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# HERBAL TOPICAL FORMULATIONS FOR THE MANAGEMENT OF MELASMA: PHYTOCONSTITUENTS, MECHANISMS, AND RECENT ADVANCES

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## ABSTRACT

Melasma is a chronic and relapsing hyperpigmentation disorder that predominantly affects sun-exposed areas of the face, leading to significant cosmetic concern and psychological impact. Conventional therapies such as hydroquinone, retinoids, chemical peels, and laser treatments often provide limited and temporary improvement, and are associated with irritation, photosensitivity, and risk of rebound pigmentation. In recent years, herbal topical formulations have gained attention as safer and effective alternatives or adjuncts in melasma management due to their multifunctional bioactivities and favorable tolerability profiles. This review highlights key phytoconstituents from medicinal plants such as flavonoids, phenolic acids, terpenoids, and alkaloids that exhibit tyrosinase inhibition, antioxidant, anti-inflammatory, and UV-protective effects relevant to melanin regulation. Mechanisms by which these compounds modulate melanogenesis include suppression of tyrosinase activity, down-regulation of melanogenic gene expression, scavenging of reactive oxygen species, and protection against UV-induced oxidative stress. Recent advances in formulation technologies such as nanoemulsions, liposomes, solid lipid nanoparticles, and hydrogels have further enhanced skin penetration, stability, and therapeutic performance of herbal actives. Clinical and preclinical evidence indicates promising results for formulations containing agents like licorice extract (glabridin), green tea polyphenols (EGCG), turmeric (curcumin), mulberry (oxyresveratrol), and others. While current data support the potential of herbal topical systems in improving melasma outcomes with reduced adverse effects, well-designed clinical trials and standardized formulation approaches are needed to validate long-term efficacy and safety. The integration of phytotherapy with modern delivery systems offers a compelling direction toward personalized and patient-friendly melasma management.

**KEYWORDS:** Melasma, Herbal topical formulations, Phytoconstituents, Tyrosinase inhibition, Antioxidants, Nanotechnology-based delivery, Skin hyperpigmentation.

## 1. INTRODUCTION

Melasma is a frequent acquired hyperpigmentation condition that mostly affects sun-exposed parts of the face, such as the cheeks, forehead, nose, and upper lip, and is characterized by symmetrical brown to gray-brown patches. Increased melanin synthesis and deposition in the dermis, epidermis, or both causes it. Melasma is a chronic, recurring, and cosmetically unpleasant disorder, although it is not life-threatening. Genetic susceptibility, UV exposure, hormonal impacts, pregnancy, oral contraceptives, and certain drugs are all part of the complex etiology. Melasma is still difficult to treat successfully due to its chronic nature and propensity for recurrence.[1]

The centrofacial, malar, and mandibular areas are most frequently affected by melasma, which manifests as irregular but distinct hyperpigmented macules and patches. It is divided into epidermal, dermal, and mixed kinds according to the level of pigmentation. Dermal melasma appears bluish-gray and is more resistant to therapy, but epidermal melasma appears light to dark brown and reacts better. The illness is closely linked to sun exposure, which increases melanin formation by stimulating melanocytes with UV light. Its high

occurrence in pregnant women and those on hormonal contraceptives can be explained by hormonal variables, particularly progesterone and estrogen.[2]


**Fig 1: Difference between normal skin and melasma skin.[3]**

### 1.1. Epidemiology and Impact on Quality of Life

Women are more likely than males to get melasma, especially when they are of reproductive age. Fitzpatrick skin types III–V, which are darker skin types, are more common among Asian, Middle Eastern, Latin American, and African cultures. Because of increased sun exposure, the frequency rises in tropical and subtropical areas. Melasma has a major psychological and social influence while not causing any physical discomfort. Due to face discolouration, affected people frequently suffer from poor self-esteem, shame, anxiety, and sadness. Effective management is crucial both medically and psychologically since it can impact social relationships, career life, and general quality of life.[4]

### 1.2. Limitations of Conventional Therapies

Topical medications such hydroquinone, retinoids, corticosteroids, azelaic acid, and kojic acid are frequently used individually or in combination to treat melasma. In resistant cases, lasers, chemical peels, and strong pulsed light therapy are also employed. These treatments do, however, have a number of drawbacks.[5] Hydroquinone usage over an extended period of time may result in rebound pigmentation, ochronosis, and skin irritation. Acids and retinoids can cause peeling, erythema, and heightened photosensitivity. In addition to being costly and requiring specialized knowledge, procedural therapies can exacerbate pigmentation if improperly applied. Furthermore, melasma has a high recurrence rate, which makes long-term care challenging, particularly if sun protection is insufficient.[6]

### 1.3. Role of Herbal Medicine in Dermatology

In recognition of its natural nature, improved patient acceptability, and typically decreased risk of serious side effects, herbal therapy is becoming more and more popular in dermatology. Bioactive substances with anti-inflammatory, anti-oxidant, and tyrosinase-inhibiting properties, such as flavonoids, phenolics, terpenoids, and alkaloids, are found in many therapeutic plants.[7] These characteristics are useful in the treatment of hyperpigmentation conditions like as melasma. Herbal remedies including licorice, aloe vera, turmeric, green tea, mulberry, and neem have demonstrated promise in lowering melanin synthesis and shielding skin from UV and oxidative damage. Particularly for long-term usage in chronic illnesses like melasma, herbal formulations provide a safer substitute or supplement to conventional therapy.[8]

