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Review Article

Role Of Ancient Ayurvedic Drugs and Their Formulations in Treatment of Hyperpigmentation of Skin

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ABSTRACT

Hyperpigmentation disorders, including melasma and post-inflammatory hyperpigmentation (PIH), are prevalent dermatological concerns that significantly affect quality of life, particularly among individuals with darker skin tones. Conventional therapies—such as hydroquinone, retinoids, corticosteroids, chemical peels, and laser treatments—often provide inconsistent outcomes and carry risks of side effects or recurrence. This has stimulated growing interest in Ayurvedic medicine, a holistic system with a long tradition of using botanicals for enhancing skin complexion and restoring balance. This review synthesizes classical Ayurvedic perspectives alongside modern pharmacological evidence, focusing on key herbs such as *Curcuma longa* (turmeric), *Rubia cordifolia* (manjistha), *Symplocos racemosa* (lodhra), *Santalum album* (sandalwood), and *Glycyrrhiza glabra* (liquorice). These botanicals exhibit antioxidant, anti-inflammatory, and melanogenesis-regulating activities, supported by preclinical and emerging clinical studies. Challenges including phytochemical variability, lack of large-scale randomized controlled trials, and formulation-related issues highlight the need for rigorous standardization and innovative delivery systems. By bridging Ayurvedic wisdom with contemporary research, this review underscores the potential of these botanicals as safe, sustainable, and effective alternatives or adjuncts for managing hyperpigmentation, while outlining future directions for integrative dermatology.

INTRODUCTION

Attaining flawless skin remains one of the most universally sought-after aesthetic ideals, and the demand for interventions that enhance skin quality

continues to expand rapidly. The condition of one's skin exerts a considerable influence on emotional well-being, self-image, overall quality of life, and interpersonal interactions. The condition of one's skin exerts a considerable influence on emotional well-being, self-image,

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overall quality of life, and interpersonal interactions. The skin's appearance conveys extensive information about an individual's overall health status. Skin condition is closely linked to systemic well-being, acting as a visible indicator of vitality, disease states, and nutritional sufficiency. It can also serve as a marker of reproductive health and fertility. Attributes such as smooth texture and uniform coloration are recognized contributors to facial attractiveness and may be associated with mate selection and reproductive success, potentially reflecting the robustness of an individual's immune system. From an evolutionary standpoint, human skin characteristics have developed under pressures related to health, disease resistance, and sexual selection. The reduced body hair of humans likely evolved as a defense against parasites and, coupled with sweat gland development, improved thermoregulation. Anthropological evidence also suggests that women in many societies evolved lighter skin than men, potentially to make visual signals such as blushing more perceptible. A dense vascular network supports skin's metabolic demands, while the skin microbiome—shaped by sex, age, anatomical site, and geographic factors—affects skin quality and can contribute to disorders when imbalanced. The condition of one's skin exerts a considerable influence on emotional well-being, self-image, overall quality of life, and interpersonal interactions.

Skin pigmentation refers to the coloring of the skin, which is determined mainly by the amount and type of melanin produced by melanocytes. Some people inherit genes that make them naturally darker or lighter. When skin makes too much melanin in spots, we call that hyperpigmentation (dark patches). Common problems include brown sunspots, melasma (brown patches on the face), and dark circles under the eyes. These issues are especially common in

people from Asia and India. Studies show our skin has about 74% eumelanin and 26% pheomelanin on average. One big reason is sunlight: ultraviolet (UV) rays from the sun can trigger or worsen dark spots on the skin. Melanin comes in two main forms: eumelanin, which gives darker tones and protects against UV damage, and pheomelanin, which produces lighter shades and offers less UV protection. Pigmentation levels vary due to genetic factors, sun exposure, hormones, and certain medications. The exact amount and mix of melanin is mostly determined by genes. Different versions of pigmentation genes (like TYR, SLC24A5, etc.) in different populations lead to the wide range of skin tones around the world. That's why Indian skin can range from very light in the north to much darker in the south. Over generations, human skin color evolved to match local sunlight levels. Near the equator (where sun is strongest) people tend to have darker skin, which protects against UV damage. Farther from the equator (weaker sun), people tend to have lighter skin so the body can make enough vitamin D from limited sunlight. Various commonly observed hyperpigmentation disorders include melasma, post-inflammatory hyperpigmentation, ephelides, lentigines, and many more. Ayurveda has shown significant potential in treatment of melasma. Ayurveda is a holistic medical system that originated in India over 3,000 years ago. In modern medicine, facial melanosis (which is similar to Vitiligo) is sometimes treated with topical steroid creams. However, these steroids can cause side effects like skin irritation or rashes and are expensive for long-term use. Ayurvedic texts, on the other hand, suggest natural therapies – such as oil massages, herbal pastes, and even blood purification – to brighten the skin. The word “Ayurveda” translates to “science of life” and emphasizes a natural approach to maintaining health and well-being. Ayurveda has long used herbal formulations for maintaining youthful skin,



