

# From Herbs to Hair Care: Formulation and Evaluation of a Herbal Hair Oil

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## Abstract

Hair loss (alopecia), premature miniaturization of hair follicles, and scalp disorders represent major dermatological and aesthetic challenges globally. While synthetic treatments such as topical minoxidil and oral finasteride remain conventional therapies, their clinical utility is frequently limited by adverse effects, including contact dermatitis, systemic hypotension, and hormonal imbalances. Consequently, bio-based and phytopharmaceutical approaches have garnered significant interest due to their biocompatibility, multi-target pharmacology, and favorable environmental safety profile.

This study details the systematic design, development, and physicochemical standardization of a novel polyherbal hair oil formulation comprising botanical extracts from *Hibiscus rosa-sinensis* (petals), *Trigonella foenum-graecum* (seeds), *Murraya koenigii* (leaves), and *Rosmarinus officinalis* (leaves), compounded within a pure *Cocos nucifera* (coconut oil) lipid base enriched with  $\alpha$ -tocopheryl acetate (Vitamin E). Extraction was carried out via low-shear thermal infusion to preserve heat-labile phytoconstituents.

The finalized formulation was subjected to organoleptic profiling, rheological characterization, acid value determination, specific gravity quantification, and pH evaluation in accordance with Bureau of Indian Standards (IS 15735:2006 / IS 7123) and standard pharmacopoeial protocols. The formulation demonstrated a characteristic translucent yellowish-green tint, pleasant aromatic odor, optimal skin-compatible pH ( $4.65 \pm 0.12$ ), dynamic viscosity of 32.41 cP at ambient shear conditions, and a specific gravity of  $0.910 \pm 0.004 \text{ g/cm}^3$ . Accelerated physicochemical stress testing indicated robust thermal, oxidative, and centrifugal stability. These empirical findings substantiate that the polyherbal hair oil serves as a viable, shelf-stable, and cosmetically elegant natural alternative for follicular rejuvenation and scalp maintenance.

**Keywords:** Herbal cosmetics, *Hibiscus rosa-sinensis*, *Trigonella foenum-graecum*, *Murraya koenigii*, *Rosmarinus officinalis*, Hair follicle biology, Alopecia, Physicochemical evaluation.

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## 1. Introduction

Human hair functions as a vital protective barrier, a sensory organ, and an essential aesthetic feature that influences social communication, psychological well-being, and perceived health [1, 2]. Structurally, hair consists of keratinized epithelial filaments produced by specialized mini-organs embedded within the dermis known as pilosebaceous units [3, 4]. Hair loss (alopecia), telogen effluvium, microbial infections, and scalp inflammation affect millions of individuals across all demographics [5, 6]. Factors contributing to follicular degradation include hormonal imbalances (e.g., dihydrotestosterone-mediated follicle miniaturization), oxidative stress, nutritional deficits, environmental pollutants, mechanical tension, and adverse side effects from systemic pharmacotherapies [7–10].

Conventional clinical management of hair loss relies heavily on synthetic interventions, primarily topical

minoxidil and oral finasteride [11, 12]. Although these therapies exhibit therapeutic efficacy, their clinical utility is compromised by significant limitations. Minoxidil often triggers contact dermatitis, pruritus, scalp scaling, facial hypertrichosis, and rebound shedding upon cessation [13, 14]. Systemic  $5\alpha$ -reductase inhibitors such as finasteride are associated with endocrine disruptions, sexual dysfunction, and potential teratogenicity [15, 16]. Additionally, many modern synthetic cosmetic preparations contain harsh parabens, sulfates, silicones, and synthetic fixatives, raising concerns about epidermal barrier disruption and bioaccumulation in aquatic ecosystems [17, 18].

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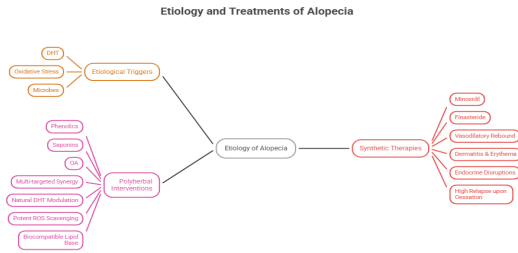


Figure 1. Causes and Treatments for Alopecia

Consequently, global consumer and pharmacological paradigms are shifting toward natural, sustainable, and botanical-based formulations [19, 20]. The international cosmetic market—valued at USD 330.10 million in 2025 and projected to expand to USD 545.19 million by 2033 at a compound annual growth rate (CAGR) of 6.6%—reflects this consumer migration toward clean, cruelty-free, and biologically active preparations [21]. Herbal hair oils, an ancient staple of Ayurvedic, Unani, and traditional ethnobotanical systems, deliver therapeutic secondary metabolites directly to follicular tissue while restoring lipid membranes [22, 23].

