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Selected Traditional Herbs for Alopecia and Hair Health: A Scientific Review

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Abstract

Alopecia, or pathological hair loss, is a widespread condition influenced by genetic, hormonal, autoimmune, environmental, and psychological factors. Conventional pharmacotherapies such as minoxidil and finasteride offer symptomatic relief but are often limited by side effects, cost, and long-term inefficacy. In recent years, the resurgence of interest in traditional herbal medicine has opened new avenues for managing hair loss through naturally derived compounds with multifaceted biological activities. This review provides a comprehensive scientific evaluation of eleven traditionally acclaimed herbs-*Mimusops elengi*, *Alkanna tinctoria*, *Nardostachys jatamansi*, *Psoralea corylifolia*, *Hibiscus rosa-sinensis*, *Artemisia pallens*, *Chrysopogon zizanioides*, *Cocos nucifera*, *Santalum album*, and *Phyllanthus emblica*—highlighting their phytochemical profiles, mechanisms of action, pharmacokinetics, and therapeutic roles in alopecia management. These botanicals exhibit anti-inflammatory, antioxidant, antimicrobial, immunomodulatory, and hair follicle-stimulating properties, offering a holistic alternative to synthetic drugs. Special attention is given to molecular pathways such as Wnt/β-catenin signalling, IGF-1 expression, and 5α-reductase inhibition. By integrating traditional ethnobotanical wisdom with contemporary scientific validation, this review aims to lay the groundwork for the development of standardised, evidence-based herbal interventions for diverse forms of alopecia. Future research should focus on clinical trials, formulation innovations, and sustainable sourcing of these valuable plant resources.

Major Findings: This review presents a thorough scientific assessment of eleven esteemed herbs, emphasising their phytochemical compositions, mechanisms of action, pharmacokinetics, and therapeutic applications in the treatment of alopecia.

Keywords: Alopecia, *Ayurvedic* Plants, Hair Loss, Herbal Medicine, Traditional Remedies

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1. Introduction

Hair is not only an essential integumentary component of the human body but also a powerful symbol of youth, vitality, beauty, and identity. While it plays a minor role in physiological functions such as thermoregulation and protection against UV rays, its socio-psychological importance is immense. Consequently, alopecia, or hair loss, can significantly impair self-esteem, social interaction, and psychological well-being, affecting both men and women across age groups and ethnicities[1]. Alopecia is broadly categorised based on the pattern, cause, and extent of hair loss. The four primary clinical forms are androgenic

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alopecia, alopecia areata, alopecia totalis, and alopecia universalis[2]. Among them, androgenic alopecia (AGA) is the most prevalent, resulting from hormonal imbalances - specifically dihydrotestosterone (DHT), a derivative of testosterone. AGA typically follows a patterned hair loss trajectory, influenced by genetic predisposition and age. On the other hand, alopecia areata is an autoimmune condition characterised by patchy baldness and is triggered by immune cells attacking hair follicles. More severe forms, alopecia totalis and universalis, entail the complete loss of scalp hair and all body hair, respectively[3]. Hair growth is a cyclical process comprising three major phases: anagen (growth phase), catagen (regression phase), and telogen (resting phase). A disruption in this cycle - such as premature transition to the telogen phase or anagen arrest - can cause excessive hair shedding. Normally, humans lose about 50 to 100 hairs per day, which is considered physiologically normal. However, persistent loss beyond this threshold may indicate underlying pathology. The aetiology of alopecia is multifactorial, encompassing genetic predisposition, hormonal fluctuations, nutritional deficiencies, psychological stress, systemic illnesses, infections, and drug-induced side effects[4].

The global burden of alopecia is rising, with studies estimating that up to 50% of men and 25% of women experience noticeable hair loss by the age of 50. Furthermore, 2% of the world population is affected by the hair loss problem. Conventional pharmacological therapies include topical agents like minoxidil and oral medications such as finasteride and spironolactone. Although these drugs are partially effective, their long-term use is often limited due to adverse effects like scalp irritation, hormonal disturbances, and sexual dysfunction. As a result, there is an increasing shift towards natural and traditional therapeutic modalities that are perceived to be safer, holistic, and culturally acceptable[3,5].

In this context, traditional herbal medicine has gained renewed interest in both public and scientific domains. Traditional systems like *Ayurveda*, *Siddha, Unani*, and Traditional Chinese Medicine (TCM) have long advocated the use of plant-based formulations for hair health and regrowth[6]. With the advancement of pharmacognosy and phytochemistry, many of these herbs have now been investigated for their bioactive compounds, mechanisms of action, and clinical efficacy. Notably, herbs with antioxidant, anti-inflammatory, androgen-modulating, and proliferative effects on dermal papilla cells show great promise in managing alopecia. A variety of plant-derived constituents, such as polyphenols, flavonoids, tannins, alkaloids, saponins, essential oils, and glycosides, are being explored for their ability to stimulate hair follicle activity, extend the anagen phase, and protect follicles from oxidative stress-induced apoptosis[7–9]. Several preclinical and clinical studies have shown that certain herbs not only reduce hair fall but also enhance hair density, thickness, and pigmentation. Moreover, traditional preparations - such as medicated oils, hair masks, decoctions, and topical pastes - are often combined with dietary and lifestyle modifications to provide comprehensive care[10,11].

This review focuses on eleven widely used traditional herbal products that have been historically applied for alopecia and hair health enhancement. These include *M. elengi*[12], *A. tinctoria*[13], *N. jatamansi*[14], *P. corylifolia*[15], *H. rosa-sinensis*[16], *S. auriculata*[17], *A. pallens*[18], *C. zizanioides*[19], *C. nucifera*[20], *S. album*[21], and *P. emblica*[22]. These botanicals have been selected based on ethnopharmacological relevance, literature support, and evidence of traditional usage in Indian and Southeast Asian cultures. Furthermore, all the plants are reported to showed effect on alopecia through different biochemical mechanisms. The primary objective of this review is to bridge the gap between traditional knowledge and scientific validation, offering a consolidated resource for researchers, clinicians, and cosmetologists interested in herbal therapies for alopecia. The paper systematically elaborates on the phytochemical composition, pharmacological properties, mechanisms of action, and therapeutic potential of each herb in relation to hair growth and scalp health. By doing so, it aims to lay a scientific foundation for the development of evidence-based, safe, and effective herbal formulations for managing hair loss.

1.1 Hair Growth Cycle: Foundation of Follicular Dynamics

The hair growth cycle is a highly dynamic, rhythmic biological process governed by a well-orchestrated interplay of cellular proliferation, differentiation,

apoptosis, and immune modulation. Understanding this cycle is essential to comprehending how various types of hair loss (alopecia) occur and to develop targeted therapeutic strategies for their prevention and treatment. Each hair follicle undergoes an independent cycle comprising three principal stages - anagen (growth phase), catagen (regression phase), and telogen (resting phase); and a less-discussed transitional phase called exogen, where the hair is shed (Figure 1). Dysregulation at any point in this cycle can lead to pathological hair loss[23].

1.1.1 Anagen Phase (Active Growth Phase)

The anagen phase is the most biologically active stage of the hair cycle and is responsible for hair length and density. During this phase, matrix keratinocytes in the bulb of the hair follicle undergo rapid mitotic activity, resulting in the formation of the hair shaft. This stage is characterised by the elongation of the hair, as melanocytes concurrently deposit melanin into the cortex, determining the hair's colour. The anagen phase can last anywhere from 2 to 6 years for scalp hair, and the length of this phase primarily determines the maximum potential hair length of an individual. The growth during anagen is facilitated by numerous growth factors and signalling pathways, including insulin-like growth factor-1 (IGF-1), vascular endothelial growth factor (VEGF), fibroblast growth factors (FGFs), and the Wnt/β-catenin signalling pathway. Wnt/β-catenin, in particular, plays a crucial role in initiating anagen by promoting the activation of hair follicle stem cells located in the bulge area. The dermal papilla (DP), a specialised mesenchymal structure at the base of the follicle, releases these paracrine signals to epithelial progenitor cells, thereby kick-starting the hair regeneration process. A prolonged anagen phase is associated with thick, pigmented terminal hairs, while a shortened anagen phase results in the production of miniaturised, vellus-like hairs, which is a hallmark of conditions like androgenic alopecia[24].

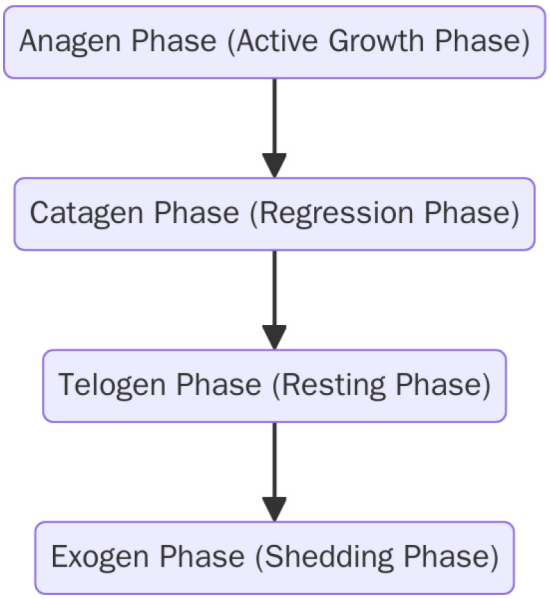


Figure 1. Hair growth cycle illustrating the sequential phases of follicular development.

