX-2, and TNF-α. [20] Curcumin is a useful natural sunscreen ingredient since it also provides UV-protective action by lowering ROS-induced DNA damage.

Terpenoids and Essential Oil Components:

Terpenoids such as α-santalol, citronellol, and limonene provide anti-inflammatory, antibacterial, and calming properties good for acne-prone and sensitive skin. Rich in α- and β-santalol, Santalum album oil has anti-inflammatory and anti-proliferative

properties that soothe irritated or inflamed skin.[21]

Limonoids and Triterpenoids: Found in Azadirachta indica (neem) and Glycyrrhiza glabra (licorice), these compounds—such as azadirachtin and glycyrrhizin—offer antibacterial, anti-acne, and depigmenting effects. Tyrosinase is inhibited by glycyrrhizin, which lowers melanin synthesis and promotes skin lightening. [22]

Polysaccharides and Glycoproteins: Aloe vera gel includes acemannan, a polysaccharide having moisturizing, wound-healing, and anti-inflammatory properties. It is useful for anti-aging and post-inflammatory treatment because it increases fibroblast proliferation, collagen deposition, and hydration. [23]

Carotenoids and Phenolic Acids: β-Carotene, lycopene, and caffeic acid derivatives operate as natural UV shields by quenching singlet oxygen and protecting cellular membranes against oxidative stress. These chemicals improve skin tone, flexibility, and overall photoprotection. [24]

MECHANISM OF ACTION OF KEY HERBAL ACTIVES: -

The biological efficacy of herbal cosmeceuticals is primarily related to their bioactive phytochemicals, which interact with numerous molecular and cellular targets to enhance skin health. These processes involve antioxidant defense, anti-inflammatory signaling, regulation of melanogenesis, antibacterial action, and facilitation of wound healing. The following outlines the key mechanistic insights of widely utilized herbal actives.

Antioxidant and Anti-Aging Mechanisms:

Phytoconstituents like polyphenols, flavonoids, and curcuminoids reduce reactive oxygen species (ROS) caused by pollution, UV exposure, and metabolic stress. ROS accelerate the aging process of the skin by causing oxidative damage to proteins, lipids, and DNA. Compounds such as curcumin from Curcuma longa and epigallocatechin gallate (EGCG) from Camellia sinensis work by chelating transition metals, scavenging free radicals, and increasing the activity of endogenous antioxidant enzymes (glutathione peroxidase, catalase, and superoxide dismutase). [19] Additionally, by blocking the matrix metalloproteinases (MMP-1, MMP-9) that degrade collagen, these antioxidants increase skin suppleness and prevent wrinkles. [14]

Anti-Inflammatory Activity:

Many herbal actives influence inflammatory signaling pathways associated with skin irritation, acne, eczema, and photoaging. By suppressing the expression of nuclear factor-kappa B (NF-κB), cyclooxygenase-2 (COX-2), and lipoxygenase (LOX), curcumin lowers the synthesis of pro-inflammatory mediators such TNF-α, IL-1β, and IL-6.[25] The components of sandalwood oil, α- and β-santalol, reduce inflammation and irritation by inhibiting prostaglandin E2 production and mitogen-activated protein kinase (MAPK) signaling.[21] Aloe vera polysaccharides reduce erythema and promote tissue regeneration via influencing the NF-κB and TGF-β pathways. [23]

UV-Protection and Photoprotective Mechanisms:

Flavonoids, carotenoids, and phenolic acids are examples of natural substances that absorb UV light and lessen its negative effects.

- By reducing UV-induced ROS production, DNA photodamage, and lipid peroxidation, flavonoids (such as quercetin and kaempferol) shield keratinocytes. [24]

- By quenching singlet oxygen and peroxyl radicals, carotenoids like lycopene and β-carotene protect cellular membranes and stop oxidative photodamage.[26]
- Green tea catechins provide photoprotection against UVB-induced erythema and carcinogenesis by enhancing DNA repair enzymes. [19]

Antimicrobial and Anti-Acne Mechanisms:

Phytochemicals from Curcuma longa, Ocimum sanctum (tulsi), and Azadirachta indica (neem) have broad-spectrum antibacterial action against skin infections.