emphasizing natural resources and seasonal routines. Anti-aging principles include Vayasthapana (age-defying), Varnya (enhancing glow), Sandhaniya (tissue regeneration), Vranaropana (deep healing), Tvachya (nourishing), Shothahara (anti-inflammatory), Tvachagnivardhani (boosting skin metabolism), and Tvagrasayana (skin rejuvenation).

Main Text :

As discussed in the introduction, hyperpigmentation encompasses conditions such as melasma, freckles, and post-inflammatory pigmentation etc, which result from increased melanin production or deposition. Hyperpigmentation can thus be classified by the site of pigment deposition (epidermal, dermal, or mixed)

Epidermal: Ephelides (freckles), lentigines (simplex, solar, ink spot, PUVA-induced, mucosal), café-au-lait macules, pigmentary demarcation lines. **Dermal:** Acquired dermal macular hyperpigmentation, lichen planus pigmentosus, erythema dyschromicum perstans, ashy dermatosis, idiopathic eruptive macular pigmentation, pigmented contact dermatitis, dermal melanocytosis (congenital dermal melanocytosis, nevus of Ota, nevus of Ito, Hori's nevus, Sun's nevus).

Dermal: Acquired dermal macular hyperpigmentation, lichen planus pigmentosus, erythema dyschromicum perstans, ashy dermatosis, idiopathic eruptive macular pigmentation, pigmented contact dermatitis, dermal melanocytosis (congenital dermal melanocytosis, nevus of Ota, nevus of Ito, Hori's nevus, Sun's nevus).

Mixed epidermal-dermal: Postinflammatory hyperpigmentation, melasma, drug-induced pigmentation.

Although several conventional treatments such as hydroquinone, retinoids, corticosteroids, chemical peels, and laser therapies are currently in use, they often produce undesirable side effects or high relapse rates. This has encouraged increasing interest in safer and more sustainable alternatives, particularly from traditional medicine systems like Ayurveda. Among these, the main focus of the article is on melasma and postinflammatory hyperpigmentation.

Melasma : Melasma is an acquired hyperpigmentation disorder, most often affecting the face of women with darker skin tones. It appears as symmetric brown-to-gray patches (often in a centrofacial distribution: forehead, nose, upper lip). Major triggers are ultraviolet (UV) exposure and hormonal influences (e.g. pregnancy, oral contraceptives). The condition is chronic and prone to recurrence, which makes it difficult to treat.



At the molecular level, melasma is associated with increased expression of inducible nitric oxide synthase and multiple genes involved in melanocyte function and pigment production (e.g., TYR, MITF, SILV, TYRP1). Alterations in Wnt signaling modulators, prostaglandin-related metabolic genes, and genes controlling lipid metabolism have also been implicated. Although

many mechanistic details remain unclear, recent research provides concrete evidence supporting both long-suspected and newly proposed factors; understanding these pathways may identify targets for novel therapies combined with ancient ayurvedic knowledge

