

# Natural Antifungal Agents in Polyherbal Shampoos for Dandruff Control: A Narrative Review of Neem, Fenugreek, Aloe Vera, Tea Tree Oil, and Camphor

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## ABSTRACT

Dandruff is one of the most common scalp disorders globally, affecting up to half of the adult population. Although not medically severe, it causes visible flaking, persistent itching, and social embarrassment. The condition is mainly associated with the overgrowth of *Malassezia* species, scalp oil imbalance, and individual sensitivity. Conventional treatments rely on chemical antifungal shampoos such as ketoconazole, selenium sulfide, or zinc pyrithione. While effective, these agents can cause scalp irritation, dryness, and resistance issues with long-term use.

This has created strong consumer demand for natural and herbal alternatives that are safe, sustainable, and cosmetically acceptable. Among the many plants explored for anti-dandruff properties, Neem (*Azadirachta indica*), Fenugreek (*Trigonella foenum-graecum*), Aloe Vera (*Aloe barbadensis miller*), Tea Tree Oil (*Melaleuca alternifolia*), and Camphor (*Cinnamomum camphora*) are of special interest. These agents possess unique phytochemical profiles and therapeutic actions: Neem and Tea Tree Oil show direct antifungal activity against *Malassezia*; Fenugreek offers scalp conditioning and anti-inflammatory effects; Aloe Vera soothes, moisturizes, and helps restore barrier function; while Camphor reduces itching and provides cooling comfort.

When combined in a polyherbal shampoo, these agents may act synergistically to reduce fungal colonization, relieve symptoms, and improve overall scalp health. However, challenges remain in terms of formulation stability, standardization of herbal extracts, safety considerations, and the need for high-quality clinical trials. This review presents a narrative synthesis of available evidence on these five natural agents, their antifungal mechanisms, their potential synergy in polyherbal formulations, and the future directions for research and product development.

**Keywords:** Dandruff, *Malassezia*, Polyherbal Shampoo, Herbal Cosmeceuticals, Antifungal Agents, Neem, Tea Tree Oil

## I. INTRODUCTION

### 1.1 Background and Global Burden

Dandruff, medically known as Pityriasis capitis, is a chronic scalp disorder characterized by visible flakes, itching, and irritation (1). It affects people worldwide regardless of ethnicity or climate, with the highest prevalence seen in adolescents and young adults (2). Epidemiological studies suggest that nearly 40–50% of post-pubertal individuals experience dandruff at some stage, making it a major dermatological concern (3). Although dandruff does not cause physical disability or systemic illness, its psychosocial impact is significant. Individuals often report embarrassment, reduced self-confidence, and social anxiety due to visible flakes on clothing and persistent itching (4). In some cases, severe forms may progress into seborrheic dermatitis, a more inflammatory skin condition (5).

### 1.2 Pathophysiology

The development of dandruff is complex and involves three interconnected factors:

- Sebum production:** After puberty, sebaceous glands in the scalp become more active, producing triglyceride-rich sebum that serves as a substrate for microbial growth (6).
- Microbial colonization:** Yeasts of the genus *Malassezia*, particularly *M. globosa* and *M. restricta*, metabolize sebum and release free fatty acids such as oleic acid. These irritate the scalp, disturb the epidermal barrier, and accelerate skin cell turnover (7,8).
- Host susceptibility:** Not everyone with *Malassezia* overgrowth develops dandruff. Individual factors such as scalp sensitivity, immune responses, and barrier integrity determine the severity of symptoms (9).

This interaction leads to itching, redness, and the shedding of clumped keratinocytes, which are observed as flakes.

### 1.3 Conventional Treatments and Limitations

Current anti-dandruff therapies mostly rely on shampoos containing chemical antifungal or keratolytic agents. Common ingredients include:

- **Azoles(ketoconazole, climbazole):** Strong antifungal action but may cause dryness or resistance (10,11).
- **Zincpyrithione:** Broad antimicrobial effects but sometimes associated with scalp irritation (12).
- **Selenium sulfide:** Effective but may leave an unpleasant odor and discoloration (13).
- **Coal tar:** Reduces cell turnover but is cosmetically unappealing (14).