## 2. PATHOPHYSIOLOGY OF MELASMA

Increased melanin synthesis and aberrant pigment distribution in the epidermis and/or dermis are the hallmarks of melasma, a multifactorial hyperpigmentation condition. Instead of a rise in melanocyte numbers, it is caused by hyperactive melanocytes. Melanogenesis is overstimulated as a result of intricate interplay between oxidative stress, hormones, UV radiation, and genetic predisposition. Melanocytes become extremely active and create extra melanin in melasma. This melanin is subsequently transported to nearby keratinocytes, resulting in noticeable dark spots on the skin.[9]

### 2.1. Melanin Synthesis and Regulation

Melanocytes contain specialized organelles called melanosomes that produce melanin. Melanogenesis is the process that starts with the amino acid tyrosine, which undergoes enzymatic reactions to produce DOPA (dihydroxyphenylalanine) and dopaquinone. Eumelanin, a brown-black pigment, or pheomelanin, a yellow-red pigment, are the final products of these processes. Signaling mechanisms including α-melanocyte-stimulating hormone (α-MSH), melanocortin-1 receptor (MC1R), cyclic AMP, and transcription factors like MITF (microphthalmia-associated transcription factor) strictly control the manufacture of melanin. Increased melanin synthesis, as observed in melasma, can result from any overexpression in these pathways.[10]