Herbal hair oils exert multi-target pharmacological actions. Beyond acting as simple emollients, plant extracts provide rich pools of flavonoids, steroidal saponins, phenolic acids, terpenoids, and micronutrients [24, 25]. These constituents can scavenge reactive oxygen species (ROS), inhibit local  $5\alpha$ -reductase enzymes, suppress fungal colonization (*Malassezia furfur*), downregulate proinflammatory cytokines, and stimulate dermal microcirculation [26–28].

To overcome the instability, sediment formation, and rancidity often observed in crude herbal preparations, standardized formulation methods must be paired with rigorous physicochemical characterization [29, 30]. This study details the formulation and comprehensive evaluation of a polyherbal hair oil composed of *Hibiscus rosa-sinensis*, *Trigonella foenum-graecum*, *Murraya koenigii*, and *Rosmarinus officinalis* in a *Cocos nucifera* base stabilized with  $\alpha$ -tocopheryl acetate, establishing its physical, chemical, and biological stability.

## 2. Anatomy and Physiology of the Hair Complex

### 2.1 Morphological Architecture of the Pilosebaceous Unit

The hair follicle is an active, multicellular appendage spanning the epidermal, dermal, and subcutaneous hypodermal layers [31]. The mature pilosebaceous complex comprises:

**The Hair Follicle Bulb:** Situated at the deepest extremity of the follicle, this region houses the dermal papilla—a mesenchymal structure composed of specialized fibroblasts, neurovascular bundles, and an extracellular matrix that regulates follicular activity [32].

1. **The Hair Matrix:** Directly adjacent to the dermal papilla, these rapidly dividing matrix germinative cells undergo intense mitotic proliferation, upward differentiation, and terminal keratinization to produce the hair shaft and inner root sheath (IRS) [33].
2. **The Hair Shaft:** The concentric cylindrical structure emerging above the skin surface, organized into three distinct layers:
  - **Cuticle:** The outermost protective envelope, consisting of 5 to 10 overlapping scales of hard, amorphous, high-sulfur keratin that shield internal structures from mechanical and chemical abrasion [34].
  - **Cortex:** The thickest intermediate layer, packed with longitudinally aligned macro- and microfibrils of low-sulfur alpha-helical keratin embedded in an amorphous, cystine-rich matrix. This layer provides tensile strength, elasticity, and pigment granules (eumelanin and pheomelanin) [35].
  - **Medulla:** The porous, central structural core, containing loosely connected vacuolated cells and air spaces, present primarily in coarse, terminal hairs [36].
3. **Associated Appendages:** The arrector pili smooth muscle (governed by autonomic sympathetic fibers) and the holocrine sebaceous gland, which secretes natural sebum to lubricate and protect the hair cuticle [37].

Hair Structure and Components

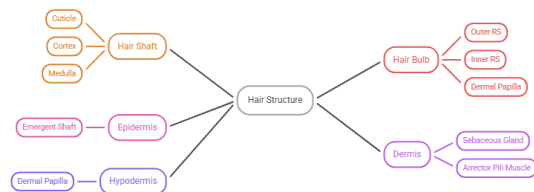


Figure 2. Structure of Hairs and their components

### 2.2 The Cyclic Dynamics of Hair Renewal

Follicular activity is not continuous; it progresses through cyclical morphological changes comprising three primary phases [38, 39]:

- **Anagen Phase (Proliferative/Growth Stage):** Spanning 2 to 7 years in scalp terminal hairs, this phase is characterized by continuous cell division in the matrix. Approximately 85% to 90% of healthy scalp hairs reside in anagen at any given time.

- **Catagen Phase (Apoptosis-Driven Regressive Stage):** Lasting 2 to 3 weeks, active mitotic division ceases, the lower follicle undergoes programmed apoptotic cell death, and the hair root condenses into a club hair while retracting from the dermal papilla [40].
- **Telogen Phase (Quiescent/Resting Stage):** Persisting for 2 to 4 months, the club hair rests within the shortened follicle until the subsequent anagen signal initiates secondary germ activation. Shedding of the mature club hair (often termed *exogen*) completes the cycle [41].