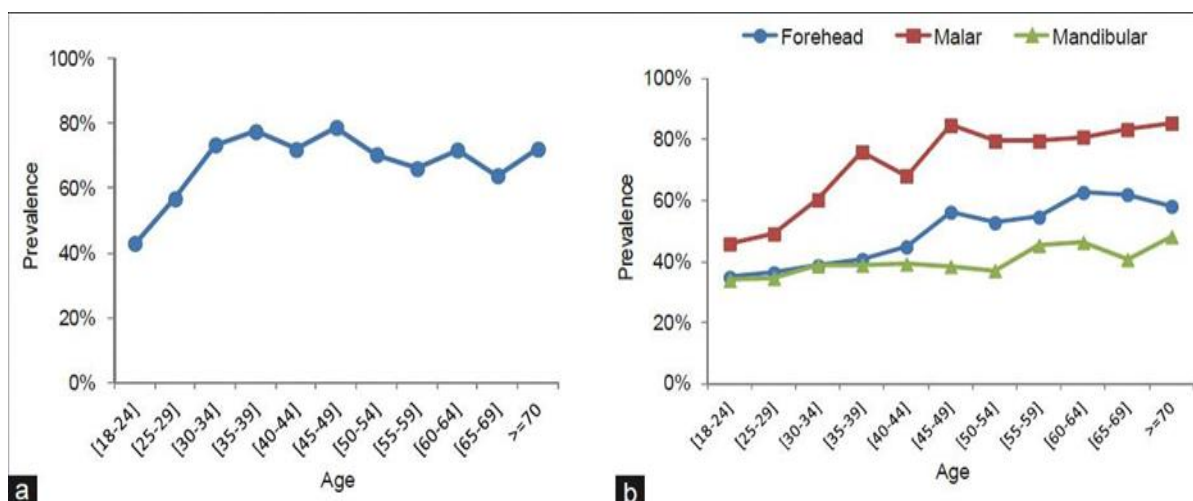
Prevalence : Estimates vary widely (roughly 1–50%) depending on skin type, ethnicity and sun exposure. Melasma typically begins in young adulthood (mean age ~20–30 years). (Mandibular-pattern melasma often starts later.) Women are far more affected than men. In India, women account for ~75–80% of cases (female-to-male ~4:1). Indian studies report ~20–25% of melasma patients are men. Hormonal changes markedly increase melasma risk. In pregnant Indian women the prevalence is very high (about 50% or more), consistent with reports that ~50–70% of pregnancies are complicated by melasma. A hereditary component is suggested by frequent occurrence of melasma among family members and higher rates in certain ethnic groups.

Postinflammatory Hyperpigmentation : Postinflammatory hyperpigmentation (PIH) is an acquired pigmentation disorder that occurs after skin inflammation or injury. PIH can follow many conditions, but it is especially linked to acne vulgaris, atopic dermatitis, impetigo, and

pseudofolliculitis barbae (PFB). Acne is a leading cause, with studies showing over half of African American, Hispanic, and Asian patients developing PIH after acne. PFB is also highly associated, with up to 90% of patients reporting hyperpigmentation.



Postinflammatory hyperpigmentation (PIH) develops due to excess melanin production or uneven pigment distribution after skin inflammation. In the epidermis, inflammatory mediators (prostaglandins, cytokines, leukotrienes, TNF- α , etc.) stimulate melanocytes, increasing pigment transfer to keratinocytes. In the dermis, injury to basal keratinocytes releases melanin, which is engulfed by macrophages (melanophages), giving the skin a blue-gray hue at the site of injury. It typically appears as diffuse brown to tan patches or multiple well-defined macules, depending on the underlying cause.



Prevalence : PIH is consistently reported at higher rates in skin-of-color populations than in Caucasians. Prevalence also varies within Asian populations, with darker-skinned groups (e.g., Malays, Indians) more affected than lighter-skinned groups (e.g., Chinese), highlighting that pigmentation depth, not ethnicity alone, increases risk.

- (a) Prevalence of hyperpigmented spots (according to age group) assessed clinically by dermatologists (N = 1,204). (b) Prevalence of hyperpigmented spots (according to age group) assessed from photographs (N = 1,196)

Ayurvedic Perspective of Pigmentary Disorders :

Vyanga is the Ayurvedic term for a skin condition on the face that causes painless, thin, bluish-black patches, reducing the natural glow of the skin. It is traditionally classified as a minor disease (Kshudra Roga) but is a significant cosmetic concern. According to Ayurvedic theory, this happens when the bodily energies (Doshas) – especially Pitta (heat) and Rakta (blood) – become unbalanced, affecting skin color.