While these shampoos provide symptomatic relief, their drawbacks limit long-term acceptance. Concerns include scalp dryness, altered hair texture, and the potential for microbial resistance (15,16).

### 1.4 Shift Toward Herbal Solutions

In recent decades, consumers have shown increasing interest in natural and herbal cosmetics (7,17). The global herbal hair care market is expanding rapidly, driven by perceptions of safety, sustainability, and added cosmetic benefits. Herbal ingredients are valued not only for their therapeutic actions but also for their ability to condition hair, soothe irritation, and provide a pleasant sensory experience.

**Polyherbal formulations**—shampoos that combine multiple herbal extracts—are particularly promising. By addressing the fungal cause, scalp inflammation, itching, and hair conditioning together, polyherbal shampoos offer a more holistic approach than single-agent products (18).

### 1.5 Rationale for This Review

Among the wide range of medicinal plants used for hair and scalp care, Neem, Fenugreek, Aloe Vera, Tea Tree Oil, and Camphor stand out due to their combined antifungal, anti-inflammatory, soothing, and conditioning properties (8–13). Each has a history of traditional use, scientific evidence supporting efficacy, and potential roles in dandruff control.

This narrative review aims to:

- Summarize the phytochemical profiles and antifungal mechanisms of these five agents.
- Compare their roles and contributions in polyherbal shampoos.
- Discuss formulation challenges and regulatory considerations.
- Identify research gaps and future opportunities for innovation.

## II. LITERATURE SEARCH STRATEGY

This review was prepared using a narrative synthesis approach. Although not a systematic review, it involved a structured and comprehensive search of the literature.

### 2.1 Databases

The following electronic databases were searched: PubMed, Scopus, Web of Science, and Google Scholar.

### 2.2 Search Terms

The search strategy included a combination of keywords and subject headings, such as:

- “dandruff,” “Pityriasis capitis,” “seborrheic dermatitis”
- “Malassezia,” “Malassezia globosa,” “Malassezia restricta”
- “antifungal,” “herbal shampoo,” “polyherbal formulation”
- “Neem,” “Azadirachta indica”
- “Fenugreek,” “Trigonella foenum-graecum”
- “Aloe vera,” “Aloe barbadensis miller”
- “Tea Tree Oil,” “Melaleuca alternifolia”
- “Camphor,” “Cinnamomum camphora”

Boolean operators (AND, OR) were used to combine search terms.

### 2.3 Inclusion and Exclusion Criteria

- **Inclusion:** In-vitro, in-vivo, and clinical studies evaluating the antifungal or scalp-health properties of these agents; review articles; relevant book chapters.
- **Exclusion:** Non-English language papers, conference abstracts without full text, and unrelated herbal studies.

### 2.4 Selection Process

Articles were screened based on titles and abstracts for relevance. Full texts of shortlisted papers were reviewed to extract information on phytochemical composition, antifungal mechanisms, scalp benefits, formulation use, and

clinical outcomes. Reference lists of key articles were manually searched for additional studies.

### 2.5 Limitations of the Search

Since this is a narrative review, studies were not systematically appraised for risk of bias, and no quantitative synthesis was performed. Instead, the findings are integrated narratively to provide a comprehensive overview of the topic.

## III. PHYTOCHEMICAL PROFILES AND THERAPEUTIC MECHANISMS OF SELECTED AGENTS

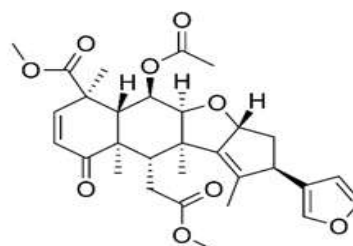
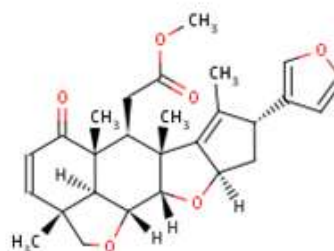
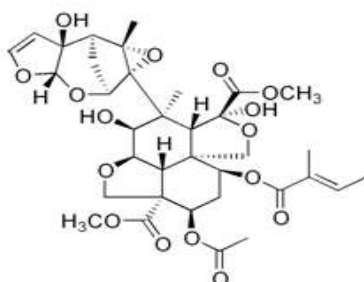
The therapeutic effectiveness of polyherbal formulations depends on the distinct yet complementary contributions of their components. Neem, Tea Tree Oil, Fenugreek, Aloe Vera, and Camphor have been widely studied for their bioactive compounds and biological activities relevant to dandruff control.