1.1.2 Catagen Phase (Regression Phase)

Catagen is a short transitional phase that lasts about 2–3 weeks and marks the end of active hair growth. It is characterised by extensive apoptosis (programmed cell death) of the lower portion of the follicle, especially affecting matrix cells, melanocytes, and outer root sheath keratinocytes. As a result, the hair follicle rapidly regresses and shrinks in size, with the lower portion of the follicle undergoing involution. During this phase, angiogenesis is suppressed, and vascular supply to the hair follicle diminishes significantly. The expression of transforming growth factor-beta (TGF-β) is upregulated, which is known to be a potent inducer of apoptosis and a critical mediator of catagen induction. The hair shaft is no longer pigmented, and the follicle enters a state of relative metabolic quiescence. Despite being a phase of regression, catagen is crucial for resetting the follicular environment and preparing it for the next growth cycle. A premature transition into catagen, often triggered by psychological stress, hormonal imbalances, or oxidative damage, can lead to thinning and increased shedding.

1.1.3 Telogen Phase (Resting Phase)

The telogen phase lasts for approximately 2-4 months and represents a period of rest in the follicular cycle. During this time, the lower two-thirds of the follicle is inactive, and the hair shaft remains anchored in the follicle but is not growing. Telogen hairs are loosely held in place and are easily dislodged by combing or washing. Although this phase is biologically less active, several key events occur to maintain follicular

health and prepare for the next anagen phase. Telogen is also when the immune privilege of the follicle is re-established, protecting it from autoimmune attacks, a mechanism that is crucial in preventing disorders like alopecia areata. In a healthy scalp, around 10-15% of hair follicles are in the telogen phase at any given time. An increase in this percentage- referred to as telogen effluvium - can occur following systemic stress, infection, or nutritional deficiency, resulting in diffuse hair shedding[25].

1.1.4 Exogen Phase (Shedding Phase)

Exogen is a recently defined phase that refers to the active shedding of the hair fibre from the follicle. It is considered an extension of telogen but is driven by a distinct set of molecular signals, such as matrix metalloproteinases (MMPs) and proteolytic enzymes, that degrade the anchoring structures of the hair shaft. Hormonal fluctuations and inflammatory mediators can exacerbate exogen, contributing to excessive daily hair fall[26].

1.2 Hair Follicle Cycling and Miniaturisation

A key pathological feature of several alopecias - especially androgenetic alopecia - is the miniaturisation of hair follicles, where terminal hairs gradually become thinner and shorter due to a shortened anagen phase and an extended telogen phase. Miniaturised follicles lack a substantial dermal papilla and often produce non-pigmented, barely visible vellus hairs. This process is largely irreversible and underscores the importance of early intervention in hair loss disorders[27].

1.3 Regulatory Factors in Follicular Cycling

Hair cycling is regulated by a multitude of intrinsic and extrinsic factors. Hormones (androgens, estrogens, thyroid hormones), cytokines (IL-1, IL-6, TNF-α), growth factors (VEGF, FGF, IGF-1), and neuropeptides (substance P, CGRP) all contribute to the complex orchestration of the cycle. Moreover, environmental influences such as UV radiation, pollutants, and psychological stress can significantly alter hair cycle dynamics by disrupting these molecular signals. Epigenetic mechanisms, including DNA methylation and histone modification, also play a crucial role in maintaining the plasticity of follicular stem cells. These regulatory mechanisms ensure that follicles can respond appropriately to developmental cues, injury, or environmental stress[28].

1.4 Mechanisms and Pathways of Hair Fall (Alopecia)

Figure 2 is a flowchart illustrating the mechanisms and pathways of hair fall (Alopecia). It shows the interconnected progression of different forms of hair loss, starting from Androgenic Alopecia (AGA) and moving through various stages and mechanisms.

1.4.1 AGA: Hormonal Dysregulation and Follicular Miniaturisation

Androgenic alopecia is the most common type of hair loss, driven by hormonal influences, particularly DHT. DHT binds to androgen receptors in the dermal papilla, initiating transcriptional changes that reduce the anagen phase and lead to follicular miniaturisation. Over time, terminal hairs convert to vellus-like hairs, resulting in thinning. Molecularly, this involves androgen receptor signalling, Wnt/β-catenin pathway inhibition, and TGF-β activation, making these pathways prime targets for both conventional and herbal interventions[29,30]. 5-Alpha reductase (Type I and II) converts testosterone into 5α-DHT, the androgen responsible for androgenetic alopecia. By inhibiting this enzyme, 5-Alpha reductase inhibitors reduce hair follicle miniaturisation[31]. Finasteride, an FDA-approved, type II-selective 5-ARI that increases hair count by halting progression, with maximum effects often seen after 12–24 months. Dutasteride, a dual-inhibitor (type I and II) that significantly reduces scalp/serum DHT, often showing faster or superior hair growth results compared to finasteride[32].

1.4.2 Telogen Effluvium (TE): Stress-induced Hair Cycle Disruption

Telogen effluvium results from a sudden shift of hair follicles from the anagen to the telogen phase, often triggered by systemic or psychological stress. This stress activates the HPA axis, elevating cortisol levels, which in turn suppresses hair matrix cell proliferation and microvascular blood flow. The inflammatory cytokines IL-1, IL-6, and TNF-α are implicated, alongside activation of the NF-κB pathway, all of which contribute to premature follicular regression[33–35].

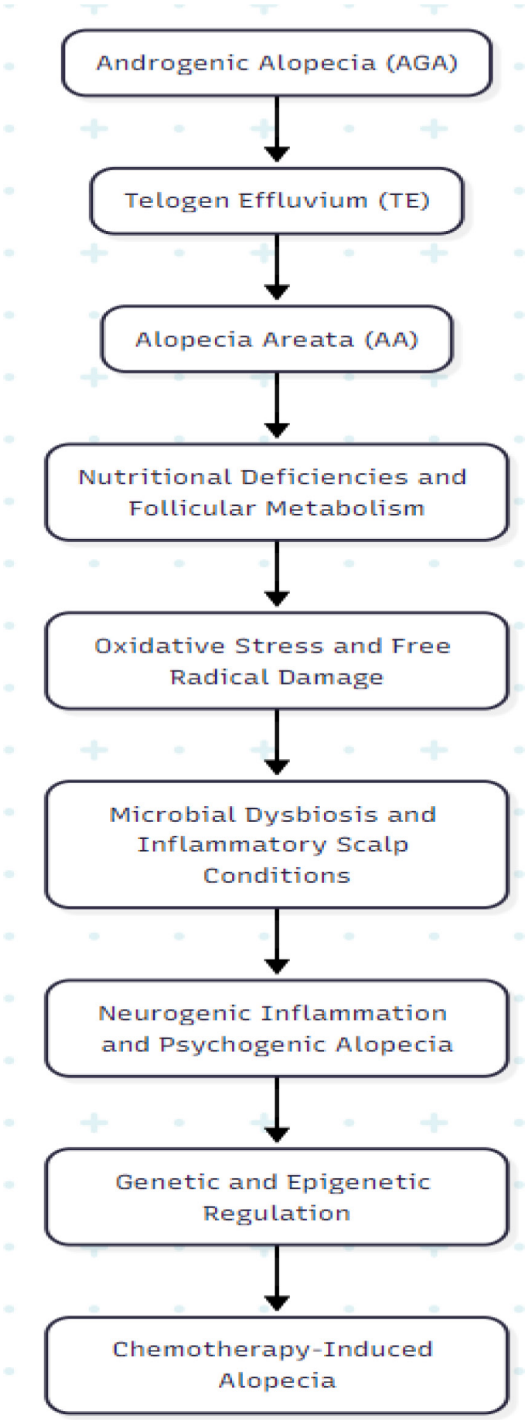


Figure 2. Multifactorial mechanisms associated with hair loss. The schematic illustrates the major clinical types and underlying mechanisms contributing to hair loss.

1.4.3 Alopecia Areata (AA): Autoimmune Follicular Attack

Alopecia areata is an autoimmune disorder wherein T cells mistakenly target hair follicle structures. Loss of immune privilege within the follicular bulb allows antigen exposure, leading to infiltration by $CD4^+$ and $CD8^+$ T cells. This immune attack disrupts follicular activity and prematurely halts hair growth. Cytokines such as IFN-γ and IL-17, and pathways like JAK-STAT, are pivotal in this process and represent therapeutic targets for immunomodulation[36,37].

1.4.4 Nutritional Deficiencies and Follicular Metabolism

Hair follicles are metabolically active and depend on micronutrients like iron, zinc, biotin, and vitamins A, D, and E. Deficiencies impair keratin synthesis, cell proliferation, and follicular resilience. Iron is essential for DNA synthesis in matrix cells, while zinc supports hair shaft formation. Nutrient imbalances also induce oxidative stress via MAPK and PI3K/Akt pathways, leading to cell death and hair fall[38].

1.4.5 Oxidative Stress and Free Radical Damage

Reactive oxygen species (ROS) from UV light, pollution, or internal metabolic imbalance damage follicular cells, lipids, and proteins. This leads to apoptosis via activation of p53 and caspases, inhibits Wnt/β-catenin signalling, and accelerates follicular aging[39,40]. Antioxidant-rich therapies are thus crucial to neutralise ROS and preserve hair follicle function[41,42].

