

PLANT-DERIVED BIOACTIVES FOR DANDRUFF MANAGEMENT:
PHYTOCHEMISTRY, ANTIFUNGAL MECHANISMS AND MODERN FORMULATION
STRATEGIESSalman M.^{1*}, Nagendra R.¹, Nithin R.^{2*}, Sinchana H. D.², Manoj C. A.², Chandan², Venkatesh³,
Hanumanthachar Joshi⁴^{1,2,3}Department of Pharmaceutics, Sarada Vilas College of Pharmacy, Mysuru.⁴Department of Pharmacognosy, Sarada Vilas College of Pharmacy, Mysuru.***Corresponding Author: Salman M. and Nithin R.**

Department of Pharmaceutics, Sarada Vilas College of Pharmacy, Mysuru.

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DANDRUFF

Dandruff is a common chronic scalp disorder characterised by excessive shedding of superficial scalp skin, producing visible flakes accompanied by itching, irritation, and mild inflammation. It commonly develops after puberty and is associated with interactions among *Malassezia* yeasts, sebaceous gland activity, scalp-barrier function, and individual susceptibility. Although dandruff shares features with seborrheic dermatitis, dandruff is generally limited to scaling and itching, whereas seborrheic dermatitis involves more prominent erythema and inflammation and may affect other sebaceous areas.^[1-3,8]

Alterations in the scalp stratum corneum and its lipid composition can impair barrier function, increase transepidermal water loss, and disturb keratinocyte differentiation and desquamation. Microbial and host interactions may further promote inflammatory responses through sebum-derived metabolites and changes in the scalp microbiota.^[2,3] Persistent dandruff may also negatively affect self-confidence and quality of life.^[3,8]

Conventional treatment includes antifungal and keratolytic agents such as ketoconazole, zinc pyrithione, selenium sulfide, salicylic acid, and coal tar. However, concerns regarding irritation, dryness, and repeated use have increased interest in herbal alternatives.^[7,8]

Medicinal plants containing flavonoids, phenolics, terpenoids, tannins, saponins, and essential oils may provide antifungal, antioxidant, anti-inflammatory, cleansing, and conditioning effects. Plants such as neem, reetha, aloe vera, tea tree, rosemary, hibiscus, *Urtica dioica*, *Clitoria ternatea*, and *Nigella sativa* are therefore being investigated for antidandruff applications.^[1,4-7] Scientific validation is essential to establish their efficacy, safety, mechanisms, and formulation compatibility.^[1-3,6,7]

2.0 TYPES OF DANDRUFF^[9,10]**2.1 Oily Dandruff (Pityriasis Steatoides)**

Oily dandruff is characterized by greasy, yellowish, adherent scales associated with increased sebum production. The lipid-rich scalp environment can favour the growth and metabolic activity of *Malassezia* species. Their interaction with sebum and the scalp may contribute to irritation, inflammation, itching, and formation of sticky scales.

Clinical features

- Large, yellowish or greasy scales that adhere to the scalp and hair.
- Excess sebum causes flakes to stick together and form thicker patches.
- Hair may appear greasy and unclear soon after washing.
- Itching and mild inflammation may occur, particularly when the condition is more pronounced.

Pathophysiology: Increased sebum production provides a lipid-rich environment that supports *Malassezia*. These yeasts metabolize sebum lipids and produce free fatty acids that may irritate the scalp and contribute to inflammation. The combination of sebum,

microorganisms, and shed corneocytes results in greasy, adherent scales.

Distribution: Oily scalp involvement may also occur in other sebaceous-gland-rich areas, including behind the ears, beard and moustache regions, central chest, and other areas of the face.

2.2 Dry Dandruff (Pityriasis Simplex/Pityriasis Sicca)

Dry dandruff is characterized by small, loose, white or greyish flakes that detach easily from the scalp and may fall onto the shoulders or clothing. It is generally less greasy and less adherent than oily dandruff. Scalp dryness, impaired barrier function, environmental conditions, and frequent use of harsh hair-care products may aggravate the condition.

Clinical features

- Small, white, powder-like flakes on the scalp and hair.
- Scales detach easily and may fall onto clothing.
- Mild itching and minimal inflammation are common.
- Significant hair loss is generally not a characteristic feature of uncomplicated dandruff.