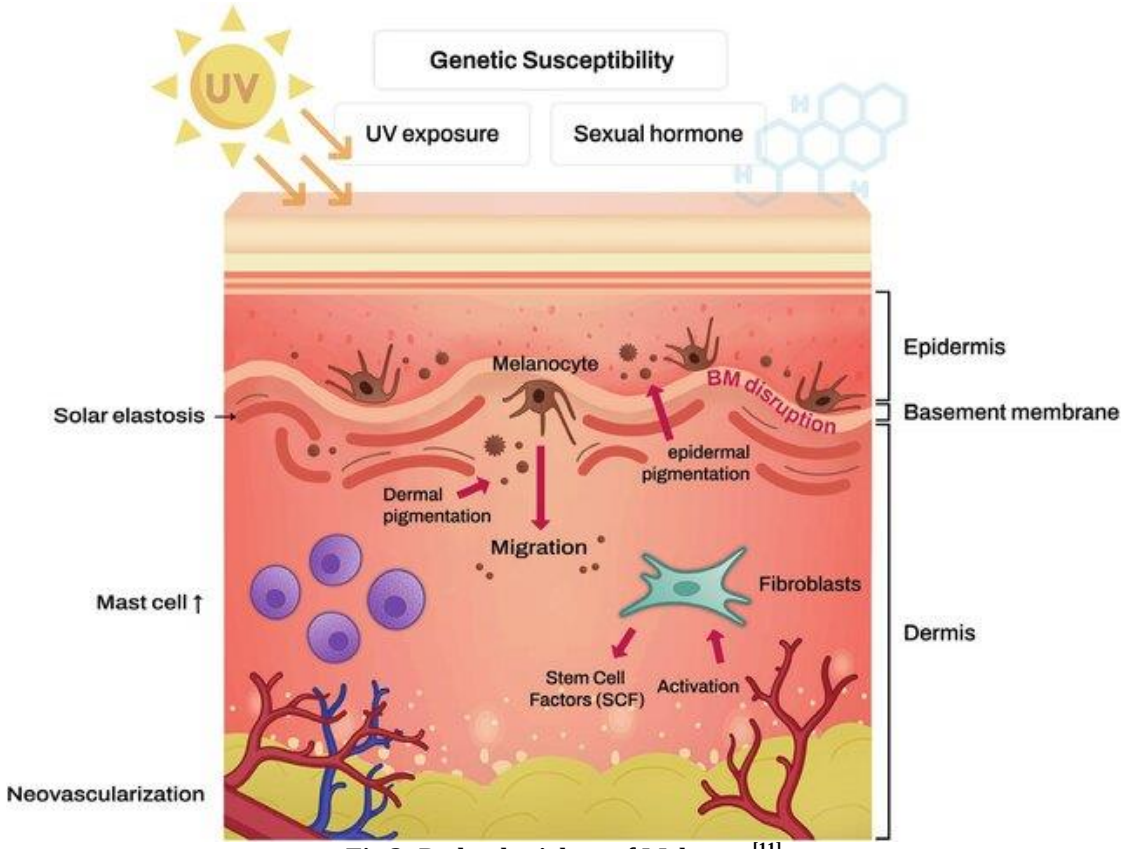


**Fig 2: Pathophysiology of Melasma.[11]**

### 2.2. Role of Melanocytes and Tyrosinase

Specialized cells called melanocytes, which are found in the basal layer of the epidermis, produce melanin, the pigment that gives skin its color. Melanocyte counts are typically normal in people with melasma, but these cells behave hyperactively and produce excessive quantities of melanin.[12] Dendritic processes connect melanocytes to nearby keratinocytes, facilitating the transfer of melanin granules to keratinocytes and causing the skin's surface to appear pigmented. In addition to increased melanin synthesis, melanocyte dendritic activity may also be elevated in melasma, resulting in more effective melanin transfer and the development of distinct hyperpigmented patches. Tyrosinase, the rate-limiting step in melanogenesis, is the primary enzyme controlling melanin formation.[12] The amino acid tyrosine is converted by tyrosinase to DOPA (dihydroxyphenylalanine) and then to dopaquinone, which finally results in the production of either pheomelanin (yellow-red pigment) or eumelanin (brown-black pigment). Elevated melanin synthesis and deposition in the dermis and epidermis are directly linked to increased tyrosinase activity. 6. Tyrosinase is the main target of the majority of synthetic and herbal anti-melasma treatments due to its crucial involvement in melanogenesis. Herbal phytoconstituents like glabridin, quercetin, and ellagic acid, as well as topical depigmenting medicines like hydroquinone, arbutin, and kojic acid, work by blocking tyrosinase activity, which lowers melanin formation.[13].

By controlling melanogenic signaling pathways, lowering dendritic activity, and inhibiting inflammatory or UV-induced stimuli that cause melanogenesis, some medicines also modify melanocyte function in addition to inhibiting enzymes. Designing successful melasma therapies requires an understanding of the interaction between melanocytes and tyrosinase, which enables therapeutic approaches to concentrate on both lowering pigment production and regulating the transfer of melanin to keratinocytes.[14]

### 2.3. Hormonal, Genetic, and Environmental Factors

Melasma is more common in women, especially during times of hormonal fluctuation like pregnancy, menstruation, or oral contraceptive use. Hormonal variables are among the most important causes of melasma growth and severity. By upregulating melanogenic enzymes like tyrosinase and promoting melanocyte proliferation, elevated levels of estrogen and progesterone increase the activity of melanocytes, the skin's pigment-producing cells.[15] In addition to increasing melanin production, this hormonal effect enhances the skin's sensitivity to ultraviolet (UV) light, increasing the likelihood of hyperpigmentation after sun exposure.

Melasma susceptibility is also significantly influenced by genetic predisposition. According to family history research, those who have first-degree relatives with melasma are more probable to get the disorder themselves, indicating that melanocyte reactivity may be

inherited. Melasma is more common in some ethnic groups, such as those of Asian, Latin American, Middle Eastern, and African ancestry. This is probably because genetic variances impact skin pigmentation, melanocyte density, and the reaction to hormonal and environmental stimuli.[16]

Melasma's development and severity are also influenced by environmental variables. The main external trigger is prolonged sun exposure since UV rays directly activate melanocytes and cause the release of inflammatory mediators that increase the formation of melanin. By producing reactive oxygen species and triggering melanogenic pathways, heat and visible light, particularly high-energy visible light, can also worsen pigmentation.[17] Additionally, by increasing the skin's vulnerability to UV-induced melanogenesis, the use of specific cosmetics, topical treatments, or drugs such as photosensitizing agents can exacerbate melasma. Melasma is chronic, recurrent, and frequently challenging to treat because of a complex network of triggers that are created by the interaction of hormonal changes, genetic predisposition, and environmental factors. These triggers either directly stimulate melanocytes or increase their sensitivity to UV radiation.[18]

### 2.4. UV Radiation and Oxidative Stress

The primary cause of melasma is UV exposure. In addition to directly stimulating melanocytes, UV radiation also boosts inflammatory mediators and α-MSH production, which increases the synthesis of melanin. Oxidative stress is brought on by UV radiation, which produces reactive oxygen species (ROS) in the skin. Pigmentation is made worse by oxidative stress, which triggers signaling pathways that promote melanogenesis and harm skin cells. Because they neutralize free radicals and lessen UV-induced melanocyte activation, antioxidants are crucial in the therapy of melisma.[19]

## 3. CONVENTIONAL TREATMENT APPROACHES AND THEIR LIMITATIONS

The basic goals of conventional melasma therapy are to remove existing pigment, increase skin turnover, and decrease melanin formation. Topical depigmenting agents, chemical peels, and energy-based tools like lasers are common methods. These techniques can enhance pigmentation, although they are frequently ineffective and prone to recurrence.[20]

### 3.1. Hydroquinone, Retinoids, and Corticosteroids

The gold standard for treating melasma is hydroquinone. It functions by selectively harming melanocytes and blocking tyrosinase, an essential enzyme for the formation of melanin. Retinoids like tretinoin stimulate melanin dispersion, accelerate epidermal turnover, and improve medication penetration.[21] In triple-combination creams, corticosteroids are frequently used with hydroquinone and retinoids to minimize irritation and inflammation. These agents have a number of drawbacks despite their efficacy. Inappropriate or prolonged usage of hydroquinone can result in rebound hyperpigmentation, ochronosis, skin irritation, and contact dermatitis. Redness, peeling, dryness, and heightened sensitivity to sunlight are common side effects of retinoids. Skin thinning, telangiectasia, acneiform outbreaks, and steroid dependency can result from long-term topical corticosteroid treatment.[22]