1.4.6 Microbial Dysbiosis and Inflammatory Scalp Conditions

Imbalances in the scalp microbiome, such as overgrowth of *Malassezia* or *Staphylococcus*, can trigger inflammation, weaken follicles, and lead to dandruff or seborrheic dermatitis. These microbes activate cytokine release (e.g., IL-8), disrupt sebum balance, and compromise follicular anchoring, thereby accelerating hair fall. Antimicrobial therapies help restore microbial balance and protect the scalp environment[43,44].

1.4.7 Neurogenic Inflammation and Psychogenic Alopecia

Psychological stress contributes to hair loss through neurogenic inflammation. Neuropeptides such as substance P and CGRP released from peripheral nerves activate mast cells, which release histamines and pro-inflammatory cytokines, impairing follicular function[45].

Moreover, serotonin and melatonin disruptions affect circadian control of hair cycles, linking mood disorders to alopecia[46].

1.4.8 Genetic and Epigenetic Regulation

Genetic factors significantly influence susceptibility to alopecia, especially androgenic alopecia. Variants in AR, EDAR, and PAX1 genes affect follicular sensitivity and development. Epigenetic modifications, such as DNA methylation and histone acetylation, also regulate gene expression related to follicle health. Environmental triggers can exacerbate these epigenetic changes, making antioxidant and adaptogenic therapies beneficial[47,48].

1.4.9 Chemotherapy-induced Alopecia: Cytotoxic Follicular Arrest

Chemotherapeutic agents target rapidly dividing cells, including those in the hair matrix, leading to anagen effluvium. These drugs induce DNA damage and activate apoptotic genes such as p53 and Bax. Follicles enter a dystrophic phase, causing abrupt hair shedding. Protective agents that mitigate oxidative and apoptotic damage can offer prophylactic or supportive benefits[49,50].

2. Materials and Methods

This review was carried out using a structured and integrative literature-based methodology designed to gather, evaluate, and synthesise available scientific information on traditional herbal remedies used for alopecia and hair health. A total of eleven herbs were selected based on their long-standing use in scalp and hair care, existing pharmacological evidence, and availability of scientific literature.

2.1 Literature Search

The literature search was conducted using several academic databases, including PubMed, Scopus, ScienceDirect, Google Scholar, and the AYUSH Research Portal. To ensure comprehensive coverage, both scientific and traditional perspectives were considered. Keywords used in the search strategy included combinations of terms such as "alopecia", "hair loss", "hair growth", "herbal medicine", "ethnobotany", "traditional medicine" and the respective botanical names of the selected plants. Only English-language articles published between 2010 and 2024 were prioritised, although older seminal works and classical texts were also included where relevant to historical or traditional uses.

2.2 Selection Criteria

To ensure the reliability and relevance of the gathered data, clear inclusion and exclusion criteria were applied.

2.2.1 Inclusion Criteria

Peer-reviewed journal articles, systematic reviews, and meta-analyses; preclinical studies demonstrating the pharmacological effects of the selected plants; articles containing detailed phytochemical profiles, pharmacokinetic data, or mechanisms of action related to hair health.

2.2.2 Exclusion Criteria

Non-peer-reviewed articles or anecdotal claims without scientific validation; studies lacking relevance to dermatological or trichological applications; articles focusing solely on unrelated pharmacological uses of the plants.

2.3 Data Extraction and Synthesis

Relevant data were extracted manually from full-text articles and tabulated to identify the key phytochemicals, pharmacokinetic properties, mechanisms of action, and reported therapeutic outcomes for each plant. Studies were categorised based on their level of evidence (*in vitro*, *in vivo*) and analysed for patterns of efficacy, safety, and traditional use. This was followed by critical synthesis and narrative integration into the main body of the review.

2.4 Scientific Validation and Integration

Each plant profile was written to reflect a standardised structure:

i. Botanical and traditional background
ii. Phytochemical composition
iii. Mechanisms of action in the context of hair health
iv. Scientific studies and pharmacokinetic considerations
v. Formulation types and clinical anecdotes

Mechanistic pathways of hair loss were also reviewed and described in detail to create a conceptual framework that links each herbal remedy to potential biological targets

such as oxidative stress, inflammation, immune response, hormonal dysregulation, and follicular miniaturisation.

2.5 Quality Assurance

To maintain scientific rigour and data quality, only articles published in journals indexed in reputable databases such as PubMed and Scopus were considered. Cross-referencing was performed to validate the consistency of phytochemical and pharmacological information across sources. In cases of discrepancy, priority was given to the most recent and methodologically sound studies. The integration of traditional use with contemporary scientific validation formed the foundation for this comprehensive review, aiming to facilitate the development of standardised and evidence-based herbal therapies for the management of alopecia.

3. Major Findings

Figure 3 illustrates the top 10 traditionally useful plants for the treatment of hair loss. The flowchart shows the progression of various plants known for their benefits in preventing or treating hair fall.

3.1 *Mimusops elengi* (*Maulsari*/Spanish Cherry)

3.1.1 Botanical Description and Traditional Use

Mimusops elengi, commonly known as *Maulsari* in Hindi and *Magizhamboo* in Tamil, is an evergreen tree belonging to the family Sapotaceae. It is native to South and Southeast Asia and thrives in tropical climates. Traditionally, nearly every part of the plant - flowers, bark, fruits, and seeds - has been used in *Ayurvedic* and *Unani* medicine for treating oral disorders, wound healing, dysentery, and inflammatory diseases. Its fragrant flowers are a prominent component in hair and skin care rituals, particularly in Southern India, where it is prized for its astringent and tonic properties[51].

3.1.2 Phytochemical Composition

The phytochemical composition of *M. elengi* is rich and diverse, with numerous bioactive constituents isolated

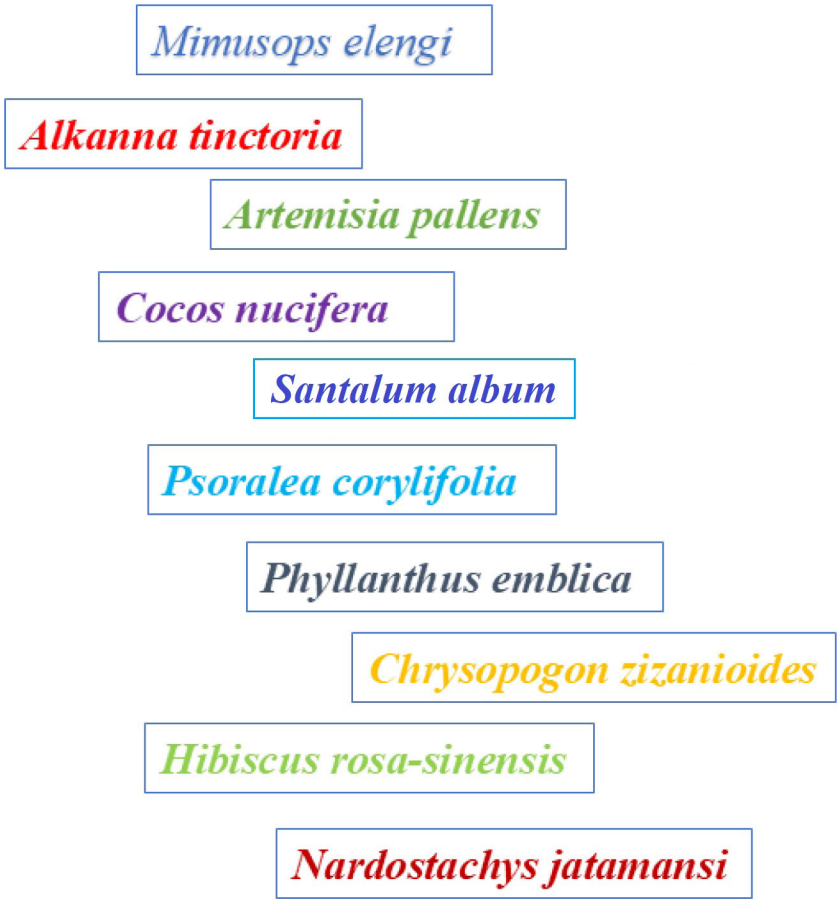


Figure 3. Traditionally useful 10 plants for the treatment of hair loss.

particularly from its flowers and seeds. The plant contains a range of flavonoids, notably quercetin and dihydroquercetin, which are known for their potent antioxidant activities. It also comprises sterols such as β-sitosterol and spinasterol, along with triterpenoids including ursolic acid and lupeol, which contribute to anti-inflammatory and potential anti-androgenic effects. Glycosides like sitosterol-3-d-glucoside and phenolic compounds such as eugenol and tannins further enhance its therapeutic profile. Additionally, the volatile oil fraction of *M. elengi* includes a variety of fatty acids- capric, lauric, myristic, palmitic, oleic, linoleic, and arachidic acids - which are important for scalp nourishment (Figure 4). Other notable compounds identified include benzyl alcohol, squalene, methylparaben, and phthalate esters[52].

3.1.3 Mechanism of Action in Hair Growth

The synergistic action of the phytochemicals underlies the plant's observed antimicrobial, antioxidant, and anti-inflammatory properties, making it a valuable candidate in promoting scalp health and managing hair loss conditions. Several mechanisms explain the role of *M. elengi* in promoting hair health and treating alopecia.

3.1.4 Antioxidant and Free Radical Scavenging

An *in vitro* study demonstrated that ethanol and methanol extracts of *M. elengi* flowers had significant DPPH and ABTS radical scavenging effects, confirming their antioxidant potential. Hair follicle cells are highly sensitive to oxidative stress, which plays a major role in the pathogenesis of alopecia, especially androgenic alopecia and alopecia areata. The polyphenols and flavonoids in *M. elengi*, particularly quercetin and ursolic acid, are potent antioxidants that[53]:

i. Scavenges free radicals (ROS).
ii. Reduce lipid peroxidation in hair follicle membranes.
iii. Protect DNA and mitochondrial structures in dermal papilla cells.