Pathophysiology: Impaired scalp-barrier function can reduce moisture retention and alter epidermal turnover,

resulting in excessive shedding of corneocytes. Cold weather, low humidity, and harsh or frequent shampooing may further increase dryness and scaling.

Distribution and symptoms: Scaling commonly begins on the scalp and may become more noticeable over the central, frontal, temporal, or occipital regions. Patients may experience scalp dryness, tightness, and mild itching, usually without prominent greasy scales.

3.0 PATHOPHYSIOLOGY OF DANDRUFF^[11-13]

Dandruff is a recurrent and multifactorial scalp condition involving interactions between sebum production, *Malassezia* activity, scalp-barrier dysfunction, microbiome alterations, and individual susceptibility. These factors can disturb scalp homeostasis and normal epidermal desquamation, resulting in visible flaking, itching, and irritation.

3.1 Sebum Production and Lipid Metabolism

Sebum provides scalp lubrication and protection. Increased sebaceous gland activity, influenced by androgens, creates a lipid-rich environment that may favour *Malassezia* growth. Changes in sebum quantity and composition can therefore contribute to dandruff development.

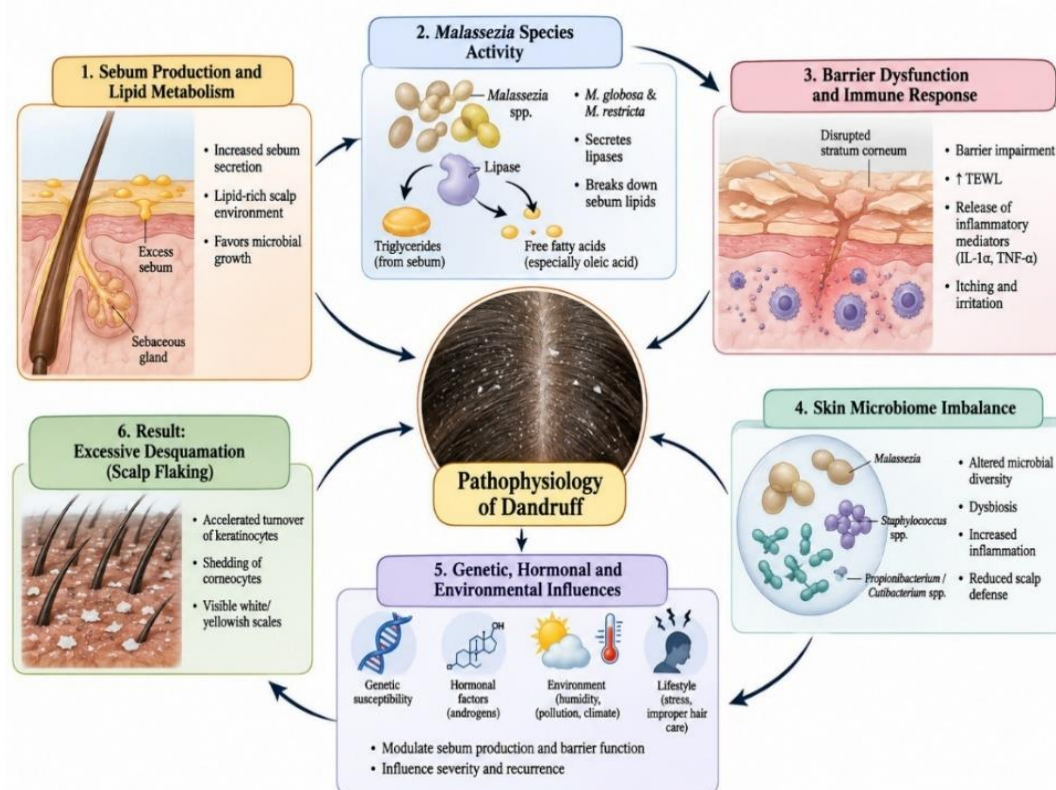


Fig.1. Pathophysiology of Dandruff.

3.2 Role of Malassezia Species

M. globosa and *M. restricta* are commonly associated with dandruff. Their lipases hydrolyse sebum

triglycerides and release free fatty acids, which may irritate the scalp, disrupt the stratum corneum barrier, and promote excessive shedding of corneocytes.