### 3.2. Chemical Peels and Lasers

Chemical peels that employ substances like glycolic acid, salicylic acid, lactic acid, or trichloroacetic acid aid in the removal of pigmented superficial skin layers and promote the growth of new skin. To dissolve pigment deposits, lasers and intense pulsed light (IPL) target melanin. These methods do have significant drawbacks, though. They can result in discomfort, redness, burning, post-inflammatory hyperpigmentation, or scarring, particularly in darker skin types, and they are costly and need skilled specialists. Instead of making melasma better, improper usage might make it worse.[23]

### 3.3. Adverse Effects and Recurrence

The high recurrence rate represents one of the main issues with traditional melasma treatment. Pigmentation frequently returns with sun exposure, hormonal changes, or stopping medication, even after effective treatment. In addition to causing irritation and inflammation, several therapies can exacerbate pigmentation by paradoxically stimulating melanocytes. Conventional treatments are difficult for the long-term management of melasma because of long-term safety issues, low patient compliance because of side effects, and the requirement for constant sun protection.[24]

## 4. KEY PHYTOCONSTITUENTS USED IN MELASMA

A variety of plant-derived bioactive substances that can lower melanin formation, control melanocyte activity, and shield the skin from oxidative and UV damage are the foundation of herbal treatment for melasma. Tyrosinase inhibition, antioxidant activity, anti-inflammatory effect, and regulation of melanogenic signaling pathways are just a few of the ways these phytoconstituents work.[25]

### 4.1. Flavonoids

Flavonoids, which have potent anti-inflammatory and antioxidant qualities, are found in a broad variety of fruits, vegetables, herbs, and medicinal plants. Flavonoids primarily reduce oxidative stress, block tyrosinase, and downregulate melanogenesis-related pathways such MITF and MAPK signaling in melisma.[26] Onions, apples, berries, green tea, and Ginkgo biloba have quercetin, whereas tea, broccoli, spinach, aloe vera, and propolis contain kaempferol. Apigenin (chamomile, parsley), luteolin (celery, thyme), rutin (buckwheat, citrus fruits), naringenin (grapefruit, citrus peel), and catechins (green tea) are other

significant flavonoids utilized in skin-lightening formulations. In addition to lowering melanin formation, these substances shield the skin against pollution and UV rays, two of the main causes of melisma.[27]

### 4.2. Phenolic Acids

Simple polyphenols called phenolic acids have potent anti-inflammatory, anti-oxidant, and tyrosinase-inhibiting properties. Green tea, grapes, pomegranates, gallnuts, and amla all contain gallic acid, which immediately inhibits tyrosinase and lowers the production of melanin. Coffee, honey, basil, thyme, and apples all contain caffeic acid, which inhibits melanogenic enzymes and shields melanocytes from oxidative damage. Ferulic acid (found in rice bran, oats, and wheat), chlorogenic acid (found in coffee beans and sunflower seeds), ellagic acid (found in strawberries, raspberries, and pomegranates), and vanillic acid (found in vanilla and olive oil) are other phenolic acids utilized in herbal preparations. Because of their dual function as antioxidants and skin-brightening agents, these chemicals are frequently included to melasma creams and gels.[28]

### 4.3. Alkaloids

Alkaloids are nitrogen-containing substances that have a variety of biological functions, including controlling pigmentation. Certain alkaloids disrupt melanocyte signaling pathways or inhibit tyrosinase. For instance, berberine from Coptis chinensis and Berberis species exhibits anti-inflammatory and antioxidant properties and can inhibit melanogenesis. Black pepper's piperine improves other active ingredients' skin penetration and may also affect melanocyte activity. Coffee and tea contain caffeine, which indirectly aids in the treatment of melasma by lowering oxidative stress and inflammation brought on by UV radiation. Other examples that have been investigated for their impact on skin inflammation and pigmentation are matrine (Sophora flavescens), harmine (Peganum harmala), and sanguinarine (bloodroot). Alkaloids may be strong, thus it's important to carefully regulate their dosage in topical applications to prevent irritation.[29]

### 4.4. Terpenoids

Terpenoids, which are frequently found in essential oils, resins, and other medicinal plants, are formed from isoprene units. They have antibacterial, anti-inflammatory, antioxidant, and photoprotective qualities. Terpenoids aid in melasma by lowering UV-induced skin damage, inhibiting inflammatory mediators, and controlling melanocyte activity. Limonene (citrus peel), linalool (lavender, coriander), menthol (mint), thymol (thyme), and camphor (camphor tree) are a few examples. Terpenoid derivatives with potent antioxidant and photoprotective properties include carotenoids like lutein (marigold, spinach), lycopene (tomato), and beta-carotene (carrot, pumpkin). Because of their calming, anti-inflammatory, and pigmentation-regulating properties, triterpenoids such as asiaticoside (Centella asiatica), glycyrrhizin (licorice), and ursolic acid (apple peel, rosemary) are frequently utilized in skin formulations.[30]