3.1.5 Anti-inflammatory Effects

An animal study using carrageenan-induced paw oedema models showed that the ethanolic extract had anti-inflammatory activity comparable to diclofenac, suggesting similar activity could extend to inflamed hair follicles[54]. Inflammatory cytokines such as TNF-α, IL-6, and IL-1β are upregulated in several types of alopecia. Flavonoids and triterpenoids in *M. elengi* downregulate these pro-inflammatory markers, reduce immune-mediated follicular damage, and restore scalp homeostasis[55].

3.1.6 Inhibition of 5α-Reductase

The triterpenoid ursolic acid is known to inhibit 5α-reductase, the enzyme that converts testosterone to DHT, which is implicated in androgenic alopecia[56]. By suppressing DHT formation, *Mimusops* species may help prevent hair follicle miniaturization[57].

3.1.7 Pharmacokinetics and Bioavailability

While comprehensive human pharmacokinetic data on *M. elengi are* limited, preliminary studies involving topical formulations provide useful insights into its dermal behaviour. Eugenol and triterpenoids, key constituents of the plant, have been shown to rapidly penetrate the stratum corneum, indicating efficient skin absorption. These bioactive compounds are predominantly lipophilic, which facilitates their accumulation in sebaceous-rich tissues like the scalp, enhancing localised therapeutic effects. Notably, the estimated dermal half-life of quercetin and ursolic acid ranges from 4 to 6 hours, implying that effective hair care formulations may require twice-daily application to maintain consistent bioactivity[58]. However, to fully elucidate the pharmacological potential of *M. elengi* in dermatological and trichological applications, further *in vivo* pharmacokinetic studies are warranted - particularly those examining tissue distribution, systemic absorption, and clearance following topical use.

3.2 *Alkanna tinctoria* (Alkanet/Ratanjot)

3.2.1 Botanical Background and Ethnopharmacology

Alkanna tinctoria (L.) Tausch is a perennial herbaceous plant belonging to the family Boraginaceae. Commonly referred to as alkanet or Ratanjot, this plant is native to the Mediterranean region, including Southern Europe, North Africa, and parts of the Middle East. It has been used since antiquity as a natural dye owing to its vividly red roots, which produce a fat-soluble pigment. In traditional *Unani* and *Ayurvedic* medicine, *A. tinctoria* has been revered not only for its colouring properties but also for its medicinal uses, particularly in the

treatment of wounds, burns, ulcers, and skin infections. In hair care practices, particularly in India and the Middle East, alkanet-infused oils are popular for their ability to improve scalp health, impart natural colour, and stimulate hair growth. The root is often macerated in coconut or sesame oil to create an oil-based infusion that serves as a potent scalp tonic[59].

3.2.2 Phytochemical Profile

The roots of *A. tinctoria* are a rich source of diverse bioactive compounds that contribute to its wide-ranging therapeutic properties. Among the most prominent constituents are the naphthoquinones alkanin and shikonin, which are optical isomers and represent the primary colouring agents as well as the main drivers of the plant's biological activity[60]. These compounds are well-documented for their potent anti-inflammatory, antioxidant, and wound-healing effects. In addition to naphthoquinones, the roots contain significant amounts of phenolic acids such as caffeic acid, ferulic acid, and chlorogenic acid, which further enhance the plant's antioxidant profile[61]. Flavonoids like quercetin and kaempferol add to its anti-inflammatory and protective effects. Other notable phytochemicals include tannins, saponins, resins, and polysaccharides, all of which contribute to the plant's astringent, antimicrobial, and skin-soothing properties[13,62,63]. This complex phytochemical synergy makes *A. tinctoria* a valuable natural agent for promoting skin and scalp health, particularly in the context of hair loss and follicular regeneration.

3.2.3 Mechanisms of Action in Hair Health

Studies have demonstrated that alkanin and shikonin can stimulate the proliferation of dermal papilla cells (DPCs), which are essential in hair follicle development and cycling[64]. These compounds enhance the expression of vascular endothelial growth factor (VEGF) and keratinocyte growth factor (KGF), leading to extended anagen phase and increased follicle density[65]. *In vitro* studies have shown that shikonin promotes cell viability and collagen synthesis in human dermal fibroblasts. A study showed that alkanin exhibits antiproliferative effects against melanoma cells while encouraging healthy epithelial growth[66]. Alkanin-rich extracts have shown wound-healing properties through enhancement of fibroblast migration and re-epithelialization[67,68]. These findings support the potential of *A. tinctoria* in scalp and hair follicle regeneration.

3.2.4 Antioxidant Defence

Hair follicles are susceptible to oxidative stress caused by UV exposure, pollution, and inflammation. The polyphenolic and naphthoquinone components of

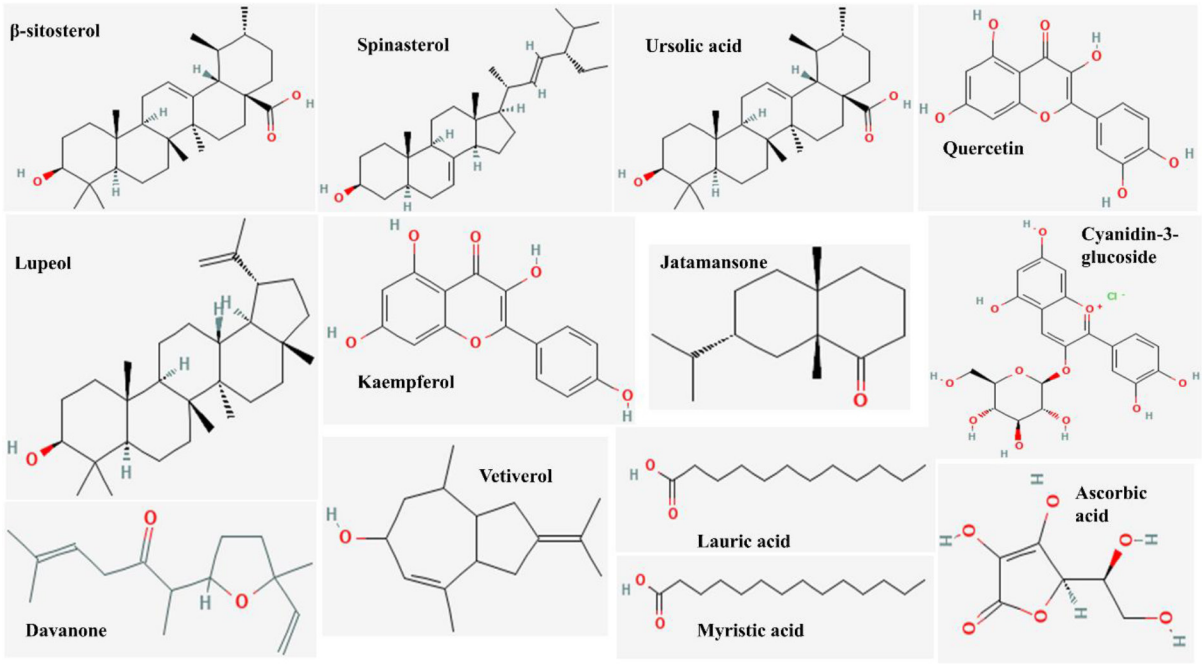


Figure 4. 2D structure of important phytoconstituents for Alopecia.

A. tinctoria neutralise ROS and reduce lipid peroxidation, thereby preserving the integrity of follicular cells[69].

3.2.5 Anti-inflammatory Activity

Shikonin and its derivatives inhibit cyclooxygenase (COX-2) and reduce the production of pro-inflammatory cytokines such as TNF-α and IL-6[70]. This is especially relevant in alopecia areata, which is often associated with autoimmune inflammation of the hair follicle.

3.2.6 Pharmacokinetics

Although systemic pharmacokinetic data on alkanin and shikonin - the primary active constituents of *A. tinctoria* remain limited, existing research offers several important observations relevant to their use in topical applications. Both compounds exhibit high lipophilicity, which facilitates efficient penetration through the skin barrier and enhances their bioactivity at the site of application[71,72]. Their behaviour is characterised by localised skin retention with minimal systemic absorption, making them particularly well-suited for dermal and scalp formulations aimed at treating hair loss and related conditions[73]. The compounds have demonstrated a low toxicity profile when used externally[74]; however, caution is warranted with oral ingestion, as high doses may pose hepatotoxic risks. To improve their therapeutic potential and optimise controlled delivery, novel formulation strategies such as nanoemulsions and liposomal carriers are currently being explored. These advanced systems aim to enhance the stability, bioavailability, and sustained release of shikonin in cosmeceutical and dermatological applications[75].

3.2.7 Formulation and Therapeutic Applications

Alkanna tinctoria is widely incorporated into various hair care formulations owing to its potent therapeutic and cosmetic properties. In traditional and modern practices alike, its extracts are commonly infused in carrier oils such as *Cocos nucifera* (coconut oil) or *Sesamum indicum* (sesame oil), forming effective hair oils that nourish the scalp and strengthen hair follicles. It is also utilised in shampoos and conditioners, valued for its antioxidant action and natural colouring ability, which impart a rich hue and protective benefits to the hair. Furthermore, *A. tinctoria* is included in hair masks and creams designed to alleviate dandruff, soothe scalp irritation, and stimulate follicular activity. Clinical anecdotes and longstanding traditional usage consistently report noticeable improvements in hair density, significant reductions in hair fall, and enhanced hair lustre with regular and sustained application, underscoring its potential as a cornerstone botanical in natural hair care regimens[76].