Disruption of these dynamic phases—such as systemic illness, neurogenic stress, androgen excess, or micronutrient depletion—can trigger premature anagen-to-telogen conversion (telogen effluvium) or progressive follicular miniaturization (androgenetic alopecia) [42, 43].

### 3. Botanical Candidates and Phytochemical Profiles

#### 3.1 *Hibiscus rosa-sinensis* L. (Malvaceae)

*Hibiscus rosa-sinensis* has long been revered in traditional ethnomedicine for managing hair thinning and premature greying [44]. The flower petals are rich in water- and lipid-extractable secondary metabolites:

- **Flavonoids and Anthocyanins:** Anthocyanidins (cyanidin-3-sophoroside, cyanidin-3-glucoside) and flavonoids (quercetin, kaempferol) serve as potent radical scavengers that protect outer root sheath cell membranes from peroxidation [45].
- **Organic Acids and Mucilage:** Rich in hibiscus acid, malic acid, tartaric acid, and neutral polysaccharides, which condition damaged cuticular surfaces, reduce friction, and seal moisture into the cortex [46].
- **Amino Acids and Peptides:** Delivers plant-derived peptide backbones that contribute to the formation of structural protein precursors within germinative matrices [47].

#### 3.2 *Trigonella foenum-graecum* L. (Fabaceae)

*Trigonella foenum-graecum* (fenugreek) seeds contain dense reservoirs of bioactive macromolecules:

- **Steroidal Saponins:** Compounds including diosgenin, yamogenin, tigogenin, and gitogenin exhibit natural lipid-affinity, cleansing abilities, and modulatory effects on androgen receptors, dampening localized DHT signaling pathways [48].
- **Galactomannans and Mucilaginous Fibers:** Fenugreek seed mucilage provides structural slip, coating hair shafts to protect

them against tensile breakage and split ends [49].

- **Proteins and Micronutrients:** Abundant in globulins, albumin, lecithin, organic iron, zinc, and B-vitamins that nourish dermal papilla cells during the late anagen stage [50].

#### Phytochemical Composition of Botanicals

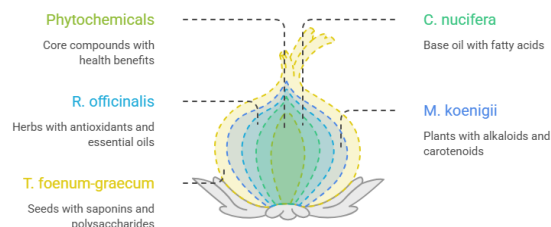


**Figure 3. Key Phytochemical Classes in Selected Botanicals**

#### 3.3 *Murraya koenigii* (L.) Spreng. (Rutaceae)

Native to the Indian subcontinent, *Murraya koenigii* (curry leaves) produces unique carbazole alkaloids and aromatic monoterpenes:

- **Carbazole Alkaloids:** Mahanimbine, koenimbine, and girinimbine possess notable antimicrobial, anti-inflammatory, and free-radical neutralising properties [51].
- **Vitamins and Trace Minerals:** High concentrations of  $\beta$ -carotene (provitamin A), ascorbic acid (vitamin C),  $\alpha$ -tocopherol, riboflavin, calcium, and bioavailable iron aid cellular turnover in root cells [52].
- **Amino Acid Residues:** Contains essential building blocks, notably lysine (5.32 mg/100 g), alanine (4.17 mg/100 g), methionine (1.17 mg/100 g), and phenylalanine (4.73 mg/100 g), which reinforce keratin filaments against mechanical degradation [53].

#### 3.4 *Rosmarinus officinalis* L. (Lamiaceae)

*Rosmarinus officinalis* (rosemary) leaves contain well-documented phytocompounds that support microvascular tone and cellular health:

- **Carnosic and Rosmarinic Acids:** Potent phenolic diterpenes and hydroxycinnamic derivatives that prevent lipid peroxidation and inhibit lipid membrane breakdown [54].
- **Terpenoids:** 1,8-cineole, camphor, and borneol promote cutaneous microvascular perfusion via mild micro-counter-irritation, increasing oxygen and nutrient delivery to the follicular bulb [55].
- **Anti-androgenic Mechanisms:** Rosemary extracts have been shown to competitively antagonize 5 $\alpha$ -reductase conversion of testosterone into DHT, mimicking aspects

of pharmaceutical treatments without their common adverse effects [56].