### 4.5. Tannins and Saponins

Tannins are polyphenolic substances that have antioxidant, astringent, and enzyme-inhibiting qualities. They can lessen melanogenesis, suppress tyrosinase, and shield skin from oxidative damage. Tea leaves, oak bark, witch hazel, pomegranate peel, grapes, and turmeric all contain tannins. For instance, tannic acid derived from tea and gallnuts is frequently included in cosmetic formulas due to its ability to tighten and brighten skin.[31]

Glycosides having surface-active characteristics and a range of biological activities are called saponins. They have anti-inflammatory and antioxidant properties and enhance the skin penetration of active substances. Licorice's glycyrrhizin, ginseng's ginsenosides, Dioscorea species' diosgenin, and soapnut (Sapindus mukorossi) saponins are a few examples. Tannins immediately lessen pigmentation in herbal anti-melasma formulations, whereas saponins assist general skin-lightening action and improve formulation effectiveness.[32]

### 4.6. Rationale for Herbal Topical Therapy

Additionally to its many therapeutic benefits, improved safety profile, and high patient acceptability, herbal topical therapy is becoming more and more popular in the treatment of melasma. The multifactorial character of melasma is addressed by plant-based formulations that contain a variety of bioactive substances including flavonoids, phenolics, and terpenoids that work in concert to inhibit tyrosinase, lower oxidative stress, and control melanocyte activity. Herbal remedies are typically less likely to cause side effects including irritation, erythema, and rebound hyperpigmentation than conventional depigmenting treatments, which makes them appropriate for long-term usage. Furthermore, patients frequently believe that herbal medications are gentler and more natural, which enhances treatment compliance. Herbal topical formulations provide a realistic and safer solution for prolonged care while lowering the danger of cumulative toxicity and skin damage because melasma is a chronic and recurring disorder needing long-term therapy and maintenance.[33]

**Table 2: Examples of Herbal-Based Topical Products Used in Melasma Treatment.[34]**

| Herbal Formulation | Active Herbal Ingredients | Formulation Type | Reported Benefits / Mechanism | Brand / Example |
|---|---|---|---|---|
| Licorice Extract Cream | Glycyrrhizin, Glabridin | Cream / Gel | Tyrosinase inhibition, anti-inflammatory, reduces melanin synthesis | Meladerm®, SkinCeuticals Discoloration Defense |
| Aloe Vera Gel | Aloesin, Polysaccharides | Gel | Antioxidant, anti-inflammatory, skin soothing, reduces pigmentation | Khadi Natural Aloe Vera Gel, Aloe Vesta® |
| Green Tea Polyphenol Cream | EGCG (Epigallocatechin gallate) | Cream / Serum | Antioxidant, photoprotective, reduces UV-induced melanogenesis | Innisfree Green Tea Seed Cream, The Face Shop Green Tea Bright Cream |
| Turmeric / Curcumin Gel | Curcumin | Gel / Cream | Antioxidant, anti-inflammatory, tyrosinase inhibition | Himalaya Pure Skin Bright Face Gel, Kama Ayurveda Turmeric Face Cream |
| Mulberry Extract Cream | Oxyresveratrol | Cream | Tyrosinase inhibition, reduces melanin production | Nature's Essence Mulberry Skin Brightening Cream |
| Pomegranate Extract Gel | Punicalagins, Ellagic acid | Gel | Antioxidant, anti-inflammatory, photoprotective | Forest Essentials Brightening Facial Gel |
| Arbutin / Bearberry Extract Cream | Alpha-Arbutin | Cream | Tyrosinase inhibition, reduces epidermal pigmentation | The Ordinary Alpha Arbutin 2% + HA, Medik8 White Balance Cream |
| Centella asiatica Gel / Cream | Asiaticoside, Madecassoside | Gel / Cream | Anti-inflammatory, antioxidant, reduces melanocyte activation | Kiehl's Centella Skin-Calming Cream, Bioaqua Centella Gel |
| Licorice + Vitamin C Serum | Glabridin + Ascorbic acid | Serum | Tyrosinase inhibition, antioxidant, photoprotection | Obagi Professional-C Bright, Murad Environmental Shield |
| Combined Herbal Nanoemulsion | Licorice, Turmeric, Green Tea | Nanoemulsion Gel / Cream | Enhanced skin penetration, tyrosinase inhibition, antioxidant, anti-inflammatory | Research formulations; experimental cosmeceutical prototypes |

## 5. MECHANISMS OF ACTION OF HERBAL AGENTS

Herbal remedies used to treat melasma address several phases of melanogenesis as well as the outside variables that cause hyperpigmentation through a variety of complimentary techniques. Herbal treatment is particularly helpful for a complicated ailment like melasma because of its multi-targeted strategy.[35]