### 3.1 Neem (*Azadirachta indica*)

Neem is often described as a “village pharmacy” in Ayurveda due to its broad therapeutic potential (19). Its leaves, bark, and seeds are rich in triterpenoids, flavonoids, tannins, and glycosides. Among these, **azadirachtin, Nimbolide, and nimbin** are the most bioactive constituents with antimicrobial actions (20).

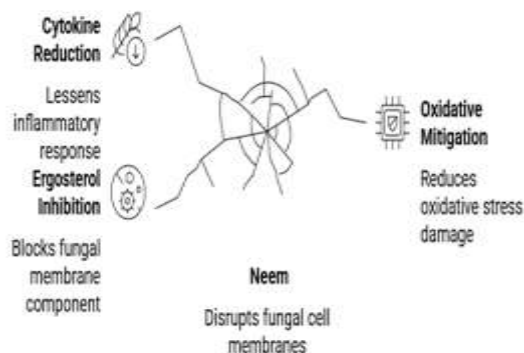
**Antifungal Mechanism:** Neem extracts exhibit potent activity against dermatophytes and yeasts, including *Malassezia* species (21). The mechanism involves disruption of fungal cell walls and interference with membrane permeability, leading to leakage of cytoplasmic content and fungal death (22). Methanolic leaf extracts have demonstrated inhibition zones comparable to ketoconazole in *M. furfur* assays (23).

Neem phytochemicals disrupt fungal cell membranes, inhibit ergosterol biosynthesis, and reduce inflammatory cytokines. Its antioxidant properties also mitigate oxidative stress, which is increasingly linked to scalp barrier dysfunction.



**Fig 1 – Chemical Structure of Azadirachtin, Nimbolide, Nimbin (46)**

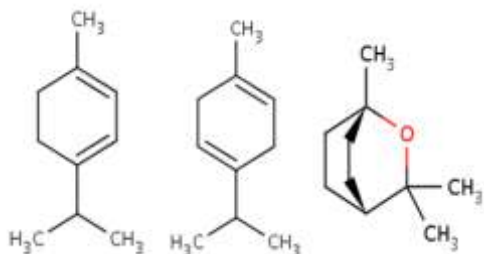
**Ancillary Benefits:** Neem also exerts anti-inflammatory and antibacterial effects, which help reduce scalp irritation and prevent secondary infections (24). Additionally, it is a natural antioxidant, protecting scalp cells from oxidative stress that may worsen dandruff (25).



**Fig 2: Neem Phytochemical Impact on Scalp Health**

### 3.2 Tea Tree Oil (*Melaleuca alternifolia*)

Tea Tree Oil (TTO) is an essential oil obtained from the Australian plant *Melaleuca alternifolia*. It contains over 100 components, with terpinen-4-ol as the major active constituent, followed by  $\gamma$ -terpinene,  $\alpha$ -terpinene, and 1,8-cineole (26).