3.3 *Nardostachys jatamansi* (*Jatamansi*/ Spikenard)

3.3.1 Botanical Description and Traditional Uses

Nardostachys jatamansi, belonging to the family Caprifoliaceae (formerly Valerianaceae), is a perennial rhizomatous herb native to the Himalayan region. Commonly known as *Jatamansi* or Spikenard, the plant grows at elevations between 3000 and 5000 meters and is widely used in *Ayurveda*, *Unani*, and Tibetan medicine. Its aromatic rhizome is the medicinal part, long revered for its neuroprotective, adaptogenic, and rejuvenating properties. Traditionally, *Jatamansi* has been used to treat stress-related disorders, insomnia, and mental fatigue—factors often associated with psychogenic alopecia. Oil infusions are used topically for hair strengthening, preventing premature greying, and promoting regeneration in cases of hair loss[77,78].

3.3.2 Phytochemical Constituents

The rhizomes of *N. jatamansi* are pharmacologically potent and contain a complex array of bioactive compounds that contribute to their therapeutic efficacy. Chief among these are sesquiterpenoids such as jatamansone (also known as valeranone), nardol, and jatamansic acid, which are primarily responsible for the plant's neurological and dermatological benefits. Jatamansone is particularly well-studied for its notable nootropic and antioxidant properties, supporting cognitive function and cellular protection[79,80]. In the context of hair health, nardal and jatamansic acid have shown promise in stimulating hair follicles and reducing scalp inflammation. Additionally, the rhizomes are rich in lignans, neolignans, flavonoids, phenolic compounds, and alkaloids, all of which work synergistically to enhance anti-inflammatory, antimicrobial, and rejuvenative effects[14,81]. This unique phytochemical profile makes *N. jatamansi* a valuable botanical for addressing stress-related hair loss and promoting overall scalp wellness.

3.3.3 Pharmacology

Stress is a critical but often overlooked factor in alopecia. *Jatamansi* modulates the hypothalamic-pituitary-adrenal (HPA) axis, reducing cortisol levels and thereby preventing stress-induced hair follicle regression. Thiobarbituric acid reactive substances (TBARS) assays have shown that *N. jatamansi* inhibits iron-induced lipid peroxidation, a marker of oxidative damage in the scalp. This protects dermal papilla cells and maintains healthy follicular function[82–84]. *In vitro* studies demonstrated that ethanolic extracts of *N. jatamansi* promote hair regrowth in chemotherapy-induced alopecia models. Extracts enhanced keratinocyte proliferation and reduced telogen phase duration[85]. Preliminary studies suggest that *Jatamansi* compounds may bind weakly to estrogen receptors, possibly explaining their benefit in female alopecia and menopausal hair thinning[86]. A study demonstrated accelerated hair growth in shaved rats treated with 2% *Jatamansi* extract in paraffin oil, comparable to 2% minoxidil[78]. Chromatographic and spectral analysis confirmed the presence of active molecules (nardal and jatamansic acid) that exhibit significant bioactivity in hair follicle models[87,88].

3.3.4 Formulation

Although data on the topical absorption of *N. jatamansi* remains limited, studies on the oral pharmacokinetics of its key bioactive compound, jatamansone, provide valuable insights[89]. When applied topically, particularly in oil-based preparations, jatamansone demonstrates favourable retention within the skin, suggesting effective localised action with minimal systemic exposure[90]. Recent advances in nano-emulsion technology have further enhanced the potential of *N. jatamansi* by improving dermal penetration and enabling sustained release of active constituents. These formulations hold promise for future clinical applications aimed at targeted scalp therapy and hair follicle rejuvenation.

3.3.5 Safety and Regulatory Status

Jatamansi is considered safe in topical applications. However, due to its endangered status in the wild, sustainable harvesting and cultivation protocols must be followed. The plant is listed under Appendix II of CITES, requiring controlled international trade.

3.4 *Psoralea corylifolia* (*Bakuchi*/Babchi)

3.4.1 Botanical Profile and Traditional Relevance

Psoralea corylifolia L., commonly known as *Bakuchi* (Hindi), Babchi (English), or *Avalguja* (Sanskrit), belongs to the family Fabaceae. It is an annual herb that grows in tropical and subtropical regions of Asia, particularly in India and China. The plant has been used in *Ayurveda*, *Unani*, and Traditional Chinese Medicine (TCM) for centuries, particularly in the management of skin disorders, vitiligo, leprosy, and, more recently, alopecia. The seeds of *P. corylifolia* are the most pharmacologically active part, traditionally incorporated into oils and pastes for application on areas affected by hair loss and depigmentation[15,91,92]. It is also used in oral formulations for hormonal balancing and immune modulation, suggesting a dual approach, systemic and topical, in the treatment of alopecia areata and pattern baldness.

3.4.2 Phytochemical Constituents

The seeds of *P. corylifolia* are a rich source of diverse and pharmacologically active compounds, making the plant highly valued in traditional and modern medicine. Notable constituents include coumarins such as psoralen and isopsoralen, which have been extensively studied for their photosensitising and therapeutic effects. The seeds also contain meroterpenes, with bakuchiol - often referred to as a "natural retinol analogue"- standing out as the principal bioactive molecule known for its potent antioxidant, antimicrobial, and anti-inflammatory properties. Additionally, the plant is rich in flavonoids like bavachin and isobavachin, along with prenylated flavones such as corylin and psoralidin, which contribute to its therapeutic breadth. Essential oils and fixed oils present in the seeds aid in dermal absorption and contribute to the emollient effects, while the presence of steroids and glycosides adds further pharmacological significance[93,94]. This complex phytochemical profile underlies the broad-spectrum benefits of *P. corylifolia*, particularly in promoting scalp health and mitigating conditions like alopecia through its multifaceted biological actions.

3.4.3 Mechanisms of Action in Hair Health

Studies indicate that bakuchiol and psoralen derivatives can enhance the proliferation of dermal

papilla cells (DPCs), which are crucial for hair follicle morphogenesis. These compounds stimulate the expression of growth factors such as VEGF and IGF-1, thereby prolonging the anagen (growth) phase of the hair cycle. This proliferative activity also promotes extracellular matrix (ECM) remodelling within the follicular niche, improving the structural and biochemical environment required for sustained hair growth. In addition, recent molecular docking studies suggest that bakuchiol may activate Wnt/β-catenin signalling, a key pathway involved in hair follicle neogenesis and regeneration. Activation of this pathway supports hair regrowth in conditions like androgenic alopecia and alopecia areata by promoting the transition of follicles from the telogen to the anagen phase[95].

Alopecia areata, an autoimmune condition, is associated with T-cell-mediated follicular attack, particularly involving Th1-dominant cytokines. *Psoralea corylifolia* has demonstrated immunomodulatory effects by suppressing pro-inflammatory cytokines such as IFN-γ and IL-2 and enhancing regulatory T cell (Treg) function, thereby promoting immune tolerance at the follicular level[96]. Additionally, the antioxidant properties of bakuchiol and other flavonoids in *P. corylifolia* help counteract reactive oxygen species (ROS) and oxidative stress-induced apoptosis in follicular keratinocytes. Psoralen, a coumarin derivative present in the plant, also enhances melanin production, offering potential benefits in managing premature hair greying and improving scalp pigmentation[97].

Scientific evidence and preclinical studies further support these findings. EC_{50} assays demonstrated that bakuchiol possesses antioxidant activity comparable to standard commercial antioxidants. *In vivo* experiments in mice showed that treatment with *P. corylifolia* seed oil significantly stimulated hair growth, with effects comparable to 2% minoxidil. Furthermore, coumarins such as psoralen have been studied for their ability to induce melanogenesis under UVB exposure, suggesting a role in scalp photoprotection and pigmentation enhancement. In a key preclinical study, topical application of bakuchiol-rich oil on shaved albino rats resulted in rapid hair regrowth within 20 days, along with a visible increase in hair density and thickness[98].

3.4.4 Pharmacokinetics

Psoralen, one of the key constituents of *P. corylifolia*, is known for its excellent oral absorption and unique property of photoactivation, making it especially effective in PUVA (psoralen and ultraviolet A) therapy for various dermatological conditions. In contrast, bakuchiol, the plant's most prominent bioactive compound, demonstrates favourable skin permeability and a low systemic toxicity profile, with a topical half-life of approximately 6 to 7 hours, suggesting its potential for prolonged therapeutic action in hair and skin applications. Saponification and extraction studies have shown that these compounds exhibit high oil solubility and slow dermal clearance, which further supports their sustained retention in the skin and hair follicle region. These pharmacokinetic features make *P. corylifolia* particularly well-suited for topical formulations aimed at treating scalp disorders and promoting hair growth.

3.4.5 Formulations and Applications

Oil formulations are infused in sesame or coconut oil for scalp massage; topical gels and creams are used in treating alopecia areata; Oral capsules are employed for hormonal regulation and immunity in autoimmune scalp disorders.

3.4.6 Safety and Toxicity

Psoralen is photosensitising and should be used cautiously under medical supervision, especially with UV exposure. Bakuchiol, however, is non-irritant and non-phototoxic, making it safe for daily use. Clinical formulations use standardised extracts to minimise side effects.