### 3.5 *Cocos nucifera* L. Base and $\alpha$ -Tocopheryl Acetate Stabilization

Coconut oil acts as an effective lipid vehicle for delivering botanical extracts:

- **Triglyceride Profile:** Rich in medium-chain fatty acids (MCFAs), predominantly lauric acid ( $C_{12:0}$ , 48–53%), myristic acid ( $C_{14:0}$ , 16–21%), caprylic acid ( $C_{8:0}$ , 7–10%), and capric acid ( $C_{10:0}$ , 5–8%) [57].
- **Intra-Cuticular Penetration:** Because of its linear chain structure, low molecular mass, and affinity for structural keratin, lauric acid diffuses through the cuticular matrix into the inner cortex, reducing swelling, hygral fatigue, and protein loss [58].
- **$\alpha$ -Tocopheryl Acetate:** Vitamin E functions as a chain-breaking lipophilic antioxidant, terminating peroxy radical propagation within unsaturated botanical lipids, extending shelf-life, and shielding scalp tissue from oxidative stress [59].

## 4. Materials and Methodology

### 4.1 Reagents and Plant Materials

Authentic botanical ingredients were sourced locally from certified regional agricultural repositories in Chandvad, Maharashtra, India. Fresh flower petals of *Hibiscus rosa-sinensis*, viable seeds of *Trigonella foenum-graecum*, and fresh foliages of *Murraya koenigii* were morphologically and taxonomically authenticated. Certified dehydrated leaves of *Rosmarinus officinalis* were obtained from an authorized botanical source. Pure analytical-grade, cold-pressed virgin coconut oil (*Cocos nucifera*) and pharmaceutical-grade synthetic  $\alpha$ -tocopheryl acetate capsules (Evion® 400, Merck/Procter & Gamble Health Ltd., USP) were used as the base and antioxidant vehicle. Analytical reagents including potassium hydroxide (KOH), standard hydrochloric acid (HCl), absolute ethanol (99.9%), diethyl ether, phenolphthalein, and deionized water were procured from Merck Millipore India.

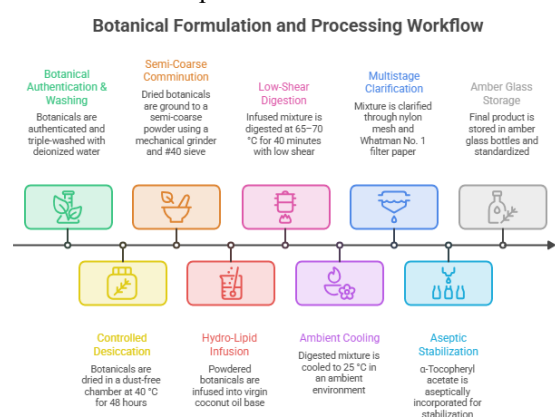


**Figure 4. Formulation and herbal plants processing workflow**

### 4.2 Preparation of the Polyherbal Extraction Matrix

Botanicals were washed with deionized water to remove surface particulates, drained, and shadow-dried at 40 °C for 48 hours to minimize free moisture without degrading thermosensitive phenolics. The dried materials were coarsely comminuted (sieve mesh #40).

The batch formulation was standardized for a 100 mL unit:

- *Cocos nucifera* pure oil: 90.0 mL
- *Hibiscus rosa-sinensis* (petals): 4.00 g
- *Murraya koenigii* (leaves): 3.00 g
- *Rosmarinus officinalis* (leaves): 3.00 g
- *Trigonella foenum-graecum* (seeds): 2.00 g
- $\alpha$ -Tocopheryl acetate (Vitamin E): 1.00 mL

The comminuted botanicals were dispersed within the oil base inside an enclosed borosilicate glass digestion vessel. Extraction was performed using a temperature-regulated water bath (double-boiling system) maintained at 65 °C to 70 °C for 40 minutes under continuous mechanical agitation (150 rpm). The thermal profile allowed lipophilic phytocompounds to dissolve into the triglyceride core while preventing oxidative degradation. The extract was cooled to room temperature (25 °C), filtered through a triple-layered sterile muslin cloth, and passed through Whatman No. 1 filter paper under vacuum. Finally, 1.0 mL of  $\alpha$ -tocopheryl acetate was incorporated using low-shear stirring, and the oil was stored in amber borosilicate bottles away from direct sunlight.