**Fig 3 – Chemical Structure of  $\gamma$ -terpinene,  $\alpha$ -terpinene, and 1,8-cineole (46)**

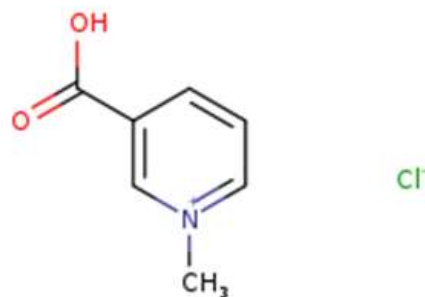
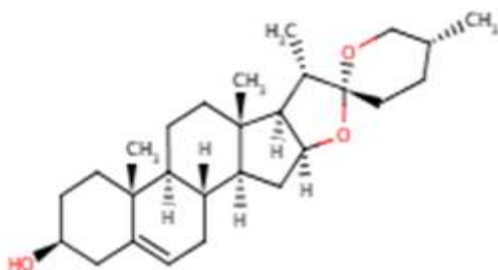
**Antifungal Mechanism:** TTO demonstrates strong antifungal activity against *Malassezia* species. Terpinen-4-ol disrupts fungal membrane integrity, increases ion leakage, and inhibits respiration (27). Its lipophilic nature allows penetration into sebaceous areas of the scalp, making it particularly effective in dandruff control.

**Clinical Evidence:** In a randomized controlled trial, a 5% TTO shampoo significantly reduced dandruff severity by 41% compared to 11% with placebo after four weeks (28). This high-quality evidence positions TTO as one of the best-validated natural antifungals for dandruff.

**Additional Benefits:** TTO also possesses antibacterial, anti-inflammatory, and mild analgesic properties, further supporting scalp health (29).

### 3.3 Fenugreek (*Trigonella foenum-graecum*)

Fenugreek seeds are valued in both culinary and medicinal traditions. They are rich in steroidal saponins (diosgenin, yamogenin), alkaloids (trigonelline), flavonoids, and mucilaginous fibers (30).



**Fig 4 – Chemical Structure of diosgenin, yamogenin and trigonelline (46).**

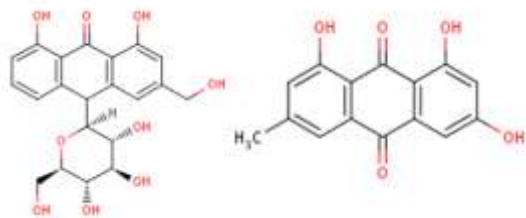
**Antifungal Mechanism:** Saponins act as natural surfactants that interact with fungal membrane sterols, creating pores and disrupting membrane integrity (31). Although its antifungal action is moderate compared to Neem and TTO, Fenugreek contributes meaningfully to an overall polyherbal effect.

**Ancillary Benefits:** Fenugreek's mucilage provides hair-conditioning properties, coating the shaft for smoothness and reduced breakage. Its flavonoids and antioxidants reduce inflammation and oxidative stress on the scalp (32). Furthermore, its proteins and nicotinic acid have been associated with improved hair strength and growth, making it desirable in hair care formulations (33).

### 3.4 Aloe Vera (*Aloe barbadensis miller*)

Aloe Vera gel contains more than 75 active compounds, including polysaccharides (acemannan), vitamins (A, C, E, B12), enzymes, minerals, and anthraquinones (34).

**Antifungal Mechanism:** Aloe Vera shows mild to moderate antifungal and antibacterial activities, largely due to anthraquinones like **aloin and emodin**, and saponins (35). While not a primary antifungal agent, it contributes to overall microbiome balance.



**Fig 5 – Chemical Structure of aloin and emodin (46).**

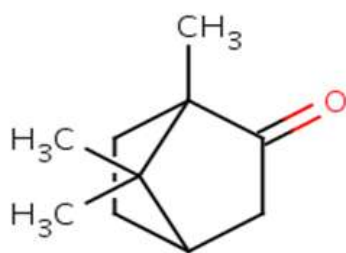
**Ancillary Benefits:** Its polysaccharides hydrate the scalp, restoring barrier function compromised by dandruff. Bradykinase enzymes reduce inflammation, while proteolytic enzymes digest dead keratinocytes, gently exfoliating flakes (36). In clinical trials, Aloe-based emulsions showed improvement in seborrheic dermatitis symptoms (37).

**Additional Role:** Aloe also accelerates wound healing and reduces redness, making it important for soothing irritated scalp conditions (38).

### 3.5 Camphor (Cinnamomum camphora)

Camphor is a terpenoid obtained from the wood of the camphor tree. It has long been used in traditional medicine for its cooling and analgesic properties.