3.3 Barrier Dysfunction and Immune Response

The stratum corneum maintains scalp hydration and protects against irritants. Alterations in its structure and lipid composition may weaken the barrier, while *Malassezia*-derived metabolites can promote local inflammatory responses involving mediators such as IL-1 α and TNF- α , contributing to itching and irritation.

3.4 Scalp Microbiome Imbalance Dandruff is associated with alterations in the scalp microbiome. Changes involving *Malassezia*, *Staphylococcus*, and *Cutibacterium* may disturb scalp homeostasis, promote inflammation and barrier dysfunction, and contribute to dandruff recurrence.

3.5 Genetic, Hormonal and Environmental Influences

Individual susceptibility affects dandruff severity and recurrence. Genetic and hormonal factors influence

sebum production and scalp-barrier characteristics, while temperature, humidity, pollution, seasonal changes, stress, and harsh hair-care practices may aggravate dryness, scaling, and irritation.

3.6 Relevance to Polyherbal Anti-Dandruff Formulation Development

The multifactorial nature of dandruff suggests that effective management should address more than fungal growth alone. Polyherbal formulations may provide a multi-target approach, as plant constituents such as flavonoids, phenolics, tannins, saponins, terpenoids, and essential oils may possess antifungal, anti-inflammatory, antioxidant, cleansing, sebum-modulating, and barrier-supporting activities. Combining suitable plants may therefore provide complementary effects; however, proposed synergistic effects require experimental confirmation.

4.0. Conventional Anti-Dandruff Agents

Agent	Class	Major mechanism of action	Application & limitations
Ketoconazole	Imidazole antifungal	Inhibits ergosterol synthesis and suppresses <i>Malassezia</i> .	Used in medicated shampoos and topical preparations; may cause dryness or irritation.
Zinc pyrithione	Antifungal/antimicrobial	Interferes with fungal metabolism and inhibits <i>Malassezia</i> growth.	Mainly used in shampoos; use is restricted in some regions.
Piroctone olamine	Hydroxypyridone antifungal	Disrupts fungal iron-dependent metabolism and inhibits fungal growth.	Used in shampoos and scalp products; may cause irritation or sensitization.
Climbazole	Imidazole antifungal	Inhibits lanosterol 14 α -demethylase and disrupts ergosterol synthesis.	Used in antidandruff shampoos; concentration limits vary by region.
Ciclopirox olamine	Hydroxypyridone antifungal	Chelates metal ions required for fungal enzymes and disrupts cellular processes.	Used in topical/scalp preparations; may cause local irritation.
Selenium sulfide	Antifungal/antiproliferative	Reduces <i>Malassezia</i> proliferation and excessive epidermal turnover.	Mainly used in medicated shampoos; may have an unpleasant odour and cause irritation.
Salicylic acid	Keratolytic	Loosens and removes accumulated scalp scales and corneocytes.	Used in shampoos and scalp preparations; excessive use may cause dryness.
Coal tar	Keratoplastic/antiproliferative	Reduces excessive epidermal proliferation and controls scaling and itching.	Used in medicated shampoos; strong odour and regulatory concerns limit use.

5.0 Plant-Based Anti-Dandruff Agents

5.1 Critical Evaluation of Evidence for Plant-Derived Anti-Dandruff Agents

Plant	Study model	Target organism	Key finding	Direct <i>Malassezia</i> evidence	Clinical evidence	Overall evidence
Tea tree	In vitro / clinical	<i>Malassezia</i> spp.	Antifungal activity and reduction of dandruff-associated symptoms	✓✓✓	✓✓	Strong
Neem	In vitro	<i>Malassezia</i> / other fungi	Growth inhibition reported	✓✓	✓	Moderate
<i>Nigella sativa</i>	In vitro / experimental	Fungi	Antifungal potential associated with bioactive constituents	✓	Limited	Emerging
<i>Urtica dioica</i>	In vitro / formulation	Fungi	Antifungal potential with scalp-supportive properties	✓/limited	Limited	Emerging
<i>Clitoria ternatea</i>	Experimental	Fungi	Antimicrobial/antioxidant potential	Limited	Limited	Emerging

6.0 Antifungal Mechanisms of Plant-Derived Bioactive Compounds

Plant-derived bioactive compounds can exhibit antifungal activity through multiple interconnected mechanisms involving the fungal cell membrane, ergosterol metabolism, oxidative balance, cell-wall integrity, biofilm formation, morphology, and intracellular metabolism. This multitarget action contributes to their potential use in plant-based antidandruff formulations.^[52,53]