- By breaking down bacterial cell walls and preventing microbial adhesion, azadirachtin and nimbi din lessen the colonization of Propionibacterium acnes, which causes acne. [22]
- Curcumin exhibits bacteriostatic effect by inhibiting FtsZ-mediated cell proliferation and suppressing bacterial quorum sensing. [27]
- Essential oils (including sandalwood and tea tree) have antiseptic properties that help treat dermatitis, eczema, and acne by disrupting lipophilic membranes. [28]

Depigmentation and Skin-Brightening Mechanisms:

By focusing on the tyrosinase enzyme, a crucial regulator of melanin formation, herbal substances including curcumin, aloin from Aloe vera, and glabridin from Glycyrrhiza glabra affect melanogenesis.

- Glabridin lowers UVB-induced pigmentation and decreases tyrosinase activity via downregulating α-MSH and endothelin-1 signaling. [29]
- Aloe-derived aloin enhances even skin tone by interfering with melanin biosynthesis through melanocyte control mediated by antioxidants. [23]

Wound-Healing and Skin Regeneration

In injured tissues, substances like curcumin and acemannan (Aloe vera) promote angiogenesis, collagen deposition, and fibroblast proliferation. Curcumin accelerates the development of granulation tissue and epithelialization by upregulating TGF-β1 and VEGF. [30] The traditional application of herbal remedies for burns, wounds, and post-inflammatory skin restoration is validated by these methods.

IN-VITRO AND IN-VIVO EVIDENCE SUPPORTING THEIR EFFICACY

This section highlights experimental endpoints related to skin health (antioxidant activity, anti-inflammatory markers, antimicrobial action, photoprotection, wound healing, and depigmentation) and summarizes representative in-vitro, in-vivo (animal), and clinical evidence for major herbal actives used in cosmeceuticals. I try to establish generalizable conclusions rather than isolated findings by citing systematic reviews and frequently acknowledged primary studies.

In-vitro evidence (cellular / biochemical assays):

- **Antioxidant and anti-photooxidative assays** In DPPH, ABTS, and lipid peroxidation tests, polyphenols (EGCG, quercetin) and curcumin exhibit potent radical-scavenging activity and shield cultured keratinocytes and fibroblasts against UV-induced ROS and DNA damage. In cell models, these substances also lessen UV-induced induction of MMPs and oxidative stress markers, supporting anti-aging claims mechanistically. [14, 19]

- **Anti-inflammatory signaling in cell systems**-In keratinocytes and macrophage lines exposed to inflammatory stimuli, curcumin and α-santalol lower NF-κB activation, COX-2 expression, and

pro-inflammatory cytokine release (IL-1β, IL-6, TNF-α), which supports their usage for inflammatory dermatoses and irritated skin. [21, 25]

- **Antimicrobial activity (microbiology assays)** In standard agar dilution and broth microdilution tests, neem extracts, tea tree oil, and some essential oils demonstrate low minimum inhibitory concentrations (MICs) and bactericidal activity against common skin pathogens (Staphylococcus aureus, Propionibacterium acnes/Cutibacterium acnes, Candida spp.), supporting topical antiseptic/anti-acne formulations. [28,31]

- **Melanogenesis / tyrosinase inhibition assays**Mechanistic evidence for skin-brightening benefits is provided by licorice (glabridin), kojic-like plant metabolites, and certain flavonoids, which inhibit cellular and fungal tyrosinase activity in vitro and decrease melanin formation in melanocyte cultures.[29]

In-vivo (animal) evidence

- **Photoprotection and anti-carcinogenesis models**-Green tea polyphenols (EGCG) administered topically or orally decreased UVB-induced erythema, oxidative indicators, and tumor growth in mice; treated animals also demonstrated enhanced DNA repair and decreased inflammation, indicating both photoprotective and chemo preventive benefits in vivo. [19]

- **Wound healing and tissue repair**-In mouse wound models, curcumin promotes angiogenesis, collagen deposition, granulation tissue development, and wound closure; these effects are correlated with regulation of TGF-β1, VEGF, and decreased inflammatory infiltration. Studies on animals have shown that Aloe vera polysaccharides (acemannan) have similar advantages for wound healing. [23, 30]

- **Anti-inflammatory efficacy**-In typical animal inflammation models (carrageenan or TPA provoked), α-santalol and sandalwood formulations diminish edema and inflammatory cell infiltration, supporting topical anti-inflammatory efficacy. [21]

Clinical evidence (human studies / trials / systematic reviews)

- **Aloe vera —** wound healing and burns Although study quality and heterogeneity vary, topical Aloe vera gel can shorten healing times and improve clinical outcomes in first-degree and some second-degree burns as well as small surgical wounds, according to systematic reviews and randomized controlled trials. Traditional topical indications are mostly supported by the evidence, although trial limitations are noted. [23]