- **Tyrosinase inhibition:** The primary enzyme in the formation of melanin is tyrosinase. Tyrosinase is inhibited by a variety of herbal phytoconstituents, including flavonoids, phenolic acids, tannins, and certain alkaloids, either by chelating the copper ions in the active site of the enzyme or by competing with its natural substrate, tyrosine. Tyrosine's conversion to DOPA and then to melanin is inhibited by substances including quercetin, gallic acid, ellagic acid, and arbutin (found in bearberries), which results in less pigment synthesis.[36]
- **Antioxidant and free radical scavenging action:** Melanocyte activity is stimulated and melanin synthesis is increased by oxidative stress brought on by UV radiation and environmental pollutants. Antioxidant-rich herbal compounds, including vitamins, polyphenols, and carotenoids, counteract free radicals and lessen oxidative damage. Green tea catechins, vitamin C-rich amla, grape resveratrol, and turmeric curcumin are examples of ingredients that shield skin cells against oxidative activation of melanogenesis.[37]
- **Anti-inflammatory effects:** By activating melanocytes through inflammatory mediators like prostaglandins and cytokines, inflammation contributes significantly to the onset and exacerbation of melasma. Aloe vera polysaccharides, glycyrrhizin (licorice), asiaticoside (Centella asiatica), and chamomile flavonoids are examples of herbal components that lessen skin irritation and inflammation while also indirectly suppressing melanocyte overstimulation.[38]
- **Photoprotective action:** Another of the primary causes of melasma is UV exposure. Numerous herbal remedies have inherent photoprotective qualities because they either absorb UV radiation or stop UV-induced oxidative and inflammatory damage. Polyphenols from green tea, chemicals from licorice and pomegranate, and carotenoids like beta-carotene and lycopene help shield skin from UV rays and lessen photo-induced hyperpigmentation.[39]
- **Melanocyte activity regulation:** In addition to inhibiting enzymes, several herbal remedies directly control melanocyte activity and melanogenic signaling pathways including cAMP, MAPK, and MITF. Phytoconstituents can decrease melanocyte proliferation, dendricity, and melanin transfer to keratinocytes via

modifying these pathways. Over time, this avoids excessive pigmentation and results in a more consistent skin tone.[40]

**Table 2: Mechanisms of Action of Herbal Agents in Melasma.[41]**

| Mechanism | Role in Melasma | Major Herbal Compounds | Examples of Plant Sources |
|---|---|---|---|
| Tyrosinase inhibition | Reduces melanin synthesis by blocking key melanogenic enzyme | Quercetin, gallic acid, ellagic acid, arbutin, tannins | Bearberry, green tea, pomegranate, amla, tea leaves |
| Antioxidant and free radical scavenging | Neutralizes ROS and prevents oxidative activation of melanocytes | Catechins, vitamin C, curcumin, resveratrol, carotenoids | Green tea, amla, turmeric, grapes, carrot |
| Anti-inflammatory effects | Reduces cytokines and mediators that stimulate melanocytes | Glycyrrhizin, asiaticoside, aloe polysaccharides, chamomile flavonoids | Licorice, Centella asiatica, aloe vera, chamomile |
| Photoprotective action | Protects skin from UV-induced pigmentation | Beta-carotene, lycopene, polyphenols | Carrot, tomato, green tea, pomegranate |
| Regulation of melanocyte activity | Controls melanocyte proliferation and melanin transfer | Flavonoids, phenolics, terpenoids | Citrus fruits, berries, licorice, Centella |

## 6. FORMULATION CONSIDERATIONS

**The selection of plant extracts:** is a crucial step in creating topical formulations that effectively treat melasma. Proven properties such tyrosinase inhibition, antioxidant capacity, anti-inflammatory effect, and photoprotection should be taken into consideration when choosing extracts. Because of their proven depigmenting and skin-protective properties, plants including licorice, green tea, amla, aloe vera, turmeric, and pomegranate are frequently selected. The extract should be devoid of impurities like pesticides and heavy metals, and the extraction technique (aqueous, hydroalcoholic, or solvent-based) should maintain active phytoconstituents.[42]

**Stability and standardization:** Complex chemical combinations found in herbal extracts are susceptible to degradation from light, heat, oxygen, and moisture. Stability tests are therefore necessary to guarantee constant efficacy over the course of the product's shelf life. By establishing the level of one or more marker chemicals (such as curcumin in turmeric and glycyrrhizin in licorice), standardization is crucial for maintaining batch-to-batch homogeneity. Stability is enhanced by the use of antioxidants, appropriate packaging, and regulated storage conditions.[43]

**Skin penetration and retention:** Active ingredients must reach the epidermal melanocytes through the stratum corneum in order to treat melasma effectively. Skin penetration is influenced by variables such formulation type, lipophilicity, and molecular size. Better therapeutic results can be achieved by improving the distribution and retention of herbal actives in the skin layers through the use of penetration enhancers, emulsions, gels, liposomes, or nano-based carriers.[44]

**Excipient compatibility:** Herbal extracts must work well with formulation excipients such emulsifiers, gelling agents, preservatives, and perfumes. Precipitation, color changes, the emergence of odors, or a decrease in activity can all result from incompatibility. In order to guarantee that the herbal actives stay viable and efficient in the final form of administration without negatively reacting with other ingredients, compatibility and preformulation tests are required.[45]