**Antifungal Mechanism:** Camphor exhibits antifungal activity by disrupting fungal membrane lipids and inhibiting enzymatic processes (39). It has been shown to inhibit yeast and dermatophyte growth in vitro.



**Fig. 6 - Chemical Structure of Camphor (46).**

**Ancillary Benefits:** Camphor primarily acts as an antipruritic agent by activating transient receptor potential (TRP) channels, producing a cooling sensation that relieves itching (40). This is particularly useful in dandruff, where the itch-scratch cycle aggravates scalp inflammation. Its anti-inflammatory effect also reduces redness and irritation (41).

## IV. POLYHERBAL SYNERGY AND COMPARATIVE ROLES

The central concept of polyherbalism is **synergy**—the therapeutic effect of multiple agents together is greater than the sum of their individual contributions (42). For dandruff, this is especially valuable because the condition has a multifactorial pathogenesis involving microbial colonization, scalp barrier disruption, inflammation, itching, and dryness (1,6).

In a polyherbal anti-dandruff shampoo:

- **Neem and Tea Tree Oil** act as primary antifungal agents against *Malassezia* species (8,27).
- **Fenugreek** supports antifungal action through its saponins and adds hair-conditioning properties (30,31).
- **Aloe Vera** soothes inflammation, hydrates the scalp, and helps exfoliate dead cells (34,36).
- **Camphor** provides immediate relief from itching, improving user comfort (40).

This functional differentiation enables simultaneous targeting of fungal overgrowth, inflammatory symptoms, and cosmetic aspects of dandruff.

The synergy reduces fungal load, calms inflammation, relieves itching, and enhances hair feel, leading to higher compliance and consumer acceptance (18,28,37).

## V. FORMULATION, STABILITY, AND REGULATORY CHALLENGES

While herbal agents are promising, their incorporation into stable, effective, and consumer-acceptable shampoo formulations is complex

### 5.1 Standardization of Herbal Extracts

- **Challenge:** Variability in plant chemistry due to soil, climate, harvest, and extraction methods. Neem leaves harvested in one season may contain higher nimbin than another batch, causing inconsistent efficacy (7,42)
- **Solution:** Use of standardized extracts with defined active marker compounds (e.g., terpinen-4-ol  $\geq$  30% in Tea Tree Oil) (11,39,28)

### 5.2 Stability of Phytochemicals

- **Challenge:** Essential oils (Tea Tree, Camphor) are volatile and degrade with light and heat; Aloe polysaccharides break down in aqueous environments (39,41)

- **Solution:** Encapsulation techniques (liposomes, nanoemulsions), pH control, and amber-colored bottles to prevent photodegradation (39,41).

### 5.3 Interaction with Shampoo Base

- **Challenge:** Surfactants like sodium lauryl sulfate (SLS) may denature plant compounds; ethanol or glycerin content affects solubility (29,30,34,37,44).
- **Solution:** Formulate with milder surfactants (cocamidopropyl betaine, sodium coco-sulfate) and optimize solvent systems (29,30,34,37,44).

### 5.4 Sensory Properties and Consumer Acceptance

- **Challenge:** Strong medicinal odor of Neem and Tea Tree Oil may reduce consumer acceptance (22,25,27,28).
- **Solution:** Blend with aromatic oils (lavender, rosemary) or use natural fragrance masking agents (35,36)

### 5.5 Safety and Dosage Optimization

- **Challenge:** High concentrations of Tea Tree Oil or Camphor can cause dermatitis (28,43,44)
- **Solution:** Keep concentrations within safe cosmetic limits (e.g.,  $\leq 5\%$  TTO,  $\leq 3\%$  Camphor). Conduct patch tests before commercial launch (20,38)

### 5.6 Regulatory Pathways

- In **India**, herbal shampoos are generally regulated under Ayurvedic/Unani/Siddha (ASU) drugs or cosmetics, depending on claims (39).
- In the **USA**, anti-dandruff shampoos with therapeutic claims are classified as OTC drugs (requiring FDA compliance). Herbal shampoos marketed as cosmetics cannot claim “cure/treat dandruff” but may say “helps control flaking.” (40).
- In the **EU**, herbal shampoos fall under the Cosmetic Regulation (EC No 1223/2009), demanding safety dossiers and labeling transparency (41).