Ayurvedic theory explains Vyanga as arising from imbalanced Pitta and blood (Rakta) due to stress or emotional factors like anger, grief, or exhaustion. These imbalances disturb the normal pigment formation in the skin, causing the dark patches. Foundational Ayurvedic works such as the Aṣṭāṅga Hṛdaya, Yoga Ratnākara, Suśruta Saṁhitā, and Chakradatta discuss both causation and therapeutic approaches for vyanga (the Ayurvedic correlate of melasma). Ayurvedic skin care is portrayed as multifaceted: internal purification and rejuvenation through Pañcakarma (bio-cleansing procedures) and Rasāyana (rejuvenation therapy), together with pathya ahara-vihāra (dietary and lifestyle measures), form the

foundation. These systemic approaches are complemented by local therapies such as abhyanga (therapeutic massage) and topical lepa (medicinal pastes).

Ayurvedic Drugs and Classical Formulation in Hyperpigmentation :

A wide range of Ayurvedic herbs and formulations have been historically prescribed for improving skin complexion and reducing pigmentation.



Haridra (*Curcuma longa*) – Turmeric (*Curcuma longa*) are the dried rhizomes of *Curcuma longa* Linn. Family: Zingiberaceae is a commonly used herb in Ayurvedic medicine and a ubiquitous culinary spice. India stands as the leading producer, exporter, and consumer of turmeric, recording a yield of 8.46 lakh tonnes in 2014–2015. The term “turmeric” originates from the Latin expression *terra merita*, meaning “meritorious earth.” Commonly referred to as “yellow root,” “golden spice,” and “Indian saffron,” it has been valued for over 6,000 years in traditional medicine as well as in religious rituals. In Sanskrit, turmeric is known by 55 different names, each reflecting its medicinal or spiritual significance. The earliest mention of turmeric can be traced back to the Atharvaveda. Its primary bioactive constituent, curcumin, is a hydrophobic polyphenolic compound that confers the characteristic yellow color of turmeric.

Compounds in turmeric (curcuminoids) show antioxidant, anti-inflammatory and lightening effects in laboratory tests and can block enzymes that break down skin matrix (like collagenase and elastase). Curcumin shows promise for inflammatory conditions (for example, PIH). Laboratory work suggests curcumin interferes with inflammatory pathways (like NF- κ B) and enzymes involved in psoriasis.

Topical forms may help lesions and can speed wound healing in animal studies by reducing inflammation and boosting collagen and new blood-vessel formation. Topical curcumin preparations have been reported to improve sun-damaged skin and some pigmentary changes when used for long periods. Preclinical research has identified multiple biological activities of curcumin, notably anti-inflammatory and antineoplastic effects. In two clinical split-face trials: Caucasian women, a cream containing turmeric extract + niacinamide significantly improved fine lines and wrinkles and showed directional improvement in pigmentation. In Asian women, a turmeric-extract-only cream reduced hyperpigmentation by approximately 14.16% at 4 weeks and 14.91% at 8 weeks (both highly significant, $P < 0.0001$). Tetrahydrocurcumin (THC) another metabolite of curcumin is recognized for its potent antioxidant activity, suggesting its potential role in alleviating oxidative stress-related disorders such as skin hyperpigmentation. Recent investigations utilizing an in vitro B16F10 melanoma cell model revealed that THC effectively suppressed α -melanocyte-stimulating hormone (α -MSH)-induced melanin synthesis. This effect was associated with a marked downregulation of the key melanogenic enzymes tyrosinase (TYR), tyrosinase-related protein 1 (TRP-1), and tyrosinase-related protein 2 (TRP-2). Complementary studies using a human keratinocyte model further demonstrated that THC

exerted a protective effect against hydrogen peroxide (H_2O_2)-induced oxidative injury. Specifically, THC improved cell viability and reduced intracellular ROS accumulation. To enhance topical delivery, THC was incorporated into a lecithin-based nanoemulsion. nanoemulsion markedly improved membrane permeation compared with a conventional THC suspension.