6.1 Disruption of Fungal Cell Membrane

Essential-oil constituents and lipophilic compounds such as **thymol, carvacrol, eugenol, terpinen-4-ol, menthol, and citral** can interact with fungal membranes, increase permeability, and cause leakage of intracellular components, ultimately reducing fungal viability.^[52, 53]

6.2 Interference with Ergosterol Biosynthesis

Ergosterol is essential for maintaining fungal membrane stability. Certain plant metabolites may interfere with its biosynthesis or alter membrane sterol composition, thereby affecting fungal growth and survival. However, molecular-docking results should be considered predictive and do not alone prove enzyme inhibition in living fungi.^[52,53]

6.3 Induction of Oxidative Stress

Some plant compounds disturb fungal redox balance and increase **reactive oxygen species (ROS)**. Excess ROS can damage lipids, proteins, nucleic acids, and mitochondria, leading to impaired growth or cell death. The extent of this mechanism varies with the compound and fungal species.^[54,55]

6.4 Alteration of Cell-Wall Integrity

Plant metabolites may interfere with fungal cell-wall formation and structural components such as chitin. Cell-wall damage weakens fungal cells and can increase their susceptibility to membrane and intracellular damage.^[52,55]

6.5 Inhibition of Biofilm and Morphological Development

Plant-derived compounds may inhibit fungal adhesion, biofilm formation, extracellular-matrix development, germ-tube formation, and hyphal development. These effects can reduce fungal persistence and colonization.^[55]

6.6 Interference with Cellular Metabolism

Botanical metabolites may affect fungal enzymes, metabolic pathways, and efflux systems involved in fungal adaptation and reduced antifungal susceptibility. Since plant extracts contain multiple constituents, their activity may result from several simultaneous effects.^[55]

6.7 Antioxidant and Anti-inflammatory Support

Phenolics and flavonoids may provide antioxidant and anti-inflammatory effects, helping maintain scalp condition and reduce irritation. However, these properties alone do not establish antidandruff efficacy.^[54]

6.8 Overall Mechanistic Perspective

Plant-derived compounds generally exhibit multitarget antifungal activity, potentially affecting membrane integrity, ergosterol-related processes, oxidative stress, cell-wall structure, biofilms, morphology, and cellular metabolism. Such effects may be valuable for dandruff management. However, mechanisms demonstrated against *Candida*, *Aspergillus*, or *Trichophyton* should not automatically be considered established mechanisms against *Malassezia*.^[55,56]

7.0 Modern Formulation Approaches for Plant-Based Antidandruff Agents

7.1 Herbal Shampoos^[57]

Herbal shampoos are topical cleansing preparations in which plant extracts, essential oils, or other botanical ingredients are incorporated into a shampoo base to cleanse the scalp while providing additional biological benefits. In an antidandruff formulation, the plant ingredients may contribute antimicrobial or antifungal activity, while the surfactant system removes excess sebum, dirt, and scalp debris.

➤ Herbal Antidandruff Shampoo Formulation^[57]

Ingredient	Function
Amla extract	Antidandruff, conditioning
Shikakai extract	Cleansing
Hibiscus decoction	Conditioning, antifungal
Reetha extract	Foaming, cleansing
Aloe vera gel	Moisturizing, soothing
Neem oil	Antifungal
Curry-leaf extract	Antidandruff, antioxidant
Fenugreek decoction	Conditioning
Onion juice	Antimicrobial
Lemon juice	Antimicrobial, pH adjustment
Rose oil	Fragrance
SLS solution (7.5%)	Surfactant
Sodium chloride (0.1 M)	Electrolyte
Acacia gum extract	Thickening/suspending agent

Glycerine	Humectant
Vitamin E	Antioxidant, conditioning
Activated charcoal	Colouring agent
Distilled water	Vehicle
Final volume	—

7.2 Herbal Gels^[58]

Herbal gels are semisolid topical preparations in which plant extracts or other botanical actives are incorporated into a suitable gelling system. Compared with rinse-off shampoos, gels can remain on the scalp for a longer

period, allowing closer contact between the botanical constituents and the affected area. This makes them useful for delivering plant extracts with antifungal activity in a more localised manner.