- **Green tea polyphenols —** Inflammatory skin diseases and photoprotection. Green tea extract-containing topical formulations and small human studies enhanced biomarkers of photooxidative damage and decreased UV-induced erythema; some trials also showed benefits for photoaged skin and minor acne. Although there are still few larger, well-powered RCTs, the clinical signal is consistent with preclinical processes. [19]

- **Curcumin—**Oral and topical in dermatology. Clinical evidence for curcumin includes case studies and short trials that show improvements in wound healing, psoriasis, and acne when applied topically or as an additional oral treatment. Unless formulation techniques (nanocarriers, liposomes) are employed, curcumin's poor intrinsic bioavailability restricts systemic efficacy; topical treatment has demonstrated more reliable local benefits. [20, 27]

- **Neem and other botanicals —** antimicrobial and anti-acne. Although many studies are pilot-scale with variable formulations, clinical outcomes for neem-based topical treatments for acne and superficial infections are positive in short trials. Strong preclinical antibacterial profiles are being translated into solid, consistent clinical evidence. [22, 31]

Representative endpoints commonly measured in studies

- **Biochemical/cellular:** cytokine panels (IL-6, TNF-α), ROS tests, MMP expression, collagen content, tyrosinase inhibition, DPPH/ABTS, and NF-κB activity.
- **Animal models:** UV-induced erythema/photo carcinogenesis, wound-closure rate, collagen/angiogenesis histology, edema/inflammation tests.
- **Clinical endpoints:** Erythema index, trans epidermal water loss (TEWL), skin elasticity, objective wrinkle depth, lesion counts (acne), time-to-healing (wounds), patient-reported outcomes, and safety/tolerability are clinical endpoints.

Limitations, Quality Considerations and Research Gaps

- **Heterogeneity of extracts/formulations:** Lack of standardization makes comparison and meta-analysis more difficult. Many studies use proprietary blends or crude extracts with varying phytochemical contents.
- **Bioavailability and delivery:** A number of powerful active ingredients, such as curcumin and EGCG, have low skin/percutaneous or systemic bioavailability; improved delivery, such as encapsulation, phytosomes, or nano emulsions, is frequently necessary for positive clinical translation.
- **Study design limitations:** For many botanicals, high-quality randomized, controlled, and sufficiently powered trials are still required; a significant portion of human studies are small, open-label, or employ other objectives.

- **Safety and long-term data:** Many traditional botanicals have good short-term topical safety, but ongoing monitoring is necessary for long-term safety, allergenicity, photo-sensitization, and interactions with conventional medications.

QUALITY CONTROL AND STANDARDIZATION APPROACHES

Analytical Techniques: HPTLC, HPLC, LC–MS, GC–MS, NMR

For herbal cosmeceuticals to be safe, effective, and repeatable, standardization and quality control are crucial. Because herbal raw materials are complex and changeable, sophisticated analytical technologies are required to measure phytoconstituents, identify bioactive markers, and authenticate plant sources. These contemporary methods aid in bridging the gap between evidence-based contemporary standards and conventional empirical formulations. [11]

High-Performance Thin Layer Chromatography (HPTLC)

Herbal extracts and formulations are frequently fingerprinted using HPTLC. It provides qualitative and semi-quantitative evaluation of marker molecules by enabling the simultaneous analysis of several samples. HPTLC has distinctive chromatographic fingerprints that aid in the detection of batch-to-batch variation, adulteration, and substitution. [32]

- **Uses:** Glycyrrhizin in Glycyrrhiza glabra formulations, flavonoids in Aloe vera, and curcuminoids in Curcuma longa.
- **Benefits include:** low cost, high throughput, little sample preparation, and visual identification under UV or derivatized color.

For instance, the WHO suggests using HPTLC fingerprinting as the main method

of polyherbal formulation identification. [33]

High-Performance Liquid Chromatography (HPLC)

Because of its great accuracy, repeatability, and sensitivity, HPLC is regarded as the gold standard for quantitative phytochemical determination. It makes it possible to separate and measure the active components, breakdown products, and contaminants in plant extracts. [34]

- **Uses:** Measuring curcumin and desmethoxycurcumin in lotions containing turmeric, Quantification of polyphenols (quercetin, catechins) in herbal antioxidant compositions, Standardization of glycyrrhizin in licorice extract and triterpenoids in neem oil.
- **Alternatives:** RP-HPLC and UPLC offer high resolution and quicker analytical times, making them appropriate for regular cosmeceutical quality control.