3.5 *Hibiscus rosa-sinensis* (Hibiscus/*Gurhal*)

3.5.1 Botanical and Cultural Background

Hibiscus rosa-sinensis, commonly known as Chinese hibiscus or *Gurhal*, is a member of the Malvaceae family[99]. Native to East Asia and widely cultivated in tropical and subtropical regions, the plant is renowned for its large, bright flowers. In *Ayurveda* and folk medicine, both the leaves and flowers are used for their emollient, astringent, and rejuvenating properties[100]. In traditional Indian medicine, hibiscus is used in hair oils, masks, and pastes to prevent hair loss, control

dandruff, and stimulate hair growth. The vibrant red or pink flowers are dried, powdered, and used topically for managing scalp disorders[101,102].

3.5.2 Phytochemical Profile

Hibiscus rosa-sinensis is a botanically rich species known for its vibrant flowers and valuable medicinal properties, particularly in hair and scalp care. The plant contains a diverse array of bioactive compounds, including flavonoids such as quercetin and cyanidin-3-glucoside, which exhibit strong antioxidant effects that help neutralise free radicals and reduce oxidative stress on hair follicles. It is also abundant in saponins, tannins, and alkaloids, which contribute to its antimicrobial and anti-inflammatory profile. Additionally, *H. rosa-sinensis* provides essential amino acids and proteins that support the structural integrity of hair, while its high mucilage content offers deep moisturization and scalp soothing effects. The presence of vitamin C further aids in collagen synthesis and follicular nourishment[103,104]. These constituents promote keratinisation, enhance follicle stability, and contribute to an optimal scalp environment conducive to hair growth and resilience.

3.5.3 Mechanisms of Action in Hair Regeneration

Hibiscus extracts have been shown to promote the induction of the anagen phase, facilitating the transition of hair follicles from the telogen (resting) stage to the anagen (growth) stage. In animal models, topical application of hibiscus flower extracts resulted in faster hair regrowth and increased follicular density compared to control groups, indicating its effectiveness in stimulating active hair cycling[105]. This growth-promoting effect is partly attributed to the nutritional richness of hibiscus, which contains essential amino acids and vitamin C. These nutrients are vital for collagen synthesis and keratin formation, both of which are necessary for the development of strong, resilient hair shafts[106].

Moreover, hibiscus offers benefits for scalp health through its mucilage and saponin content. The mucilage provides deep hydration to the scalp, improving moisture retention, while saponins help regulate sebum secretion, reducing conditions such as dandruff and seborrhea that are often associated with follicular stress[9,107]. Hibiscus extract also possesses notable antimicrobial and anti-inflammatory properties[108,109]. It exhibits inhibitory activity against *Malassezia* species, common fungi implicated in dandruff, and reduces scalp inflammation, which can otherwise contribute to follicular miniaturisation and hair thinning[110].

In vivo studies conducted on rats demonstrated that daily application of hibiscus flower extract over a period of time promoted hair growth[106]. *In vitro* showed increased cell viability and metabolic activity within 48-72 hours of exposure to the extract, suggesting a direct proliferative effect on follicular cells[111]. Spectral quantification of hibiscus extract has identified the presence of bioactive compounds such as phytosterols and fatty acids, which are believed to play a key role in follicle stimulation and hair regeneration[112].

3.5.4 Pharmacokinetics and Formulation

Although systemic pharmacokinetic data on *Hibiscus rosa-sinensis* are limited, available topical studies indicate that its bioactive compounds exhibit gradual dermal absorption with effective retention in the stratum corneum and upper dermis. The flavonoids, particularly quercetin and cyanidin-3-glucoside, demonstrate a moderate half-life of approximately 4 to 6 hours following topical application, supporting their use in daily or bi-daily hair care routines[113,114]. Traditionally, *H. rosa-sinensis* is widely used in hair oils, where its flowers and leaves are infused in coconut or sesame oil to nourish the scalp and strengthen the hair. In modern formulations, it is commonly incorporated into shampoos and conditioners for its hair-softening effects and to control dandruff due to its antimicrobial and anti-inflammatory properties[115]. Additionally, hibiscus is frequently included in hair masks, often in combination with fenugreek and *amla*, to provide deep conditioning, enhance shine, and promote follicular rejuvenation[102]. This multipurpose application reinforces its reputation as a versatile botanical in holistic hair care.

3.5.5 Safety and Toxicity

Hibiscus rosa-sinensis is generally regarded as safe (GRAS) for topical use. No irritation, sensitisation, or toxicity has been reported in dermal models. However, internal consumption should be limited due to its mild estrogenic effects[116].

3.6 *Senna auriculata* (Avaram Senna)

3.6.1 Botanical Overview and Traditional Uses

Senna auriculata (L.) Roxb., also known as Avaram, is a flowering plant in the *Fabaceae* family, native to

India and Sri Lanka. It is traditionally used in *Siddha*, *Ayurveda*, and *Unani* medicine systems. The flowers, leaves, and bark are employed in remedies for diabetes, urinary infections, and skin disorders[117]. In hair care, the flowers are particularly prized for their anti-inflammatory, antioxidant, and hypoglycemic effects, indirectly benefiting individuals whose hair loss may be linked to metabolic syndromes.

3.6.2 Phytochemical Composition

Senna auriculata is endowed with a rich phytochemical profile that contributes to its multifaceted therapeutic effects, particularly in maintaining scalp and hair health. It contains a notable concentration of flavonoids such as kaempferol and quercetin, which are powerful antioxidants that protect hair follicle cells from oxidative stress and environmental damage. The presence of phenolic acids like gallic acid and caffeic acid further enhances its free radical-scavenging ability while also imparting anti-inflammatory and antimicrobial benefits. Additionally, the plant is a source of tannins, alkaloids, and polysaccharides, which collectively support antibacterial activity, promote scalp cleansing, and regulate local metabolic functions[118,119]. These bioactive compounds make *S. auriculata* especially useful in herbal formulations aimed at reducing scalp irritation, managing dandruff, and supporting healthy follicular function, particularly in individuals with metabolic imbalances or oxidative stress-induced hair loss.

3.6.3 Mechanisms of Action in Hair Health

Senna auriculata has demonstrated significant potential in promoting scalp and hair health through multiple biochemical pathways. One of its primary mechanisms involves enhancing the body's endogenous antioxidant defence system. The extract has been shown to upregulate critical antioxidant enzymes such as glutathione, superoxide dismutase (SOD), and catalase, which collectively combat ROS responsible for follicular oxidative damage[120]. This antioxidant action is particularly important in mitigating the effects of environmental stress and ageing on the scalp.

In addition to direct antioxidant effects, *S. auriculata* exhibits ferrous ion-chelating activity, thereby reducing ferrous ion-induced ROS generation through Fenton reactions. This mechanism is relevant in preventing follicular senescence and premature hair greying, as excessive ROS and metal ion accumulation are associated with melanocyte depletion and hair pigment loss. The plant also contributes to improved scalp microcirculation by decreasing oxidised Low-density Lipoprotein (LDL) and pro-inflammatory mediators. Enhanced microvascular blood flow ensures optimal delivery of oxygen and nutrients to hair follicles, which is critical for maintaining active hair growth. Furthermore, *Senna auriculata* holds promise in regulating systemic metabolic conditions that indirectly affect hair health. Its hypoglycemic properties may support individuals experiencing diabetes-associated alopecia by minimising insulin resistance-related inflammatory pathways that impair follicular function. Antioxidant assays such as DPPH and ABTS have confirmed its potent radical scavenging capacity, with IC_{50} values comparable to ascorbic acid. *In vivo* experiments have demonstrated significant elevation of antioxidant enzyme levels in follicular tissues following topical application of the flower extract[121,122].

3.6.4 Pharmacokinetics

When applied topically, *S. auriculata* exhibits low systemic absorption, making it a safe option for regular use in hair care formulations. Its phenolic constituents demonstrate good follicular retention, ensuring localised activity within the scalp and hair follicles without significant systemic exposure[123,124]. This favourable pharmacokinetic profile, coupled with its low toxicity, supports its suitability for daily application[17]. Traditionally, *S. auriculata* is utilised in the form of topical pastes and herbal decoctions to treat scalp inflammation and dandruff. It is also commonly infused into oils for therapeutic scalp massage, promoting circulation and nourishment[125,126]. In polyherbal formulations, it is often combined with other potent botanicals like *amla* and hibiscus to enhance its efficacy, providing synergistic benefits for hair strengthening, follicular stimulation, and overall scalp health[127].

3.7 *Artemisia pallens* (*Davana*)

3.7.1 Botanical Description and Traditional Use

Artemisia pallens, commonly known as *Davana*, belongs to the family *Asteraceae* and is an aromatic herb widely cultivated in India, particularly in the

southern states. Traditionally, the plant has been used in *Ayurvedic* and *Siddha* medicine systems for its therapeutic effects on various ailments, including skin disorders, fevers, infections, and menstrual problems. Its strong aromatic profile has also made it a valued component in perfumery and cosmetic formulations. In the context of hair health, the essential oils and phenolic compounds present in *Davana* have garnered attention for their antioxidant, antimicrobial, and anti-inflammatory properties, which are crucial in maintaining scalp hygiene and preventing follicular damage[128].