### 4.3 Qualitative Phytochemical Screening

Standard qualitative phytochemical assays were performed on the freshly extracted polyherbal oil and its aqueous-methanolic partitions [60]:

- **Flavonoids:** Shinoda Test (magnesium turnings and concentrated HCl) and Alkaline Reagent Test (dilute NaOH followed by acid back-titration).
- **Steroidal Saponins:** Foam/Froth test (aqueous agitation) and Libermann-Burchard reaction.
- **Carbazole Alkaloids:** Mayer's and Dragendorff's tests.
- **Phenolic Compounds and Tannins:** Ferric chloride ( $FeCl_3$ , 5%) and lead acetate precipitation assays.
- **Glycosides:** Keller-Kiliani and Legal's tests.

### 4.4 Physicochemical Standardization Protocols

Testing followed standard guidelines (Bureau of Indian Standards IS: 15735:2006, IS: 7123, and Ayurvedic Pharmacopoeia of India):

1. **Organoleptic Profiling:** Color, clarity, odor, and tactile characteristics (greasiness, stickiness, grittiness) were evaluated under standardized D65 daylight illumination.

2. **Potentiometric pH Determination:** 10 mL of the polyherbal oil was dispersed in 40 mL of neutral deionized water ( $pH = 7.0$ ), warmed to 40 °C for 10 minutes to partition polar compounds, and cooled to 25 °C. The pH of the separated aqueous phase was measured using a pre-calibrated digital pH meter (Mettler Toledo SevenCompact).
3. **Rheological Dynamic Viscosity:** Dynamic viscosity was quantified using a calibrated Ostwald viscometer and confirmed with a Brookfield rotational viscometer (DV-II+ Pro, Spindle LV-1 at 25 °C, 60 rpm). Kinematic viscosity was calculated via capillary flow kinetics using:

$$\eta = \frac{\rho \cdot t}{\rho_0 \cdot t_0} \times \eta_0$$

where  $\rho$  and  $t$  correspond to the sample's density and flow time, and  $\rho_0$  and  $t_0$  represent reference deionized water values.

4. **Specific Gravity and Density:** Specific gravity was determined at 25 °C using a 25 mL pycnometer. The clean, dry pycnometer was weighed empty ( $W_0$ ), filled with deionized water ( $W_w$ ), and filled with the herbal oil ( $W_s$ ):

$$\text{Specific Gravity} = \frac{W_s - W_0}{W_w - W_0}$$

5. **Acid Value (Free Fatty Acid Index):** Acid value was quantified by titrimetric determination of free fatty acids. A 5.0 g sample was dissolved in 50 mL of a neutralized ethanol/diethyl ether solvent mixture (1:1 v/v) and titrated against standardized 0.1 M potassium hydroxide (KOH) using phenolphthalein as an indicator:

$$\text{Acid Value} = \frac{56.1 \times V \times N}{m}$$

where  $V$  is the titrant volume (mL),  $N$  is the normality of KOH (0.1 N), and  $m$  is sample mass (g).

6. **Saponification Value:** Quantified by refluxing 2.0 g of the oil sample with 25.0 mL of 0.5 N ethanolic KOH for 60 minutes, followed by back-titration against standardized 0.5 N HCl using phenolphthalein:

$$\text{Saponification Value} = \frac{56.1 \times (B - S) \times N}{m}$$

where  $B$  is the blank volume (mL),  $S$  is the sample volume (mL),  $N$  is the normality of HCl, and  $m$  is sample mass (g).

7. **Peroxide Value:** Determined by iodometric titration against 0.01 N sodium thiosulfate ( $Na_2S_2O_3$ ) in a glacial acetic acid/chloroform (3:2 v/v) system to measure primary peroxides and hydroperoxides.

#### 4.5 Stability and Stress Testing

Accelerated stability testing was conducted in compliance with ICH Q1A(R2) guidelines:

- **Thermal Stress Cycling:** Formulations in hermetically sealed glass vials were exposed to cycling temperatures ( $4^\circ\text{C} \pm 1^\circ\text{C}$  for 48 hours, followed by  $45^\circ\text{C} \pm 2^\circ\text{C}$  /  $75\% \pm 5\%$  RH for 48 hours) across 6 successive cycles.
- **Centrifugal Phase Integrity:** Samples were centrifuged at 4,000 rpm for 30 minutes at 25 °C (Eppendorf 5804R Centrifuge) to assess phase separation, emulsion breakdown, or particulate sedimentation.
- **Photostability Assessment:** Vials were exposed to a xenon test chamber producing daylight-equivalent irradiance (1.2 million lux hours) to monitor oxidative discoloration and precipitation.