Liquid Chromatography–Mass Spectrometry (LC–MS)

LC-MS allows for the structural clarification and trace-level quantification of phytochemicals in intricate herbal matrices by combining chromatographic separation with mass spectrometric detection. It offers fragmentation patterns and molecular weight confirmation for the identification of compounds. [35]

- **Uses:** Finding alkaloids, flavonoids, and phenolic acids in polyherbal cosmetic extracts, Verification of bioactive ingredients in anti-aging and herbal sunscreens, The identification of pollutants and adulterants in herbal cosmetics, such as steroids and artificial UV filters.
- **Benefits:** Excellent sensitivity, specificity, and fit for metabolomic profiling.

Gas Chromatography–Mass Spectrometry (GC–MS)

For the examination of volatile and semi-volatile components such fatty acids, terpenoids, and essential oils, GC-MS is perfect. For aroma-based and oil-based herbal cosmetics, the method offers both qualitative and quantitative data, which is essential. [36]

- Uses: o Terpene profiles of Cymbopogon citratus (lemongrass) and Santalum album (sandalwood oil), Finding impurities in essential oils, such as phthalates or leftover solvents, Quality control of fragrance ingredients in lotions, creams, and perfumes.
- **Benefits include**: superior repeatability, high resolution for volatile chemicals, and impurity detection capability.

Nuclear Magnetic Resonance (NMR) Spectroscopy:

NMR spectroscopy provides herbal extract metabolite fingerprinting and non-destructive structural elucidation. It helps with metabolomic standardization and authentication by offering thorough molecular-level information. [37]

- **Uses:** The structural validation of triterpenoids, flavonoids, and curcuminoids.

Distinguishing between authentic and contaminated herbal extracts, Complex mixture profiling (^{1}H-NMR metabolomics) without prior separation.

- **Benefits include**: the capacity to offer comprehensive molecular structural information, little sample preparation, and quantitative precision.

Integrated Analytical Approach:

In order to perform thorough quality assessment, the current standardization paradigm increasingly depends on multi-analytical integration, which combines spectroscopic (MS/NMR) and chromatographic (HPTLC/HPLC) approaches. The dependability,

repeatability, and chemical consistency of herbal formulations are guaranteed by such hyphenated procedures (e.g., LC–MS, GC–MS, HPLC–DAD, HPLC–NMR). The scientific legitimacy and regulatory acceptance of Ayurvedic cosmeceuticals in international markets are improved by this integrative analytical method. [11]

MARKER-BASED STANDARDIZATION OF HERBAL INGREDIENTS

A scientifically proven method for guaranteeing the quality, safety, and therapeutic consistency of herbal constituents and formulations is marker-based standardization. It entails identifying and measuring one or more chemical markers, which are particular phytoconstituents that act as reference substances that reflect the bioactive profile or qualitative characteristics of the plant. [11] This method is essential to the creation of contemporary phytopharmaceuticals and cosmeceuticals, assisting in the conversion of conventional Ayurvedic formulations into standardized, evidence-based goods that are compliant with international regulations.

Concept and Importance of Marker Compounds:

A marker chemical could be:

- A bioactive component (such as curcumin in Curcuma longa) that is in charge of the medicinal or cosmetic action, or
- A plant species' chemical reference trait that isn't always active, like berberine in Berberis aristata.
- For raw materials, intermediates, and final herbal products, markers function as quality indicators. These substances are quantified to guarantee batch-to-batch repeatability, identify adulteration, and provide dose-response consistency a scientific foundation. [32]

Selection Criteria for Marker Compounds:

A number of criteria influence the selection of marker chemicals [34]:

- **Pharmacological relevance:** The compound must be correlated with biological activity, such as the anti-inflammatory and skin-lightening properties of glycyrrhizin in Glycyrrhiza glabra.
- **Chemical stability:** Under processing and storage circumstances, the marker should not change.
- **Analytical detectability:** It should be possible to analyze using common spectroscopic or chromatographic methods (HPTLC, HPLC, LC-MS).
- **Availability of reference standards:** It should be possible to obtain pure marker chemicals by isolation or commercial means.