Manjistha (*Rubia cordifolia*) – It is the roots and stem of *Rubia cordifolia* Linn. family: Rubiaceae. In Ayurveda, root of *Manjistha* (Indian Madder) has traditionally been prescribed to enhance facial complexion (Ayurvedic Pharmacopoeia of India, 2001). It is a key component of Kumkumadi taila, a classical polyherbal formulation valued for rejuvenating skin texture (Hazra & Panda, 2013). Ethnomedicinally, its root has been applied externally to manage a variety of skin conditions, including wounds, ulcers, and acne (Joshani et al., 2010). In classical texts, Acharya Charaka described *Manjistha* as a rejuvenative herb with detoxifying properties, while Acharya Sushruta, the renowned surgeon, recommended its use for maintaining balance among the body's bio-elements. Beyond dermatological applications, extracts of *Manjistha* have demonstrated diverse pharmacological activities such as antioxidant, anti-inflammatory, radioprotective, and hepatoprotective effects. While modern phytochemical investigations attribute these effects to active constituents such as anthraquinones and glycosides. The roots of this

plant are particularly rich in purpurin, an anthraquinone compound along with its glycosides (Mouri and Laursen, 2012). Additionally, several other anthraquinones—such as xanthopurpurin, mollugin, alizarin, lucidin primeveroside, ruberythric acid, and rubiadin—are also found in varying amounts (Son et al., 2008). anthraquinones that prevent oxidative stress and protect cells from damage, are comparable to vitamin E. The plant is rich in antioxidants such as alizarin, rubiadin, and other hydroxyl-anthraquinones. Extracts protect against oxidative damage by scavenging free radicals, boosting glutathione levels, and improving enzyme activity, comparable to vitamin C and E supplementation. Studies suggest that *R. cordifolia* may serve as an antioxidant and anti-inflammatory agent, particularly because of its antioxidant and free-radical scavenging properties, which are beneficial in treating hyperpigmentation. However, the conventional isolation of active compounds from the plant can be slow and labor-intensive. To address this challenge, modern strategies such as cell suspension cultures and genetic manipulation are recommended to boost the production of valuable secondary metabolites.



Lodhra (*Symplocos racemosa*) – It is the stem bark of *Symplocos racemosa* Roxb. family Symplocaceae. In Ayurveda, Lodhra is highly valued for its astringent (Kashaya rasa) and cooling (Sheeta veerya) qualities. These properties help in reducing excessive secretions, controlling

bleeding, and promoting quick wound healing. Because of its Ruksha (drying) and Laghu (light) nature, it removes excess moisture and stickiness from the skin, which helps in reducing inflammation, acne, and other skin eruptions. Lodhra is beneficial in treating Kushtha (skin diseases) and especially Pittaja skin disorders due to its cooling effect that balances aggravated Pitta dosha, a common cause of pigmentation and skin discoloration. Flavonoids from *Symplocos racemosa* possess structural features (phenolic groups, glycosidic linkages) that enable them to scavenge free radicals and reduce oxidative stress, a property central to their antioxidant action. Certain flavonoids in *S. racemosa* were able to suppress nitric oxide production in immune cells, indicating their role in controlling inflammation. Though their activity was weaker than dexamethasone, this still highlights therapeutic potential. Therefore, the flavonoids in *Symplocos racemosa* may help regulate melanin synthesis by limiting oxidative and inflammatory pathways, suggesting a potential role in skin-lightening and pigmentation control therapies. Quercetin, kaempferol, and catechin are well-established antioxidants known to inhibit melanogenesis and calm inflammation in skin cells. Eriodictyol also possesses UV-protective and anti-inflammatory properties, potentially reducing melanocyte overstimulation.



Chandana (*Santalum album*) –Sandalwood, known as Chandana in Sanskrit, has been deeply