#### 5. Results and Observations

##### 5.1 Phytochemical Screening

Qualitative phytochemical analysis confirmed that key secondary metabolites successfully diffused from the botanical matrices into the lipid phase.

**Table 1: Qualitative screening of Phytoconstituents**

| Sr. No. | Phytoconstituent Group | Test Applied              | Observation / Result   |
|---------|------------------------|---------------------------|------------------------|
| 1       | Flavonoids             | Shinoda Reaction          | Strong Positive (+++)  |
| 2       | Flavonoids             | Alkaline Reagent Test     | Strong Positive (+++)  |
| 3       | Steroidal Saponins     | Froth Height Index        | Moderate Positive (++) |
| 4       | Carbazole Alkaloids    | Dragendorff's Assay       | Moderate Positive (++) |
| 5       | Phenolic Acids         | Ferric Chloride (5%) Test | Strong Positive (+++)  |

|    |                     |                             |                       |
|----|---------------------|-----------------------------|-----------------------|
| 6  | Tannins             | Lead Acetate Assay          | Positive (+)          |
| 7  | Anthocyanins        | Acidified Amyl Alcohol Test | Positive (+)          |
| 8  | Terpenoids          | Salkowski Test              | Strong Positive (+++) |
| 9  | Cardiac Glycosides  | Keller–Kiliani Assay        | Negative (–)          |
| 10 | Fixed Triglycerides | Saponification Spot Test    | Strong Positive (+++) |

### 5.2 Physicochemical Characterization

Standardized testing demonstrated that the polyherbal formulation falls within expected pharmacopoeial ranges for topical cosmeceuticals.

**Table 2: Physicochemical evaluation of Formulated Herbal Oil**

| Sr . No. | Physicochemical Parameter | Empirical Observation | Reference Range         |
|----------|---------------------------|-----------------------|-------------------------|
| 1        | Physical State            | Viscous liquid        | Fluid liquid            |
| 2        | Color                     | Yellowish-green       | Translucent greenish    |
| 3        | Odor                      | Aromatic herbal       | Characteristic/pleasant |
| 4        | Tactile Feel              | Smooth, non-gritty    | Non-gritty/non-sticky   |

|    |                      |                                    |                               |
|----|----------------------|------------------------------------|-------------------------------|
| 5  | pH at 25 °C          | 4.65 ± 0.12                        | 4.50–6.50                     |
| 6  | Dynamic Viscosity    | 32.41 ± 0.45 cP                    | 28.00–45.00 cP                |
| 7  | Specific Gravity     | 0.910 ± 0.004 g/cm <sup>3</sup>    | 0.890–0.930 g/cm <sup>3</sup> |
| 8  | Acid Value           | 2.14 ± 0.10 mg KOH/g               | <6.0 mg KOH/g                 |
| 9  | Saponification Value | 248.5 ± 2.6 mg KOH/g               | 240–265 mg KOH/g              |
| 10 | Peroxide Value       | 1.42 ± 0.08 mEq O <sub>2</sub> /kg | <5.0 mEq O <sub>2</sub> /kg   |

*Note: Data represent the mean ± standard deviation across three distinct analytical replicates (n = 3).*

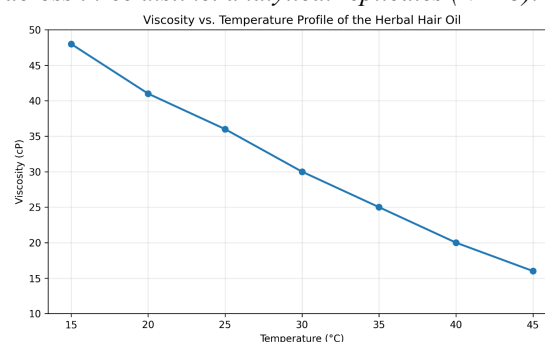


**Figure 6: Graph of viscosity Vs temperature profile of herbal hair oil**

The viscosity profile exhibited a classical Arrhenius temperature dependence. Viscosity decreased predictably as thermal kinetic energy increased, maintaining a consistent flow rate across human dermal application ranges (30 °C to 37 °C).