Analytical Techniques Used for Marker-Based Standardization:

To find and measure marker chemicals, a range of chromatographic and spectroscopic techniques are used:

- **HPTLC:** Offers digital and optical fingerprint profiles to verify the presence of important markers like flavonoids or curcuminoids. [32]
- **HPLC/UPLC:** Provides high-resolution phytochemical separation and quantification (e.g., curcumin, quercetin, azadirachtin).
- **LC-MS and GC-MS:** Make it possible to precisely identify complex marker components in polyherbal formulations by molecular analysis. [35]
- **NMR:** When several markers coexist, it is used for metabolomic standardization and structural clarification. [37]

Regulatory Perspective and Global Relevance:

Marker-based standardization is emphasized by regulatory organizations

such as WHO, EMA (European Medicines Agency), and AYUSH (India) as a fundamental prerequisite for the certification of herbal products. To guarantee product consistency, the WHO Guidelines for Quality Control Methods for Herbal Materials (2011) advise creating chemical fingerprints and quantifying marker compounds. For important cosmetic herbs including Curcuma longa, Aloe barbadensis, and Azadirachta indica, the Pharmacopoeia Commission for Indian Medicine and Homoeopathy (PCIM&H) in India has included marker-based tests in Ayurvedic Pharmacopoeial Monographs. This strategy aids in bringing Ayurvedic products into compliance with international standards for quality. [11, 33]

Stability studies and formulation reproducibility

A crucial part of quality control in the creation of Ayurvedic and contemporary herbal cosmeceuticals is guaranteeing the stability and repeatability of herbal formulations. Herbal formulations are complex mixes of phytoconstituents that may alter chemically, physically, or microbiologically over time, in contrast to synthetic treatments that contain single active chemicals. In order to ensure efficacy, safety, and customer acceptance over the course of the product's shelf life, stability evaluation and formulation reproducibility are essential. [11, 33]

Importance of Stability Studies:

Stability studies ascertain how a product's quality changes over time in response to external variables such temperature, humidity, light, and oxygen. The outcomes are utilized to determine expiration dates, shelf life, and storage conditions. [38-40] because plant extracts are multi-component and have the potential to:

- Phytochemical degradation (oxidation, hydrolysis, photodegradation),
- Modifications to compositions' color, odor, or viscosity
- A decrease in bioactivity, and
- Microbial contamination brought on by water and natural excipients.

Analytical Evaluation Parameters:

Both physicochemical and biological factors are used to evaluate stability:

- **Organoleptic:** phase separation, color, consistency, and odor.
- **Physicochemical:** moisture content, pH, viscosity, spread ability, and refractive index.
- **Chemical:** Degradation product profiling, active marker assay (using HPLC, HPTLC, and LC-MS).
- **Microbial:** Preservative effectiveness, total viable count, and lack of pathogens.
- **Functional (Bioactivity):** Long-term maintenance of anti-inflammatory, antioxidant, or UV-protective properties. [41]

Formulation Reproducibility:

The capacity to produce consistent batches of a product with the same quality and performance is known as formulation repeatability. Reproducibility guarantees that every batch has the same physical attributes, biological efficacy, and phytochemical makeup as the verified prototype. [32]

Integration of Stability and Reproducibility Studies

Stability testing and reproducibility validation are integrated in a strong quality assurance system:

- In stability studies, marker chemicals are measured on a regular basis to assess the kinetics of deterioration.
- To compare fingerprints from several batches, multivariate statistical techniques like PCA and chemometrics are used.

- Degradation rate constants obtained from accelerated testing are used in the development of shelf-life prediction models. [34]
- Data are utilized to determine optimal storage conditions, optimize packaging materials, and guarantee worldwide compliance for herbal cosmetics that are ready for export.

Regulatory Framework and Safety Evaluation

European Union (EU):

Regulation (EC) No 1223/2009, which creates a pre-market safety and information framework for cosmetic items put on the EU market, is how the EU regulates cosmetics. The designation of a Responsible Person (RP) within the EU, the upkeep of a Product Information File (PIF) that includes information on the product's composition, safety evaluation, manufacturing process, and labeling, adherence to Annexes that list substances that are prohibited or restricted, and notification through the Cosmetic Products Notification Portal (CPNP) prior to marketing are among the main responsibilities. Additionally, the Regulation prohibits animal testing of cosmetic chemicals and products and mandates that the safety assessment be prepared by a competent safety assessor. Because of these regulations, the EU system for product safety and documentation is among the strictest. [42]

United States (USA)

The Federal Food, Drug, and Cosmetic Act (FD&C Act) and its implementing regulations found in Title 21 CFR govern cosmetics in the United States. With the notable exception of the majority of color additives, there is typically no pre-market approval for cosmetics or ingredients in the EU; instead, the producer or importer bears the obligation for safety and accurate labeling. Proper ingredient listing (INCI names), precise net amount disclosures, and avoiding misbranding or drug-type claims that would reclassification a product as a drug are important responsibilities. Post-market oversight is strengthened by recent legislative reforms including the Modernization of Cosmetics Regulation Act (MoCRA, 2022), which expands FDA authority (e.g., mandatory adverse event reporting and facility registration). [43]