## VI. RESEARCH GAPS AND FUTURE DIRECTIONS

Despite promising evidence, significant gaps remain in the field of herbal anti-dandruff therapies.

### 6.1 Lack of High-Quality Clinical Trials

Most evidence for Neem, Aloe, and Fenugreek comes from laboratory studies or small clinical trials. Large-scale, randomized, double-blind trials comparing polyherbal shampoos with standard chemical shampoos (e.g., ketoconazole) are urgently needed (15,28).

### 6.2 Synergy Validation

Synergy is often assumed rather than proven (42). Proper factorial study designs could compare:

- Neem alone vs Tea Tree Oil alone vs both combined.
- Full polyherbal formula vs individual components.

### 6.3 Mechanistic Studies

Advanced techniques like:

- **Metabolomics:** To identify how herbal extracts alter scalp metabolites.
- **Transcriptomics:** To study gene expression changes in scalp tissue after treatment.
- **Microbiome sequencing:** To track how herbal shampoos affect scalp microbial balance.

### 6.4 Long-Term Safety and Resistance

- Herbal agents are believed to reduce risk of resistance, but long-term studies are limited.(44,53).
- Chronic use safety, especially with Camphor and essential oils, must be established.

### 6.5 Innovative Formulation Technologies

- **Nanoemulsions:** Improve solubility and stability of essential oils.
- **Hydrogel carriers:** Provide prolonged scalp contact.
- **Biopolymer coatings:** Control release of actives during shampooing.

### 6.6 Consumer-Centric Research

Since dandruff is also a cosmetic concern, consumer satisfaction studies are critical. Future research should explore:

- Texture, fragrance, lather acceptability.
- Hair smoothness and shine after use.
- Willingness to switch from chemical shampoos to herbal alternatives.

### 6.7 Role of Artificial Intelligence in Herbal Formulation

AI-based tools can predict optimal herbal combinations, simulate interactions, and analyze consumer feedback to design more effective

polyherbal shampoos. This is an emerging area in herbal product development (54).



Fig 7 - Research Gaps and Future Directions

## VII. CONCLUSION

The increasing prevalence of dandruff and the limitations of conventional chemical treatments have created a strong demand for safe, effective, and consumer-friendly alternatives. Polyherbal shampoos combining Neem,

Tea Tree Oil, Fenugreek, Aloe Vera, and Camphor present a rational, holistic approach.

- **Neem and Tea Tree Oil** form the antifungal backbone, targeting *Malassezia* growth directly.
- **Fenugreek** contributes supportive antifungal action while improving hair quality and scalp comfort.
- **Aloe Vera** restores hydration, barrier integrity, and reduces inflammation.
- **Camphor** provides rapid itch relief and enhances consumer acceptability with its cooling effect.

Together, these agents address the **etiological cause** of dandruff and its **associated symptoms**. Their complementary roles provide a therapeutic synergy that is difficult to achieve with single-ingredient formulations.

However, important gaps remain. Standardization of extracts, stability of phytochemicals, formulation optimization, and regulatory compliance are pressing challenges. Most critically, there is a lack of robust, large-scale clinical trials to establish the efficacy of polyherbal shampoos against standard chemical treatments. Future research should also focus on advanced

delivery systems, safety assessments during long-term use, and consumer acceptability studies.

If these hurdles are addressed with scientific rigor, polyherbal shampoos based on Neem, Fenugreek, Aloe Vera, Tea Tree Oil, and Camphor could emerge as the **next generation of natural anti-dandruff therapies**—combining efficacy, safety, and cosmetic appeal in a single formulation.