## 7. RECENT ADVANCES IN HERBAL THERAPY FOR MELASMA

### 7.1. Novel delivery systems

These days, sophisticated delivery methods are frequently employed to address the volatility and poor skin penetration of herbal actives. Liposomes with curcumin or licorice extract have demonstrated improved skin retention and decreased irritation. Aloe vera and green tea polyphenol nanoemulsions increase penetration and provide quicker lightening effects. Quercetin and silymarin phytosomes combine flavonoids with phospholipids to increase bioavailability. Higher stability and prolonged release are demonstrated by solid lipid nanoparticles and nanostructured lipid carriers containing pomegranate, mulberry, or turmeric extract. For instance, it has been observed that quercetin nanoemulsion cream and curcumin-loaded SLN gel had better anti-pigmentation benefits than traditional creams.[46]

### 7.2. Clinical studies on herbal products

A number of herbal remedies have undergone clinical testing for melasma. Compared to hydroquinone, licorice extract-based creams have demonstrated a notable decrease in erythema and pigmentation with fewer adverse effects. Melasma sufferers' skin tone and moisture have improved when aloe vera gel and vitamin E are combined. Tyrosinase inhibition and apparent lightening have been shown in clinical studies using mulberry extract and arbutin formulations. Melasma Area and Severity Index (MASI) was reduced in a formulation that contained sandalwood oil and turmeric.

UV-induced pigmentation and general skin brightness have been improved with green tea polyphenol lotions. The safety and long-term applicability of herbal preparations are supported by these investigations.[47]

### 7.3. Patents and marketed formulations

Herbal depigmenting compounds with novel combinations and delivery methods are the subject of several patents. Combinations of licorice, bearberry, mulberry, and green tea extracts in liposomal or nanoemulsion form are among the patented compositions. Products that are sold include mulberry extract creams, green tea antioxidant serums, aloe vera and turmeric gels, and herbal skin-lightening creams and serums that include licorice (such as licorice-based brightening creams). Because of their high safety profile, brands in the cosmeceutical market provide treatments including herbal anti-pigmentation creams, aloe-turmeric fairness gels, and licorice and vitamin C plant-extract serums that are commonly used for the prolonged treatment of melisma.[48]

## 8. CHALLENGES AND LIMITATIONS

### 8.1. Variability of herbal raw materials

The chemical makeup of herbal raw materials varies greatly by nature. For instance, depending on whether the plant is produced in China, India, or the Middle East, the quantity of glycyrrhizin in licorice roots might vary significantly. In a similar vein, the kind of soil, climate, and harvesting season all affect the amount of curcumin in turmeric. Catechin levels vary depending on the season in which green tea leaves are picked. The concentration of active chemicals in extracts is impacted by this fluctuation, which causes uneven therapeutic outcomes when treating melasma. Sensitive phytoconstituents like flavonoids and vitamins can also be degraded by variations in drying techniques, storage conditions, and transportation.[49]

### 8.2. Lack of standardization

There aren't many herbal formulations that are standardized to certain marker chemicals. For example, the skin-lightening effects of licorice extracts vary depending on the amount of glabridin or glycyrrhizin present. Depending on the extraction technique, the curcumin level in turmeric extracts may vary. Two products with the same botanical name on the label may exhibit drastically differing effectiveness in the absence of standardization. Because the precise chemical composition of the herbal material utilized is frequently unclear, this lack of uniformity also makes it challenging to compare clinical trials or replicate study findings.[50]

### 8.3. Regulatory concerns

The laws governing cosmetics and herbal items vary greatly between nations. Compared to pharmaceutical pharmaceuticals, herbal creams and serums require less safety and effectiveness testing because they are sold as cosmetics in some areas. Products that lack substantial clinical data may end up on the market as a result. There have been instances of herbal skin-lightening remedies adulterated with steroids and hydroquinone to produce quick effects, or tainted with hazardous metals like lead or mercury. Additionally, patients and physicians have concerns about safety and trust due to confusing labeling, a lack of knowledge regarding active ingredients, and the lack of uniform quality control. It is difficult to guarantee the safety, efficacy, and consistency of herbal anti-melasma medications due to these regulatory loopholes.[51]

## 9. FUTURE PERSPECTIVES

### 9.1. Integration with nanotechnology

One of among the most promising methods to improve the effectiveness of anti-melasma formulations is the combination of nanotechnology and herbal treatment. Conventional herbal creams and gels frequently have drawbacks such limited stability, poor solubility, insufficient skin penetration, and quick active chemical breakdown.[52] These difficulties can be solved by nanotechnology-based carriers such phytosomes, liposomes, niosomes, nanoemulsions, solid lipid nanoparticles (SLN), and nanostructured lipid carriers (NLC). These systems preserve and enhance the dermal absorption of bioactive herbal substances such as quercetin, glabridin from licorice, catechins from green tea, and curcumin from turmeric.[53] For instance, research has demonstrated that SLN gels enriched with curcumin improve epidermal retention and lessen pigmentation more successfully than traditional creams. In a comparable way, licorice extract liposomes reduce skin irritation while increasing bioavailability and penetration into the epidermis. These nano-formulations' controlled release characteristics enable long-lasting therapeutic activity, lower dosage frequency, and improve patient compliance, making them an effective treatment for long-term ailments like melisma.[54]