rooted in Indian traditions for centuries. It is the heartwood obtained from *Santalum album* Linn. belonging to family Santalaceae. In Ayurveda, the paste made from its heartwood is valued not only for religious and spiritual purposes but also for enhancing beauty and skin health. Sandalwood is traditionally regarded as a symbol of vitality and is widely used in cosmetics and skincare, being suitable for all skin types. Sandalwood oil (SWO) has long been an important ingredient in Ayurvedic medicine. The oil and paste are considered natural coolants; the paste is used as an ointment to relieve body heat and simultaneously works as a cosmetic to improve complexion and radiance. Its essential oil, which contains 80–90% sesquiterpenoid alcohols, is a key component in many skin-brightening formulations and has demonstrated low acute oral and dermal toxicity in laboratory studies. Active phytochemicals in Sandalwood for skin lightening are α -Santalol and β -Santalol, Santalene (α - and β -santalene) Santalene derivatives (santalone, santalenic acid) phenolic compounds. (minor constituents). Recent research highlights that α -santalol, the principal constituent of sandalwood oil, acts as a strong tyrosinase inhibitor ($IC_{50} = 171 \mu\text{g/mL}$), comparable to established agents such as kojic acid and arbutin ($IC_{50} \approx 149 \mu\text{g/mL}$), underscoring its potential application in skin-care products. In a 2022 study Santalol inhibited tyrosinase isolated from the mushroom *Agaricus bisporus* in a dose-dependent and competitive manner, with maximum inhibition at $\sim 50 \mu\text{M}$. It likely occupies the enzyme's active site, preventing the natural substrate (L-DOPA) from binding. Another clinical study evaluated the efficacy of Indian sandalwood oil (*Santalum album* L.) in protecting skin against oxidative stress induced by urban dust and blue light (412 nm). In a randomized, double-blind trial with 22 participants, formulations containing 0.1%, 1%, and 10% sandalwood oil were compared with

placebo and α -tocopherol. The protective effect was assessed by measuring squalene monohydroperoxide (SQOOH), a lipid peroxidation marker. Lipid peroxidation matters because it is a key biochemical marker of oxidative stress in the skin. Results showed a dose-dependent reduction in SQOOH, with 1–10% concentrations significantly reducing oxidative damage and outperforming α -tocopherol. This study provides the first in vivo evidence that sandalwood oil has potent antioxidant and anti-aging properties, supporting its application in cosmetic formulations targeting pollution- and light-induced skin damage.



Liquorice (*Glycyrrhiza glabra* Linn.) – These are the roots and stolons of *Glycyrrhiza glabra* Linn. family Fabaceae (Leguminosae). In Ayurveda, Yashtimadhu (liquorice) is described as Varnya, meaning it supports skin complexion. It is also described as wound healing and skin repair (Ropana, Sandhaneeya). Anti-itching and skin comfort (Kandughna): Its use in relieving itching also adds to its dermatological and cosmetic significance. This property links directly to its use in improving pigmentation and maintaining an even skin tone. Liquorice root contains phytochemicals such as glabridin, liquiritin, and isoliquiritin, which have been reported to inhibit melanin synthesis. The herb is highlighted for its skin-regenerating and antioxidant properties, which further contribute to its role in

depigmentation. One study conducted in vitro using Murine melanoma B16F10 cells – to assess melanin production, tyrosinase activity, and expression of melanogenesis-related genes (MITF, TYR, TRP-1, TRP-2) showed that heat-treated (*Glycyrrhiza glabra* × *G. uralensis*), licorice extract (WH-130) showed higher phenolic content, stronger antioxidant activity, and more effective inhibition of melanin production than non-heated extract. This effect was linked to increased isoliquiritigenin levels and suppression of melanogenesis-related genes, supporting its potential as a natural skin-whitening agent. The findings suggest that heat treatment enhances the bioactivity of licorice extracts. A clinical trial on 38 women with malar melasma measured the Melasma Area and Severity Index (MASI) scores at baseline and biweekly. After eight weeks, licorice extract significantly reduced MASI scores from 10.59 to 2.59, though hydroquinone cream produced a greater reduction.

Safety, Standardization, and Quality Concerns:

Although Ayurvedic herbs are generally regarded as safe when used traditionally, concerns regarding raw material variability, adulteration, and contamination have been consistently reported (Wahab et al., 2021). Such challenges highlight the need for stringent quality control measures to ensure the safety and efficacy of herbal formulations. Standardization through phytochemical markers, authentication methods such as DNA barcoding, and adherence to Good Manufacturing Practices (GMP) are essential to achieve reproducibility and global acceptance (Rajput et al., 2024). For example, studies on *Symplocos racemosa* and its flavonoid content emphasize the importance of profiling bioactive markers to minimize inconsistencies across samples (Jung et al., 2014; Shukla et al., 2024). Similarly, the stability and bioavailability

challenges observed with curcumin formulations stress the necessity of advanced delivery systems and rigorous standardization (Tabanelli et al., 2021). Furthermore, systematic reviews of botanical therapies for melasma underscore that the therapeutic potential of Ayurvedic herbs must be coupled with robust safety validation and reproducible quality benchmarks before widespread clinical translation (Wang et al., 2022).