➤ Representative Formulation Composition

Ingredient	Function
Fenugreek aqueous leaf extract	Antidandruff/antifungal active
Sodium alginate	Gelling agent
Glycerin	Humectant
Propyl paraben	Preservative
Methyl paraben	Preservative
Citronella oil	Fragrance
Purified water	Vehicle

7.3 Herbal Creams and Lotions^[59]

Herbal creams and lotions are topical formulations designed to keep plant-derived active ingredients in contact with the scalp for a longer duration than rinse-off preparations. For dandruff management, an oil-in-water cream can provide prolonged contact of the botanical

antifungal ingredient with the scalp and may therefore be useful when repeated or longer exposure is desired. The study by Parjo *et al.* specifically selected an oil-in-water hair cream containing *Kaempferia galanga* rhizome extract for this purpose.

➤ Representative Antidandruff Hair-Cream Formulation

Phase	Ingredients reported in the article	Role
Phase A	Distilled water	Vehicle
	Carbopol	Gelling/thickening agent
	Glycerin	Humectant
Phase B	Glyceryl monostearate	Emulsifying/consistency agent
	Refined corn oil	Oil phase/emollient
	Olivoil emulsifier	Emulsifier
	Stearic acid	Consistency/emulsifying agent
Phase C	Vitamin E	Antioxidant
	Propylene glycol	Solvent/humectant
	Microkill COS	Preservative
	<i>Kaempferia galanga</i> rhizome extract	Antidandruff/antifungal active

7.4. Herbal Oils^[60]

Herbal hair oils are topical oil-based preparations containing plant extracts, fixed oils, essential oils, or other botanical ingredients intended for application to the scalp and hair. For antidandruff use, the oil vehicle can provide prolonged contact with the scalp, while selected

plant constituents may contribute antifungal activity and the carrier oils help with spreading and scalp conditioning. A representative study by Hati *et al.* developed and evaluated a polyherbal antidandruff hair oil containing extracts and volatile oils selected for activity against *Malassezia furfur*.

➤ Polyherbal Antidandruff Hair-Oil Formulation

Ingredient	Function/role
<i>Eucalyptus globulus</i> volatile oil	Antifungal/essential oil
<i>Ocimum gratissimum</i> volatile oil	Antifungal/essential oil
<i>Phyllanthus emblica</i> dried water extract	Botanical active
<i>Tridax procumbens</i> dried petroleum-ether extract	Antifungal/hair-growth-supporting active
<i>Hibiscus rosa-sinensis</i> dried petroleum-ether extract	Antifungal/hair-care active
Perfume	Fragrance
Sesame oil + coconut oil	Base/carrier oils

7.5 Emulsions^[61]

Emulsions are biphasic topical systems in which an oil phase and an aqueous phase are dispersed with the help of an emulsifying agent. For plant-based antidandruff

preparations, dilute emulsions can be useful for incorporating botanical extracts while providing a spreadable formulation with longer scalp contact than rinse-off products.

➤ Representative Formulation Composition

Ingredient	Function
<i>Cananga odorata</i> flower extract	Antidandruff/antifungal active
Ethanol 96%	Solvent
Menthol	Cooling agent
Propylene glycol	Humectant
Methyl paraben	Preservative
Sodium metabisulfite	Antioxidant
Glycerin	Emollient
Tween 80	Surfactant/emulsifier
Aquadeast	Vehicle

7.6 Microemulsions^[62]

Microemulsions are thermodynamically stable systems containing oil, water, surfactant, and often a co-surfactant. Their small internal droplet size can improve

the solubilization, dispersion, and stability of poorly water-soluble botanical constituents, making them useful for topical delivery of plant extracts.

➤ Representative Formulation of *Acacia concinna* Pod Extract-Loaded Microemulsion

Ingredient	Function
Tea seed oil	Oil phase
Polysorbate 85	Surfactant
Ethanol	Co-surfactant
<i>Acacia concinna</i> pod extract	Botanical active
Purified water	Aqueous phase/vehicle

7.7 Nanoemulsions^[63]

Nanoemulsions are fine oil-in-water (O/W) or water-in-oil (W/O) dispersions containing very small droplets, typically in the nanometer range (approximately 20–500 nm), stabilized using suitable surfactants and, when

required, co-surfactants. Their small droplet size provides a large interfacial area and can improve the dispersion, stability, solubilization, and topical delivery of poorly water-soluble plant-derived bioactive compounds.