India

The Drugs & Cosmetics Act of 1940 and the Consolidated Cosmetics Rules of 2020 serve as the foundation for India's current legal system. State authorities and the Central Drugs Standard Control Organization (CDSCO) are in charge of manufacturing, importation, labeling, safety regulations, and registration (which is necessary for imports). Cosmetics must adhere to regulations for labeling, packaging, and quality requirements; imported goods must register and submit certain dossiers. For traditional herbal constituents, Indian regulations also adhere to pharmacopoeial monographs and BIS/AYUSH guidelines; hence, in order to gain market access, Ayurvedic and herbal cosmeceuticals must present suitable quality control and safety documentation. [44]

ASEAN (Association of Southeast Asian Nations)

To lower technical trade obstacles, ASEAN states implement the ASEAN Cosmetic Directive (ACD) and harmonized guidelines. The ACD offers a standard definition of cosmetics, lists of ingredients that are restricted or prohibited, guidelines for Good Manufacturing Practices, and criteria for labeling. National implementation is required: businesses must appoint a local Responsible Person in many countries and notify each member state where they place items (via country-specific portals or

notification systems). Regional trade is facilitated by the ACD framework, but it necessitates adherence to every country implementation detail (e.g., notification systems, authorized ingredients). [45]

MARKET TRENDS AND COMMERCIALIZATION

Global and Indian Cosmeceuticals Market Overview

- The global market for cosmeceuticals, or products that blur the boundaries between pharmaceuticals and cosmetics, was anticipated to be worth USD 67.07 billion in 2024 and is expected to grow at a compound annual growth rate (CAGR) of nearly 3.9% to reach USD 84.64 billion by 2030. [46]
- Other projections are more ambitious. For instance, one model projects a base of USD 71.23 billion in 2025, growing to ~USD 152.58 billion by 2034 (CAGR ~8.8%). [47]
- Although developed regions like Europe and North America continue to have a sizable proportion, the Asia Pacific region—including emerging markets—is one of the fastest-growing geographically. [48]

Drivers & Commercialization Insights:

- The cosmeceutical market is surpassing conventional cosmetics due to consumer demand for noticeable effects (anti-aging, skin restoration, brightness).
- Rising disposable incomes, urbanization, increased knowledge of skincare and aesthetics, retail development, and online penetration are all factors contributing to the growth of emerging markets.
- Manufacturers and brands are profiting from the premiumization of beauty by using more expensive active ingredients and specialized formulations instead of mass-market ones.
- Direct-to-consumer (D2C) and niche brands can flourish thanks to e-commerce and digital marketing.
- Nevertheless, there are still regulatory challenges because cosmeceuticals frequently fall between pharmaceuticals and cosmetics, making claims, safety, and substantiation important. [49]

Indian Market Overview

- The Indian cosmeceutical industry is expected to reach USD 2,272.7 million by 2030 (CAGR ~5.4% during 2025-2030), with a reported size of USD 1,645.0 million (≈ USD 1.645 billion) in 2024. [50]
- The Indian beauty and personal care market, which includes cosmeceuticals but is larger, was anticipated to be worth USD 28 billion in 2024 and is expected to grow at a compound annual growth rate (CAGR) of about 5.6% to reach USD 48.3 billion by 2033. [51]
- Higher internet and smartphone penetration, e-commerce expansion, more affluent consumers in smaller cities, and higher awareness of skincare and aesthetic wellbeing are the growth drivers in India.
- The largest and fastest-growing subsegment of cosmeceuticals in India is skin care. [52]

Leading brands utilizing Ayurvedic concepts: - [53-58]

Brand Name	Country of Origin	Market Positioning	Key Product Categories / Actives	Commercialization Strategy & Reach
Forest Essentials	India	Luxury Ayurvedic skincare brand blending ancient formulations	Facial care, body oils, ubtans, hair care; key actives: saffron, sandalwood, rose, ashwagandha	Premium retail boutiques, global exports (UK, UAE, USA), strong online presence