## LIST OF ABBREVIATIONS

- A. indica** – *Azadirachta indica* (Neem)  
**AI** – Artificial Intelligence  
**AV** – Aloe Vera (*Aloe barbadensis miller*)  
**AYUSH** – Ayurveda, Yoga, Unani, Siddha, and Homeopathy (India regulatory body)  
**C. camphora** – *Cinnamomum camphora* (Camphor)  
**CADD** – Computer-Aided Drug Design  
**CAPB** – Cocamidopropyl Betaine  
**CFU** – Colony Forming Unit  
**CPNP** – Cosmetic Products Notification Portal (European Union)  
**DL** – Deep Learning  
**EMA** – European Medicines Agency  
**EU** – European Union  
**FDA** – Food and Drug Administration (United States)  
**GMP** – Good Manufacturing Practice  
**HPLC** – High Performance Liquid Chromatography  
**HPMC** – Hydroxypropyl Methylcellulose  
**LNPs** – Lipid Nanoparticles  
**MeSH** – Medical Subject Headings  
**MFC** – Minimum Fungicidal Concentration  
**MIC** – Minimum Inhibitory Concentration  
**ML** – Machine Learning  
**NPs** – Nanoparticles  
**OTC** – Over-The-Counter  
**PC** – Pityriasis capitis  
**PEG** – Polyethylene Glycol  
**QC** – Quality Control  
**RCT** – Randomized Controlled Trial  
**ROS** – Reactive Oxygen Species  
**SD** – Seborrheic Dermatitis  
**SLS** – Sodium Lauryl Sulfate  
**T. foenum-graecum** – *Trigonella foenum-graecum* (Fenugreek)  
**TLC** – Thin Layer Chromatography  
**TTO** – Tea Tree Oil (*Melaleuca alternifolia*)  
**TRP** – Transient Receptor Potential (ion channels)  
**WHO** – World Health Organization

**Table 1: Phytochemical Constituents and Therapeutic Roles of Selected Agents**

Agent	Major Phytochemicals	Antifungal Mechanism	Additional Benefits	Role in Polyherbal Shampoo
Neem	Azadirachtin, nimbin, nimbidin, flavonoids	Disrupts fungal membranes; inhibits growth of Malassezia	Anti-inflammatory, antibacterial	Primary antifungal driver
Tea Tree Oil	Terpinen-4-ol, cineole, terpinene	Penetrates fungal cells; disrupts membrane & respiration	Anti-inflammatory, pleasant fragrance	Primary antifungal driver
Fenugreek	Saponins, trigonelline, flavonoids, mucilage	Saponins increase fungal membrane permeability	Conditioning, anti-inflammatory	Supportive antifungal + hair conditioner
Aloe Vera	Polysaccharides, aloin, emodin, bradykinase	Mild antifungal; maintains scalp microbiome balance	Moisturizing, healing, soothing	Symptom relief & scalp recovery
Camphor	Monoterpenes (camphor, cineole, borneol)	Membrane disruption; enzyme inhibition	Cooling, antipruritic, anti-inflammatory	Rapid itch relief & sensory enhancer

**Table 2: Comparative Contributions of Selected Agents in Polyherbal Shampoo**

Agent	Primary Role	Secondary Role(s)	Key Contribution in Polyherbal System
Neem	Potent antifungal	Anti-inflammatory, antibacterial	Core antifungal activity against Malassezia
Tea Tree Oil	Potent antifungal	Anti-inflammatory, fresh fragrance	Evidence-based antifungal driver
Fenugreek	Conditioning agent	Mild antifungal, anti-inflammatory	Enhances hair quality, scalp comfort
Aloe Vera	Soothing & healing	Mild antifungal, moisturizing	Restores barrier, hydrates scalp
Camphor	Antipruritic (itch relief)	Mild antifungal, cooling effect	Rapid symptomatic relief, user satisfaction

**Table 3: Common Formulation Challenges and Potential Solutions**

Challenge	Example(Agent Affected)	Possible Solution
Variability in phytochemicals	Neem, Fenugreek	Use standardized extracts, batch testing
Volatile compound degradation	Tea Tree Oil, Camphor	Encapsulation, amber packaging
Surfactant interaction	Aloe Vera polysaccharides	Use mild surfactants, adjust solvents
Strong odor	Neem, Tea Tree Oil	Fragrance masking or blending
Irritation at high doses	Tea Tree Oil, Camphor	Safe concentration limits, patch testing
Regulatory restrictions	All	Comply with local cosmetic/OTC rules

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