Challenges and Future Perspectives :

The main challenges include lack of large-scale randomized controlled trials, systematic reviews of herbal treatments for melasma and topical botanical trials point out the small sample sizes, short durations, and inconsistent endpoints used across studies. For example, many active constituents (e.g., curcuminoids, anthraquinones, glabridin) are chemically unstable or poorly skin-penetrant; trials therefore require advanced delivery systems and stability testing.

Turmeric - evidence of curcuminoids in humans is limited to small, short studies (e.g., a 4-week, 50-participant RCT of 0.25% tetrahydrocurcumin vs 4% hydroquinone) and scattered pilots, making it hard to power larger follow-ups and estimate realistic effect sizes and endpoints. Curcumin rapidly decomposes (light, pH), producing multiple degradation products; this confounds which molecule causes observed bioactivity in vitro. Simple co-administration with absorption enhancers (notably piperine) can inhibit metabolism and raise plasma curcumin. Colloidal lipid systems: Micelles, emulsions, nanoemulsions, liposomes, solid lipid nanoparticles (SLNs), and nanostructured lipid carriers (NLCs) are widely studied and have shown substantial increases in curcumin plasma AUC in human and animal studies.



Simplocos Racemosa - mechanistic work is often limited to general antioxidant/anti-inflammatory assays without direct melanogenesis or signaling pathway studies. Multiple classes (phenolics, triterpenoids, glycosides) are reported but few studies fully profile or quantify putative actives across samples, complicating mechanistic attribution. Future work needs to focus on signal transduction pathways, receptor interactions, and gene expression profiles that are modulated by its phytochemicals (e.g., quercetin, betulinic acid, symplocoside).

Manjistha (Rubia cordifolia) -multiple anthraquinones / naphthohydroquinones (e.g., rubiadin, purpurin) exist; mechanistic studies often use crude extracts, making it unclear which constituent drives an effect. Some anthraquinones are cytotoxic at concentrations near those used for mechanistic assays, blurring anti-melanogenic vs general cytotoxic effects. Modern methodological improvements: the use of metabolomics, network pharmacology, and spectrum–effect correlations to pinpoint active compounds, plus better-standardized extracts and rigorous experimental designs.

Sandalwood – α - and β -santalol content varies by source, adulteration and distillation — mechanistic studies using different oils are not comparable. Many studies test whole oil/extracts (mixtures with many volatiles); specific molecular targets in melanocytes are little studied. Synthetic/biotechnological alternatives (microbial santalol production) that can supply chemically defined material for reproducible mechanistic experiments. Chemical standardization (santalol profiling, ISO standards), DNA-barcoding and traceability approaches that let mechanistic studies use authenticated, chemically consistent sandalwood oil/fractions.

Liquorice – glabridin, liquiritigenin, glycyrrhizin and others have distinct activities and ADME; mechanistic studies sometimes focus on one molecule while extracts contain many. In vivo metabolites differ from parent compounds studied in vitro, complicating translation. While glabridin-rich fractions show promise, commercial extracts vary and many clinical reports use proprietary standardized extracts (hard to compare). Encapsulation targets delivery to melanocytes and mitigates bioavailability/metabolism issues of single actives.

Future directions involve integrative dermatology, phytochemical-based drug development, and personalized approaches considering Prakriti [Ref: Ayurveda-modern integration papers].

CONCLUSION:

Ayurvedic herbs and formulations present promising alternatives for managing hyperpigmentation, particularly melasma and post-inflammatory hyperpigmentation, due to their antioxidant, anti-inflammatory, and melanogenesis-regulating properties. Botanicals such as turmeric, manjistha, lodhra, sandalwood, and liquorice align with both traditional Ayurvedic wisdom and emerging experimental evidence. However, their broader clinical acceptance is limited by challenges in standardization, quality control, and the scarcity of large-scale, well-controlled clinical trials. Future directions must prioritize phytochemical profiling, advanced delivery systems, and integration of Ayurvedic principles with modern pharmacological research.

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