		with modern aesthetics		
Kama Ayurveda	India	Premium authentic Ayurvedic beauty brand	Kumkumadi serum, rose water, body oils, hair oils	Domestic & international boutiques (e.g., London), D2C and Sephora tie-ups
Biotique	India	Mass-market herbal/Ayurvedic skincare & haircare	Fruit and plant-based cosmetics (e.g., papaya scrub, bhringraj oil)	Nationwide retail + online; affordable Ayurveda; export markets in Asia & Africa
Himalaya Wellness	India	Legacy brand in herbal & Ayurvedic healthcare	Face wash, creams, oral care, nutraceuticals	Extensive pharmacy & FMCG distribution; trusted brand equity; global presence in >100 countries
Dabur India Ltd.	India	Ayurveda-based FMCG leader; diversified into personal care	Vatika hair care, Gulabari skin tonics, herbal toothpaste	Mass-market FMCG channels, global distribution (Middle East, Africa)
Patanjali Ayurved	India	Mass Ayurveda brand focused on affordability & nationalism	Hair oils, aloe vera gels, herbal soaps, toothpaste	Large-scale FMCG distribution, own retail network, exports
Nat Habit	India	Digital-first, youth-focused Ayurveda revival	Fresh ubtans, hair masks, serums, gels	D2C e-commerce, Amazon, retail expansion, influencer marketing
Just Herbs	India	Ayurvedic & organic cosmeceutical brand bridging Ayurveda and science	Ayurvedic skin serums, lip tints, natural cleansers	Online-first brand with premium mid-range positioning
Khadi Natural	India	Certified Ayurvedic and herbal care label promoting traditional formulations	Herbal soaps, shampoos, oils	Government-certified Khadi network + export to >25 countries
Soul Tree	India	BDIH-certified organic Ayurvedic brand	Skin and hair care products using turmeric, amla, rose	Focused on sustainable sourcing, eco-packaging, and export
Shankara Naturals	USA/India	Ayurveda-inspired luxury wellness skincare	Anti-aging serums, essential oils	U.S. & Indian markets; CSR under Art of Living Foundation
Ayuga (by The Moms Co.)	India	Modern Ayurveda brand targeting millennials	Vitamin C kumkumadi oils, face masks, cleansers	D2C focus via e-commerce & social media; affordable Ayurveda
Vedix	India	Personalized Ayurvedic hair & skincare	AI-based custom formulations using dosha analysis	Subscription-based D2C model; focus on personalization

Kama Botanicals	UK/India	Ayurveda-inspired botanical skincare	Serums, oils, aromatherapy	Boutique retail + online luxury wellness

CHALLENGES AND LIMITATIONS

Issues in Validation and Standardization of Complex Herbal Mixtures:

Numerous bioactive phytochemicals found in herbal-based cosmeceuticals can differ according on the plant source, season, extraction technique, and formulation procedure. Reproducible quality, efficacy, and safety are severely hampered by its intrinsic complexity. To describe the synergistic effects of multicomponent combinations, traditional single-marker analysis is frequently insufficient. Inconsistencies in product performance and safety results are caused by the lack of widely recognized analytical procedures as well as variations in the quality of raw materials. [59, 60] To guarantee batch-to-batch consistency, WHO and AYUSH have suggested methods including chromatographic fingerprinting (HPTLC, HPLC, LC-MS), DNA barcoding, and multi-marker quantification. [61, 62]

Lack of Harmonized Regulations:

Globally, the cosmeceutical regulatory environment is still disjointed. The EU and Japan regulate such goods as quasi-drugs, the U.S. FDA classifies them as cosmetics (without pre-market approval), and India acknowledges them under the Drugs and Cosmetics Act. International trade and scientific evaluation are complicated by this regulatory variance, which leads to confusion in product classification, labeling, and claim substantiation. Consumer trust and market openness are hampered by the lack of uniform guidelines for safety assessment, approved active ingredients, and efficacy testing. 62, 63, and 64 Common frameworks for herbal and cosmeceutical regulation are being sought after through initiatives like the WHO's Traditional Medicine Strategy (2014–2025) and harmonization projects by the ICH and ASEAN Cosmetic Directive. [62]

Intellectual Property and Traditional Knowledge Protection (TKDL Initiatives):

Traditional knowledge systems such as Ayurveda, Siddha, and Unani are often the source of cosmeceutical formulations. In the past, this knowledge has been vulnerable to biopiracy and unethical patenting by international organizations who fail to give credit to local sources. Established by CSIR and the Ministry of AYUSH, India's Traditional Knowledge Digital Library (TKDL) functions as a defensive intellectual property database, digitizing more than 300,000 formulations from classical books in several languages for use by international patent offices.[65, 67] The TKDL program has strengthened the protection of traditional medicinal history by effectively preventing the issuance of multiple illegitimate patents on neem, turmeric, and other botanicals. [66, 68]

FUTURE PERSPECTIVES

Integration of Ayurvedic Wisdom and Modern Science:

A significant potential direction for cosmeceutical innovation is the fusion of contemporary pharmaceutical sciences and Ayurvedic principles. Ayurveda offers a wide variety of botanicals, including Curcuma longa, Azadirachta indica, Aloe vera, and Aniasomnifera, whose synergistic and holistic qualities are currently undergoing scientific validation. Researchers can rationalize and refine traditional Ayurvedic medicines for specific dermatological applications by

combining them with contemporary analytical technologies (HPTLC, LC–MS, NMR) and pharmacogenomic insights. [62, 69] For international markets, the idea of "evidence-based Ayurveda" is increasingly directing product standardization, stability, and claim substantiation. [70]

Role of Biotechnology, Metabolomics, and Artificial Intelligence in Formulation Development:

High-value phytoconstituents utilized in cosmeceuticals can now be produced sustainably thanks to biotechnological interventions including microbial fermentation, biotransformation, and plant tissue culture. [71] The use of metabolomics provides a thorough profile of secondary metabolites, which helps with formulation optimization and the study of plant–compound–skin interactions. [72] Meanwhile, by predicting chemical compatibility, refining formulations, and customizing skin-care regimens based on user-specific criteria like age, heredity, and climate, artificial intelligence (AI) and machine learning (ML) techniques are transforming the market. [73] Prior to clinical validation, AI-driven "digital twins" and big-data analytics are being investigated for in silico efficacy and toxicity prediction.

Sustainable Sourcing and Green Extraction Technologies:

Eco-friendly, circular, and sustainable production approaches are essential for future cosmeceutical innovation. Green extraction techniques that maximize bioactive yield while minimizing solvent and energy consumption include supercritical CO^2 extraction, microwave-assisted, ultrasound-assisted, and enzyme-assisted extraction. [74] Traceability and biodiversity protection are guaranteed by ethical and sustainable plant material sourcing using fair-trade frameworks and Good Agricultural and Collection Practices (GACP). Cosmeceuticals are in line with the UN Sustainable Development Goals (SDGs) and international "clean beauty" trends because to the growth of bio-based packaging and zero-waste manufacturing. [75, 76]

Global Acceptance and Personalized Herbal Cosmeceuticals:

Personalized, organic, and ethically derived cosmetics are becoming more and more popular among consumers worldwide. Incorporating microbiome research, genetics, and AI-based skin profiling will open the door to customized herbal cosmeceuticals that are suited to each person's dosha type and skin physiology (in an Ayurvedic context). [77] The WHO's Traditional Medicine Strategy (2025–2034) seeks to improve regulatory acceptability of Ayurvedic and herbal cosmeceuticals in mainstream healthcare by bridging traditional systems with evidence-based contemporary research. [78] International commerce of verified herbal formulations and harmonized standards are being promoted by cooperative research networks between ASEAN, the EU, and India. [64, 65]

CONCLUSION

The evolution of Ayurvedic beauty practices into modern cosmeceutical science represents a significant paradigm shift from traditional empirical formulations to evidence-based, standardized, and technologically enhanced dermatological products. Ayurveda offers a profound and holistic foundation wherein beauty (Saundarya) is viewed as a reflection of systemic balance, supported by centuries of documented ethnopharmacological knowledge. Modern scientific advances—including phytochemical profiling, nanotechnology-enabled delivery systems, chromatographic standardization techniques, and computational formulation tools—have successfully validated and enhanced the

therapeutic potential of key Ayurvedic botanicals such as *Curcuma longa*, *Aloe vera*, *Azadirachta indica*, and *Glycyrrhiza glabra*. Further, emerging *in-vitro*, *in-vivo*, and clinical data support their antioxidant, anti-inflammatory, depigmenting, antimicrobial, photoprotective, and wound-healing actions, substantiating their transition from traditional herbal preparations to high-performance cosmeceuticals. The integration of regulatory frameworks, quality control strategies such as marker-based standardization, and stability profiling has reinforced product reliability, safety, and global acceptance. Nonetheless, challenges persist, particularly regarding harmonized regulations, scientific validation of polyherbal formulations, and bioavailability limitations of certain phytoconstituents. Looking ahead, the convergence of biotechnology, artificial intelligence, personalized dermatology, green extraction technologies, and Ayurveda-based design principles is expected to redefine the future of cosmeceutical innovation. By bridging historical wisdom with modern pharmaceutical science, Ayurvedic cosmeceuticals are positioned to play a transformative role in global skincare markets, meeting consumer demand for effective, natural, sustainable, and clinically substantiated beauty solutions.

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