➤ Formulation Variables and Optimized Composition

Ingredient/variable	Function
<i>Avicennia marina</i> heartwood extract	Plant-derived active/anti-dandruff ingredient
Virgin coconut oil (VCO)	Oil phase
Tween 80	Surfactant
Sorbitol	Co-surfactant
Propylene glycol	Co-solvent/solubilizing agent
Butylated hydroxytoluene (BHT)	Antioxidant
Distilled water	Continuous aqueous phase
Final batch volume	—

7.8 Liposomes^[64]

Liposomes are vesicular delivery systems composed mainly of one or more phospholipid bilayers surrounding an aqueous core. They can incorporate both hydrophilic

and lipophilic active compounds and are useful in topical formulations because they may improve drug/extract entrapment, protect sensitive constituents, and provide controlled release and prolonged contact with the scalp.

➤ Representative Formulation Components

Component	Function
Ketoconazole	Conventional antifungal active
<i>Azadirachta indica</i> leaf extract	Herbal antimicrobial/antifungal component
Phospholipid	Liposomal bilayer-forming material
Cholesterol	Membrane stabilizer
Other formulation excipients	Gel formation and topical application

7.9 formulation Comparison

Delivery system	Major advantage	Limitation	Suitable plant actives	Evidence
Shampoo	Easy application, cleansing	Short contact time	Water-soluble extracts	Moderate
Gel	Longer contact	May feel sticky	Hydrophilic extracts	Moderate
Oil	Prolonged contact	Difficult washing	Lipophilic compounds	Moderate
Microemulsion	Improved solubilization	High surfactant requirement	Poorly soluble compounds	Emerging
Nanoemulsion	Small droplet size	Stability/manufacturing issues	Essential oils	Emerging
Liposome	Controlled delivery	Cost/complexity	Hydrophilic + lipophilic	Emerging

8.0 Future Perspectives

Plant-based antidandruff formulations have considerable potential as alternatives or complementary options to conventional treatments. Future research should focus on identifying and standardizing the active phytoconstituents responsible for antifungal and anti-inflammatory effects, as variation in plant material and extraction methods can affect formulation performance. Advanced delivery systems such as nanoemulsions, liposomes, niosomes, phytosomes, nanogels, solid lipid nanoparticles, and nanostructured lipid carriers may help improve the stability, solubility, scalp retention, and controlled release of herbal actives. Further studies should also explore combinations of phytoconstituents that can act against *Malassezia* while reducing scalp inflammation and maintaining the normal scalp microbiome.

More evidence from in vivo studies and well-designed clinical trials is needed to confirm the efficacy and safety of these formulations. Standardized methods for evaluating antifungal activity, dandruff severity, scalp irritation, and recurrence would allow better comparison between different herbal products.

Sustainability is another important area for future development. The use of green extraction methods, biodegradable excipients, natural surfactants, and environmentally friendly manufacturing processes could make plant-based antidandruff products more sustainable. Overall, future research should aim to combine standardized herbal ingredients with suitable modern delivery systems to develop safe, effective, stable, and consumer-friendly antidandruff formulations.

9.0 CONCLUSION

Plant-based antidandruff agents offer a promising approach for the management of dandruff because many medicinal plants contain phytoconstituents with antifungal, anti-inflammatory, antioxidant, and scalp-protective properties. Several plant extracts and bioactive compounds have shown activity against *Malassezia* species and other factors associated with dandruff, supporting their potential as alternatives or complementary agents to conventional treatments. However, the effectiveness of herbal preparations can vary because of differences in plant source, phytochemical composition, extraction methods, and formulation. Modern formulation approaches, including emulsions, nanoemulsions, liposomes, niosomes, phytosomes, lipid nanoparticles, nanogels, and polymeric

nanoparticles, can help overcome some of these limitations by improving the stability, solubility, retention, and delivery of plant-derived actives to the scalp.

Despite encouraging laboratory findings, further work is needed to establish standardized herbal ingredients, clarify their mechanisms of action, assess long-term safety, and confirm their efficacy through well-designed clinical studies. Future development should also consider the scalp microbiome, sustainable formulation practices, and consumer acceptability. Overall, combining the therapeutic potential of medicinal plants with appropriate modern delivery technologies may provide a promising pathway for developing safer, effective, and more sustainable plant-based antidandruff formulations.

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