3.7.2 Photochemical Constituents

The chemical composition of *A. pallens* includes a wide range of secondary metabolites such as monoterpenes (e.g., davanone, isodavanone), sesquiterpenes, flavonoids, and coumarins. The essential oil extracted from the aerial parts contains high concentrations of davanone, which is primarily responsible for its biological activity[129]. The role of oxidative stress in hair follicle ageing and alopecia has been well-established, and *Davana*, by virtue of its rich antioxidant content, helps mitigate this damage. Its radical scavenging potential has been validated using assays such as DPPH, ABTS, and FRAP, where extracts demonstrated significant free radical neutralisation comparable to ascorbic acid[130,131].

3.7.3 Mechanism of Action for Hair Health

Mechanistically, *A. pallens* exerts its effect on hair health by stabilising follicular cells against oxidative insults, thereby maintaining the anagen phase of the hair cycle. This is particularly important in telogen effluvium and pattern hair loss, where oxidative stress accelerates follicle miniaturisation. The essential oil also exhibits anti-inflammatory properties by inhibiting the production of nitric oxide (NO) and pro-inflammatory cytokines in macrophage cell lines. This is beneficial in conditions such as seborrheic dermatitis and folliculitis, where local inflammation contributes to hair shedding[18,132].

Moreover, *Davana* enhances peripheral circulation, a vital factor for effective nutrient delivery to the hair root matrix. Improving microvascular blood flow, it ensures that essential micronutrients and oxygen reach the growing follicle, thereby supporting keratinocyte activity and structural protein synthesis. Its antimicrobial property, particularly against *Malassezia* and *Staphylococcus aureus*, further supports scalp health, especially in individuals prone to dandruff and infection-induced hair loss[133].

3.7.4 Pharmacokinetic and Formulation

Though pharmacokinetic data on *A. pallens* are limited, its essential oil constituents are known to be highly lipophilic, enabling effective dermal penetration and prolonged retention in the scalp tissues. The volatile nature of its components aids in rapid absorption through the stratum corneum, with minimal systemic exposure[134]. This makes it a safe and effective candidate for topical formulations like hair serums, oil infusions, and scalp sprays. Formulation-wise, *Davana* is frequently used in traditional oil preparations, often infused in a sesame or coconut oil base. Its combination with other herbs like *H. rosa-sinensis* and *P. emblica* creates a synergistic effect, enhancing its efficacy in promoting hair growth and reducing shedding. The pleasant fragrance of the oil also adds to its appeal in cosmetic applications[135].

3.8 *Chrysopogon zizanioides* (*Vetiver*/*Khus*)

3.8.1 Botanical Description and Traditional Use

Chrysopogon zizanioides, commonly referred to as *Vetiver* or *Khus*, is a perennial grass of the Poaceae family and is widely cultivated in India for its aromatic roots. Traditionally used in *Ayurveda* and folk medicine, *Vetiver* is known for its cooling, soothing, and detoxifying properties. Its application in hair care is deeply rooted in Indian ethnomedicine, where its root extract or infused oil is used for treating scalp irritation, hair fall, and premature greying[136].

3.8.2 Phytochemical Constituents and Uses

The roots of *Vetiver* are a reservoir of bioactive compounds such as vetiverol, vetivone, khusimol, tannins, and flavonoids[137]. These phytochemicals have been shown to possess potent antioxidant, anti-inflammatory, and antimicrobial properties, all of which are critical in preserving hair follicle integrity and promoting healthy hair growth[138,139]. The presence of phenolic acids and flavonoids in *Vetiver* contributes to its strong free radical scavenging capacity, which protects the scalp and follicular cells from oxidative

damage, a primary contributor to alopecia and hair thinning[140]. Furthermore, the mechanism by which *C. zizanioides* supports hair health is primarily centred on its ability to inhibit oxidative stress and enhance dermal microcirculation. *Vetiver* root extract reduces lipid peroxidation levels and downregulates pro-inflammatory mediators, thereby minimising inflammatory insults to the hair follicles. In addition, it increases the expression of natural antioxidants like glutathione and catalase in the scalp, further strengthening the antioxidant defence system[141]. Its astringent properties help in tightening the scalp pores and reducing excess sebum production, creating a clean and balanced scalp environment conducive to follicular activity.

3.8.3 Pharmacokinetic and Formulation

Pharmacokinetic data on *C. zizanioides* constituents are limited, but essential oils derived from the roots are known to be lipophilic and exhibit good skin penetration. They are retained within the dermal and subcutaneous layers, allowing for sustained release and prolonged action. These oils are also non-irritating, which makes them suitable for individuals with sensitive scalp conditions. Traditionally, *Vetiver* is used in hair oils and herbal shampoos. In cosmetic applications, it is often combined with ingredients like aloe vera and neem for enhanced scalp therapy. The roots are also used to create herbal infusions or decoctions, which are applied to the scalp to treat dandruff and chronic itching[142,143].

3.9 *Cocos nucifera* (Coconut/*Nariyal*)

3.9.1 Botanical Description and Use

Cocos nucifera, or the coconut tree, belongs to the Arecaceae family and is widely grown across tropical regions, especially in India, Southeast Asia, and the Pacific Islands. Every part of the coconut palm is used for nutritional, medicinal, and cosmetic purposes, earning it the epithet "Tree of Life". Among its numerous derivatives, coconut oil, extracted from the kernel of mature coconuts, has long been celebrated in traditional medicine for its extensive application in hair care[144].

3.9.2 Phytochemical Constituents

Coconut oil is composed primarily of medium-chain triglycerides (MCTs) such as lauric acid, capric acid, caprylic acid, and myristic acid. Lauric acid is particularly important due to its low molecular weight and straight-chain structure, which allows it to penetrate deeply into the hair shaft and the scalp. Coconut oil also contains phytosterols, tocopherols (Vitamin E), and polyphenols, all of which contribute to its antioxidant and emollient properties[145].

3.9.3 Mechanism of Action for Hair Health

One of the most significant mechanisms by which coconut oil supports hair health is by reducing protein loss. Coconut oil outperformed mineral and sunflower oils in preventing protein loss from both damaged and undamaged hair[146]. This effect is attributed to lauric acid's high affinity for hair proteins and its ability to bind to the keratin structure, thereby reinforcing the hair shaft and reducing breakage.

Coconut oil also exhibits antimicrobial and antifungal activity, which is beneficial in managing scalp conditions like dandruff, seborrheic dermatitis, and folliculitis. Lauric acid and capric acid disrupt microbial lipid membranes, effectively eliminating pathogenic bacteria and fungi that can exacerbate hair loss[147]. The oil's anti-inflammatory properties further enhance its utility in treating scalp irritation and redness. It inhibits the synthesis of inflammatory mediators such as prostaglandins and leukotrienes, creating a calming effect on the scalp and allowing follicles to function optimally[20].

3.9.4 Pharmacokinetics and Uses

Although formal pharmacokinetic studies on coconut oil as a topical agent are scarce, it is well known for its excellent skin permeation. It remains in the dermal layers longer than other vegetable oils, facilitating sustained moisturization and delivery of active components. Virgin coconut oil (VCO), which is minimally processed, retains more antioxidants and has superior emollient properties compared to refined oil[148,149].

Traditional uses of coconut oil include scalp massage, oil baths, and pre-wash hair treatments. Its ability to condition the scalp, strengthen the roots, and enhance shine has made it a staple in hair care rituals across cultures[150]. Recent formulations have integrated coconut oil into serums, conditioners, and hair masks, often blended with herbs like hibiscus, *amla*, and

fenugreek. In a study conducted in Bangladesh, a polyherbal oil containing *C. nucifera* was compared with standard coconut oil in reducing hair fall. The experimental formulation showed a 76% reduction in hair fall over 90 days, confirming its efficacy when used in combination with other herbal ingredients[151].

3.10 *Santalum album* (Sandalwood/ *Chandan*)

3.10.1 Botanical Description and Traditional Use

Santalum album, commonly known as Indian Sandalwood or *Chandan*, is a small evergreen tree belonging to the family Santalaceae. It is native to the Indian subcontinent and Southeast Asia and is regarded as one of the most valuable trees in the world due to its fragrant heartwood and essential oil[152,153]. For centuries, sandalwood has been revered in *Ayurvedic*, *Unani*, and Chinese medicine for its calming, cooling, and rejuvenating properties. In the context of dermatology and trichology, sandalwood has gained attention for its potent antioxidant, anti-inflammatory, antimicrobial, and even hormonal regulatory effects that play a critical role in hair and scalp health[154,155].

3.10.2 Phytochemical Constituents

The primary constituents of *S. album* essential oil include α-santalol and β-santalol, which collectively comprise up to 90% of the oil's composition. These sesquiterpenoid alcohols are responsible for both the characteristic fragrance and the pharmacological effects of sandalwood. Other bioactive compounds found in the plant include terpenes, phenols, flavonoids, and tannins[156]. These constituents contribute to the plant's wide-ranging therapeutic profile, including its potential to support hair follicle health and stimulate hair growth.

3.10.3 Mechanism of Action for Hair Health

One of the most fascinating scientific discoveries related to *S. album* is its interaction with olfactory receptors (ORs) located in the skin and hair follicles[157]. Traditionally thought to exist only in the nasal epithelium, olfactory receptors such as OR2AT4 have been identified in keratinocytes and hair follicle cells[158]. A study demonstrated that sandalwood oil (Sandalore®) can activate OR2AT4 in human scalp tissue, leading to increased expression of insulin-like growth factor-1 (IGF-1) - a key regulator of the anagen (growth) phase of the hair cycle. This activation enhances hair follicle proliferation and delays apoptosis of follicular keratinocytes, offering a molecular explanation for sandalwood's traditional use in promoting hair growth[159].