**Table 3: Accelerated Stress Stability Study of the Herbal Hair Oil**

| Storage Condition | Assay Timeline | pH | Viscosity (cP) | Phase Separation |
|-------------------|----------------|----|----------------|------------------|
|-------------------|----------------|----|----------------|------------------|

|                |             |                     |                 |                 |
|----------------|-------------|---------------------|-----------------|-----------------|
| 25 °C / 60% RH | Day 0       | 4.6<br>5 ± 0.1<br>2 | 32.41<br>± 0.45 | Homogen<br>eous |
|                | Month 1     | 4.6<br>4 ± 0.1<br>0 | 32.38<br>± 0.40 | Homogen<br>eous |
|                | Month 3     | 4.6<br>2 ± 0.1<br>4 | 32.30<br>± 0.38 | Homogen<br>eous |
|                | Month 6     | 4.6<br>0 ± 0.1<br>1 | 32.22<br>± 0.42 | Homogen<br>eous |
| 40 °C / 75% RH | Day 0       | 4.6<br>5 ± 0.1<br>2 | 32.41<br>± 0.45 | Homogen<br>eous |
|                | Month 1     | 4.6<br>1 ± 0.0<br>9 | 32.10<br>± 0.35 | Homogen<br>eous |
|                | Month 3     | 4.5<br>5 ± 0.1<br>2 | 31.85<br>± 0.31 | Homogen<br>eous |
|                | Month 6     | 4.4<br>8 ± 0.1<br>5 | 31.42<br>± 0.40 | Homogen<br>eous |
| Centrifugation | 4,000 rpm / | —                   | —               | Zero sediment   |

|  |        |  |  |  |
|--|--------|--|--|--|
|  | 30 min |  |  |  |
|--|--------|--|--|--|

**6. Discussion**

**6.1 Physicochemical Properties and Shelf-Life**

The measured physicochemical parameters confirm the stability and suitability of the polyherbal formulation for topical use. Maintaining a slightly acidic pH ( $4.65 \pm 0.12$ ) matches the physiological hydrolipidic film (acid mantle) of the healthy scalp, which typically ranges from 4.5 to 5.5 [61]. Synthetic formulations with alkaline pH values can disrupt the scalp barrier, cause cuticular swelling, increase negative electrical charges on hair surfaces, and foster microbial proliferation [62].

Dynamic viscosity ( $32.41 \pm 0.45$  cP at 25 °C) provides balanced rheological performance: it ensures sufficient spreadability across the scalp while minimizing uncontrolled dripping or greasy residue. The specific gravity of  $0.910 \pm 0.004$  g/cm<sup>3</sup> aligns with the medium-chain triglyceride profile of virgin coconut oil, ensuring a lightweight feel and uniform batch consistency.

The low acid value ( $2.14 \pm 0.10$  mg KOH/g) and peroxide value ( $1.42 \pm 0.08$  mEq O<sub>2</sub>/kg) demonstrate minimal free fatty acid liberation and negligible lipid auto-oxidation. This stability is largely attributed to the synergistic antioxidant network formed by the plant phenolics (rosmarinic acid, quercetin, mahanimbine) alongside added  $\alpha$ -tocopheryl acetate, which interrupts free-radical chain reactions during storage.

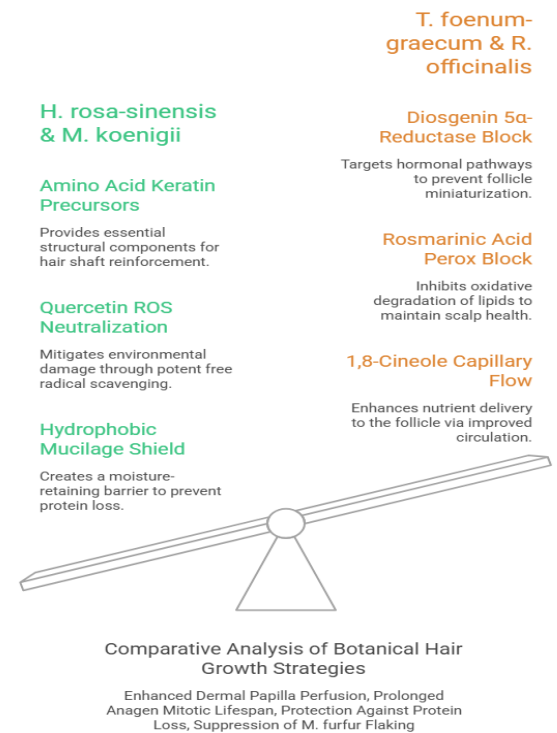


**Figure 7. A Mechanistic synergy: phytochemistry to clinical outcomes**

**6.2 Pharmacological Mechanisms of Action**

The therapeutic potential of this polyherbal preparation stems from complementary biological pathways:

1. **Suppression of 5 $\alpha$ -Dihydrotestosterone (DHT) Signaling:** Androgenetic alopecia is driven by the 5 $\alpha$ -reductase-mediated conversion of testosterone into DHT, which binds to androgen receptors in genetically susceptible dermal papillae, triggering follicular miniaturization. Steroidal saponins from fenugreek (diosgenin) and diterpenes from rosemary (carnosic acid) can downregulate 5 $\alpha$ -reductase activity, reducing local DHT synthesis without the systemic endocrine side effects associated with finasteride [63, 64].
2. **Induction of Anagen Signaling Cascades:** *Hibiscus rosa-sinensis* extracts have been shown to upregulate vascular endothelial growth factor (VEGF) and basic fibroblast growth factor (bFGF) in folliculocytes, activating  $\beta$ -catenin and sonic hedgehog (Shh) pathways to maintain follicular matrix proliferation and prolong the anagen growth stage [65, 66].
3. **Protection Against Cuticular Protein Loss:** Due to its linear configuration and high lauric acid content, the *Cocos nucifera* base diffuses past the hydrophobic epicuticle into the keratin-rich cortex, reducing protein dissolution, hygral fatigue, and environmental damage [67].
4. **Antifungal and Anti-Inflammatory Effects:** Carbazole alkaloids from *Murraya koenigii* and cineole from *Rosmarinus officinalis* inhibit the proliferation of *Malassezia furfur*, reducing dandruff, follicular inflammation, and microvascular congestion [68, 69].

## 7. Quality Assurance, Packaging, and Scalability

### 7.1 Good Manufacturing Practices (GMP) and Industrial Scale-Up

To ensure reproducible quality across commercial production, manufacturing must follow clear quality assurance benchmarks:

- **Botanical Authentication and Fingerprinting:** High-Performance Thin-Layer Chromatography (HPTLC) and Gas Chromatography-Mass Spectrometry (GC-MS) should be used to standardize reference markers (e.g., carnosic acid, diosgenin, mahanimbine).
- **Contaminant Screening:** Testing raw materials for toxic heavy metals (lead, cadmium, arsenic, mercury via atomic absorption spectroscopy), pesticide residues, aflatoxins, and microbial pathogens in compliance with pharmacopoeial standards.

- **Continuous Infusion Processing:** Industrial processing can employ closed-circuit jacketed stainless-steel (SS 316) reaction vessels equipped with low-shear anchor impellers and counter-current nitrogen flushing to prevent aerobic oxidation during thermal digestion.

### 7.2 Container Closure System and Stability Design

Because polyunsaturated phytochemicals and monoterpenes are vulnerable to photo-oxidation, the packaging system plays a critical protective role:

- **Primary Packaging:** Amber borosilicate (USP Type I/III) glass bottles or high-density polyethylene (HDPE) containers with internal fluorinated barriers that block ultraviolet radiation (290–400 nm).
- **Dispensing Optimization:** Precision calibrated dropper assemblies or metered pump dispensers limit atmospheric headspace exposure and prevent product degradation over repeated consumer use.

## 8. Conclusion

This study demonstrates the systematic formulation, physical stabilization, and physicochemical characterization of a polyherbal hair oil designed to promote hair health and scalp maintenance. Incorporating *Hibiscus rosa-sinensis*, *Trigonella foenum-graecum*, *Murraya koenigii*, and *Rosmarinus officinalis* within a virgin *Cocos nucifera* lipid base stabilized with  $\alpha$ -tocopheryl acetate yielded a preparation with good stability, skin-compatible pH ( $4.65 \pm 0.12$ ), balanced dynamic viscosity (32.41 cP), and an optimal resistance to oxidative degradation. Accelerated stress testing confirmed the physical integrity and phase stability of the formulation under varied storage conditions. Future research should prioritize randomized, double-blind clinical trials to confirm long-term efficacy and evaluate quantitative changes in anagen-to-telogen ratios and hair density in target patient populations.

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