### 9.2. Evidence-based herbal therapy

Evidence-based methods and thorough scientific validation are essential for the future of herbal therapy in the treatment of melasma. Although preclinical research has shown promise for several herbal drugs, clinical data is frequently restricted because of small sample numbers, inconsistent extract quality, and lack of standardization.[55] To assess effectiveness, safety, and long-term results, carefully planned randomized controlled trials (RCTs) using standardized herbal extracts and contemporary administration methods are required.[56] For research to be repeatable and consistent, active ingredients like curcumin in turmeric or glycyrrhizin in licorice must be standardized. Phytochemical profiling in conjunction with pharmacokinetic and pharmacodynamic studies can shed light on the best dosage, penetration, and effectiveness.[57] Evidence-based research will encourage broader clinical use of herbal medicines as safe and efficient substitutes or supplements to traditional depigmenting drugs, strengthening regulatory approval

while also boosting patient adherence and healthcare provider trust.[58]

### 9.3. Personalized skincare

The next development in melasma treatment is personalized herbal therapy, which focuses on customizing therapies to meet the needs of each patient.[59] Genetic predisposition, hormonal effects, skin type, pigmentation depth, and lifestyle variables including sun exposure all affect melasma severity, recurrence, and response to therapy.[60] Dermoscopy, reflectance spectroscopy, and even genetic profiling are diagnostic technologies used in personalized skincare to categorize the kind and level of pigmentation.[61] Then, particular herbal actives and concentrations that are appropriate for every patient can be added to formulations.[62] For instance, nano-formulated licorice or mulberry extracts may be beneficial for epidermal melasma, while antioxidant-rich phytosome creams containing green tea catechins, vitamin C, or carotenoids may be used to address photo-induced pigmentation. These customized methods can increase patient compliance, lower the chance of discomfort or adverse effects, improve treatment results, and offer better long-term, sustainable melasma therapy. Personalized herbal skincare offers a comprehensive and patient-centered treatment for persistent hyperpigmentation issues by fusing the safety and allure of plant-based products with contemporary scientific accuracy.[63]

## 10. CONCLUSION

For the treatment of melasma, a chronic and recurring hyperpigmentation problem with substantial esthetic and psychological effects, herbal topical therapy presents a promising and safer option. Bioactive substances derived from plants, such as flavonoids, phenolic acids, terpenoids, alkaloids, tannins, and saponins, reduce pigmentation as well as avoid recurrence through a variety of mechanisms, including tyrosinase inhibition, antioxidant activity, anti-inflammatory effects, photoprotection, and regulation of melanocyte function. Gels, creams, and nano-based delivery systems are examples of advanced formulation techniques that have enhanced the skin penetration, stability, and therapeutic efficacy of these herbal actives, making long-term care more practical and patient-friendly.

Widespread clinical use is hampered by issues such the unpredictability of herbal raw ingredients, a lack of standardization, and regulatory loopholes, despite the great promise. In order to improve efficacy and safety, future research should concentrate on evidence-based validation; extract standardization, and integration with nanotechnology. A developing strategy that blends the safety of natural remedies with contemporary scientific accuracy is personalized herbal skincare, which is customized to each person's skin type, lifestyle, and pigmentation patterns. All things considered, herbal topical treatment has the potential to play a significant role in the safe, efficient, and long-term management of melasma if it is backed by cutting-edge delivery methods and thorough clinical research.

Additionally, the combination of interdisciplinary techniques that blend ancient knowledge with contemporary pharmacological technology holds the key to the future of herbal therapy for melasma. Herbal formulations can be improved for optimal therapeutic value by utilizing phytochemistry, dermatology, nanotechnology, and personalized medicine. In addition to improving the bioavailability and skin penetration of phytoconstituents, nano-carriers including liposomes, phytosomes, and solid lipid nanoparticles also offer regulated and prolonged release, lowering dosage frequency and minimizing discomfort. One of the primary drawbacks of herbal medicine will be addressed by standardization of extracts, quality control of raw materials, and thorough clinical assessment, which will guarantee repeatability, safety, and efficacy. Additionally, a more comprehensive approach to therapy can be achieved by combining many herbal actives with complimentary mechanisms in a single formulation to target melanogenesis at different phases, from tyrosinase inhibition to antioxidant protection and anti-inflammatory actions. Individualized skincare techniques that take into account a patient's skin type, melasma subtype, hormonal state, and sun exposure habits can further enhance results, increasing the efficacy and patient-centeredness of therapy. Herbal topical therapy has the ability to bridge the gap between natural remedies and contemporary dermatological care by providing a long-term, safe, and scientifically proven option for the management of melasma with continuing innovation, research, and regulatory backing.

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