Moreover, *S. album* exerts powerful anti-inflammatory effects that are critical for managing conditions like alopecia areata and seborrheic dermatitis. Santalol inhibits the synthesis of pro-inflammatory cytokines such as IL-1β, TNF-α, and IL-6 by modulating nuclear factor-kappa B (NF-κB) signalling. This reduces inflammatory damage to the hair follicle bulge region, thereby preserving stem cell niches crucial for regeneration. Additionally, sandalwood oil has been shown to reduce scalp irritation, itching, and redness, which are often precursors to follicular dropout[160].

Its antioxidant properties further enhance its value in hair care. The phenolic constituents scavenge ROS, preventing oxidative stress that accelerates hair follicle ageing and miniaturisation. This is particularly relevant in androgenetic alopecia, where oxidative damage synergises with hormonal factors to impair follicular function[161].

Antimicrobial activity is another cornerstone of *S. album*'s therapeutic potential[162]. Essential oil extracts have shown broad-spectrum activity against bacteria and fungi, including *Staphylococcus aureus*, *Pityrosporum ovale*, and *Candida albicans*, all of which are implicated in scalp conditions like folliculitis and dandruff. By controlling microbial load, sandalwood maintains a healthy scalp environment conducive to hair retention and regrowth[163].

3.10.4 Pharmacokinetics and Uses

Topical pharmacokinetics of sandalwood essential oil indicate rapid absorption through the stratum corneum, with bioactive molecules like santalol reaching dermal layers within 30 minutes of application. The oil is lipophilic, which enhances its penetration and retention in sebaceous tissues, including hair follicles. The minimal systemic absorption and low dermal toxicity make it ideal for routine use in hair oils, serums, and therapeutic creams[164–166].

In traditional practice, *S. album* is frequently infused into base oils like coconut or sesame

oil and applied as a scalp massage treatment. Modern formulations also include sandalwood in aromatherapeutic scalp tonics, anti-dandruff shampoos, and post-wash hair conditioners, often combined with cooling agents like *aloe vera* or menthol[167]. Due to its calming effect, it is also employed in stress-relief hair oils, indirectly preventing stress-induced hair fall by modulating the autonomic nervous response[168,169].

3.10.5 Safety Concern

Despite its benefits, the overharvesting of *S. album* has led to its classification as a vulnerable species, and its international trade is regulated under CITES Appendix II[170]. Sustainable sourcing and cultivation practices are essential for its continued use in both traditional and modern medicine.

3.11 *Phyllanthus emblica* (*Amla*/Indian Gooseberry/*Nellikkai*)

3.11.1 Botanical Description and Traditional Use

Phyllanthus emblica, commonly known as *Amla* or Indian Gooseberry, is a deciduous tree of the family Phyllanthaceae. Native to the Indian subcontinent, it holds a revered place in *Ayurvedic* medicine and is often classified as a "*Rasayana*" or rejuvenator. The fruit of *Amla* is considered a superfood, rich in vitamins, minerals, and polyphenols. It is used traditionally to promote longevity, enhance immunity, improve digestion, and, critically, to maintain hair strength, lustre, and color[171]. In *Ayurvedic* formulations like *Triphala* and *Chyawanprash*, *Amla* acts as a key ingredient for systemic rejuvenation, and in hair care, it is widely used in oils, tonics, and shampoos for preventing hair loss and premature greying.

3.11.2 Phytochemical Constitution

The exceptional hair-promoting effects of *Amla* are attributed to its diverse and potent phytochemical composition, including Vitamin C (ascorbic acid), gallic acid, ellagic acid, emblicanin A and B, quercetin, kaempferol, phyllemblin, and tannins. Emblicanin A and B, in particular, are powerful antioxidants that help in restoring cellular integrity and prolonging the life cycle of dermal and epidermal cells[22,172].

3.11.3 Mechanism of Action for Hair Health

Amla supports hair growth through multiple mechanisms. Its high antioxidant capacity neutralises free radicals and ROS that damage the follicular cells and disrupt the anagen phase. Oxidative stress is increasingly being recognised as a central factor in alopecia, and *Amla*'s ability to reduce lipid peroxidation and protein carbonylation ensures the maintenance of cellular homeostasis in hair follicles[173]. Furthermore, *Amla* upregulates pro-survival genes in dermal papilla cells and inhibits apoptotic pathways, effectively promoting follicular longevity[174]. It also enhances the tensile strength of new hair[175].

A significant advantage of *Amla* is its anti-inflammatory action, mediated through the downregulation of key cytokines such as TNF-α, IL-1β, and IL-6[176]. In inflammatory scalp conditions like seborrheic dermatitis or alopecia areata, this property helps in reducing follicular inflammation and promoting regeneration. In addition, studies have shown that *Amla* enhances the proliferation of dermal papilla cells and improves their capacity to secrete essential growth factors such as FGF-7 and VEGF, which are crucial for hair shaft formation and anchoring[177,178].

Amla also exhibits mild phytoestrogenic activity, which may benefit individuals suffering from hormone-related hair loss, especially postmenopausal women. The extract has been shown to modulate 5α-reductase activity, thereby indirectly reducing the levels of DHT, a major contributor to androgenic alopecia[179].

Several experimental studies provide scientific support for *Amla*'s trichological benefits. In one study, topical application of *Amla* extract in a murine model resulted in a significantly higher number of anagen-phase hair follicles compared to the control group. Another comparative study found *Amla* extract more effective than ketoconazole in reducing dandruff severity and restoring hair shine and texture[180]. Moreover, its antimicrobial action helps in maintaining a healthy scalp microbiome[181,182].

3.11.4 Pharmacokinetics and Uses

Pharmacokinetic evaluations indicate that *Amla*'s water-soluble antioxidants like Vitamin C are readily

absorbed transdermally, although their retention is influenced by formulation base. Oil-based preparations show enhanced follicular delivery, while aqueous extracts offer faster absorption but shorter retention. *Amla* is highly stable in dried or powdered form, making it ideal for incorporation into polyherbal formulations[183].

Traditionally, *Amla* is macerated in coconut or sesame oil to prepare hair oils that are massaged into the scalp. This practice not only improves follicular nourishment but also facilitates penetration of lipid-soluble bioactives. In commercial formulations, *Amla* is found in shampoos, conditioners, serums, and hair masks, often combined with *Brahmi, Shikakai*, or Hibiscus for synergistic effects[184].

3.11.5 Safety Profile

Clinically, *Amla* is considered safe for topical and oral use, with no significant adverse reactions reported even with prolonged application. Its high tannin content, however, necessitates quality control during extraction to prevent over-drying of the scalp in sensitive individuals[185].

4. Importance of Herbal Medicine

Herbal therapy facilitates the body's intrinsic healing mechanisms, typically functioning subtly to eliminate excesses or address deficiencies, rather than merely alleviating symptoms. Synthetic medications frequently emphasise symptom alleviation or targeted diseases, resulting in a limited range of efficacy. Plant-based medicines comprise many bioactive substances that synergistically enhance efficacy and reduce side effects, as one ingredient may counteract the unfavourable effects of another. Synthetic medications typically depend on a singular, isolated active ingredient[186]. Herbal medicine provides a comprehensive approach to health by targeting the underlying causes of illness and treating the individual as a whole, incorporating physical, mental, and emotional wellness, rather than simply alleviating isolated symptoms. Unlike synthetic pharmaceuticals, which are often designed to target a specific biological route, herbal medicines employ intricate, multi-component formulations that function synergistically to influence numerous systems concurrently[187].

5. Future Directions

While traditional use and preclinical evidence for these herbs are compelling, more rigorous, controlled clinical trials are needed to establish efficacy, dosage, safety, and formulation compatibility. Future research should focus on the standardisation of active phytoconstituents for reproducible results; development of novel delivery systems such as nanoemulsions and liposomes for enhanced scalp penetration; evaluation of herb-drug interactions to ensure compatibility with conventional therapies; and multi-targeted polyherbal formulations tailored to specific types of alopecia.

Integration of these herbs into mainstream dermatological practices will require collaboration between ethnobotanists, pharmacologists, dermatologists, and cosmetic scientists. With sustainable sourcing, quality assurance, and modern validation, these traditional herbs can offer a scientifically backed, culturally accepted solution to one of today's most pressing cosmetic concerns[188].

6. Conclusion

The reviewed herbal agents demonstrate multifaceted therapeutic actions relevant to hair growth and scalp health. They act through diverse mechanisms, ranging from 5-alpha-reductase inhibition and dermal papilla stimulation to anti-inflammatory, antioxidant, and immunomodulatory pathways. Among the most promising are *Psoralea corylifolia*, with its Wnt/β-catenin activation and immune modulation; *Hibiscus rosa-sinensis*, with its keratinocyte proliferation effects; and *Phyllanthus emblica*, which provides comprehensive antioxidant and regenerative support. The synergy of these herbs with one another and with modern formulations offers a promising integrative approach to alopecia management.

7. References

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Author Contribution

Kundan Kumar: Conceptulization, methodology, analysis and writing-original manuscript. M. K.Mohan Maruga Raja: Methodology, analysis, reviewing and editing. Agilandeswari Devarajan: Analysis, resources, reviewing and editing. Shankar Thapa: Conceptulization, methodology, supervision, reviewing, and editing. All authors have read and agreed to the published version of the manuscript.