



“Herbal Hair Serum: A Comprehensive Review of Formulation Strategies, Bioactive Ingredients, and Evaluation Approaches”

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ABSTRACT :

Hair is widely regarded as one of the defining features of personal appearance, and disturbances such as hair loss, dandruff, premature greying, and scalp infections continue to drive consumer demand for effective topical preparations. Hair serums — concentrated, leave-in cosmetic liquids formulated to coat and protect the hair shaft — have attracted substantial research interest over the past decade because of their ability to deliver active ingredients directly to the follicular environment. Among the available serum types, herbal formulations have gained particular favour owing to their perception as safer, more sustainable alternatives to silicone-based and synthetic products.

This review draws on research published between 2015 and 2026 to examine the pharmacognostic basis of commonly used botanical ingredients, the physicochemical principles that govern serum design, the battery of in vitro and in vivo tests used to validate finished products, and the emerging evidence for efficacy. Key ingredients covered include Aloe barbadensis gel, Zingiber officinale rhizome, Nigella sativa seed oil, Linum usitatissimum (flaxseed) extract, Trigonella foenum-graecum (fenugreek) seeds, Cocos nucifera (coconut) oil, Prunus dulcis (almond) oil, tocopherol (vitamin E), Rosa damascena (rose) water, Citrus sinensis peel extract, Piper betle leaf extract, and Ixora coccinea leaf extract. Evaluation parameters including pH, viscosity, spreadability, homogeneity, skin irritation, antifungal activity, and stability are discussed in depth. The review concludes that well-designed herbal hair serums can meet both safety and performance benchmarks and highlights directions for future clinical investigation.

Keywords: *herbal hair serum, hair loss, alopecia, natural cosmetics, formulation, evaluation, botanical extracts, scalp health*

1. Introduction

Hair represents far more than a biological appendage; in virtually every human culture it carries significant social, aesthetic, and psychological meaning. Structurally, the hair shaft is composed of three concentric layers — the outer cuticle, the load-bearing cortex, and the innermost medulla — all built from α -helical keratin proteins cross-linked by disulfide bonds. Beneath the surface, the hair follicle — an invaginated epidermal structure embedded in the dermis — passes cyclically through the anagen (active growth), catagen (regression), telogen (resting), and exogen (shedding) phases, each governed by a precise cascade of molecular signals [1, 2].

Disorders affecting this system are widespread. Androgenetic alopecia, the most prevalent form of hair loss, affects roughly 50% of men by the age of 50 and a comparable proportion of women by 70 years of age [3]. Conditions such as seborrhoeic dermatitis, tinea capitis, alopecia areata, telogen effluvium, and trichorrhexis nodosa further burden scalp health and hair quality. The underlying drivers are diverse — genetic predisposition, dihydrotestosterone (DHT)-mediated follicular miniaturisation, oxidative stress, nutritional deficiencies, microbial colonisation, and environmental insults — and rarely operate in isolation [4, 5].

Conventional pharmacological approaches rely principally on topical minoxidil and oral finasteride, both of which carry well-documented limitations including side effects, the requirement for sustained use, and modest efficacy in advanced disease. This therapeutic gap has catalysed interest in botanical alternatives, an interest reinforced by a broader shift in consumer preferences toward products perceived as natural, eco-friendly, and free from synthetic surfactants, parabens, and silicones [6].

Hair serums occupy a distinctive niche within this landscape. Unlike rinse-off shampoos or conditioning treatments, serums are leave-in formulations of relatively low viscosity that deposit a thin, active-ingredient-rich film on the hair shaft and scalp. This mode of application prolongs contact time between

botanical actives and their biological targets, making serums an inherently more efficient delivery vehicle than wash-off products [7]. The present review systematically examines the published literature from the past decade to provide an updated, integrated account of herbal hair serum science, covering ingredients, formulation design, evaluation methodology, and safety considerations.

2. Hair Biology: A Framework for Understanding Serum Action

2.1 Structure of the Hair Shaft

The cuticle consists of 6–11 overlapping, scale-like cells that project from root to tip, forming a protective envelope for the cortex. Its surface carries a layer of 18-methyleicosanoic acid (18-MEA) that confers hydrophobicity and governs frictional properties; chemical and thermal damage preferentially strip this lipid layer, yielding a surface that is porous, rougher, and more susceptible to protein loss [8]. The cortex, comprising some 80% of hair mass, houses the macrofibrils and melanin granules responsible for mechanical strength and colour respectively. Vitamin E and fatty-acid-rich plant oils are believed to partially restore the lipid envelope by forming a quasi-protective layer over damaged cuticle scales, which is one reason they feature prominently in herbal serum formulations [9].

2.2 The Hair Follicle and Growth Cycle

The dermal papilla, located at the base of each follicle, serves as the command centre for the hair cycle. It houses androgen receptors that bind DHT — generated from testosterone by 5 α -reductase — and translate hormonal signals into follicular miniaturisation in susceptible individuals. Several botanical compounds, including the saponins in fenugreek seeds, are proposed to interfere with DHT binding, although rigorous clinical confirmation remains limited [10].

Blood supply to the papilla is critical: without adequate microcirculation, nutrient and oxygen delivery falls and hair growth slows. Ginger-derived gingerols and shogaols are vasodilatory stimulants that have been incorporated into serums with the stated objective of improving local blood flow [11]. Similarly, tocopherol (vitamin E) has been reported to enhance peripheral blood circulation by dilating capillary beds in the superficial dermis, thereby accelerating nutrient delivery to the follicular matrix [12].

2.3 The Scalp Microenvironment

Sebum produced by sebaceous glands maintains the scalp at a slightly acidic pH between 4.5 and 5.5. This acidity is bacteriostatic and keeps the hair cuticle scales tightly adherent. Alkaline disruption — from harsh surfactants or high-pH products — opens the cuticle, increases porosity, and predisposes hair to breakage. A central design criterion for any hair serum is therefore pH compatibility with the scalp: the literature consistently recommends a target range of 4.5–6.5 [13]. All herbal serum formulations reviewed in this article reported final pH values within this range, which partly explains their favourable tolerability profiles.

3. Botanical Ingredients: Pharmacognostic Profiles and Hair-Related Bioactivities

3.1 *Aloe barbadensis* Miller (*Aloe Vera*)

Aloe vera gel, extracted from the parenchymal tissue of mature leaves, is arguably the most widely incorporated herbal ingredient in cosmetic serums worldwide. Its hair-relevant bioactive profile includes: polysaccharides — principally acemannan — that provide intense, film-forming hydration to the hair shaft; vitamins A, C, E, and B12 that supply antioxidant protection to follicular keratinocytes; minerals zinc, copper, and selenium that are cofactors for enzymes governing hair tissue repair; and proteolytic enzymes such as alkaline phosphatase that remove keratinous debris from follicular ostia, potentially unclogging follicles and normalising the growth environment [14, 15].

Aloe vera gel also carries a naturally acidic pH (4.5–5.5), which aligns almost perfectly with the scalp's own pH, making it an ideal aqueous vehicle for a hair serum. Multiple in vivo studies have demonstrated its ability to reduce scalp inflammation and control dandruff associated with *Malassezia* spp., consistent with its anti-inflammatory and antifungal properties [16].

3.2 *Zingiber officinale* Roscoe (*Ginger*)

Ginger rhizome contains a constellation of bioactive phenolic compounds including gingerols (particularly 6-gingerol), shogaols formed during drying or heating, zingerone, and the sesquiterpene zingiberene. This phytochemical complexity translates into multiple hair-relevant activities. Gingerols are potent antioxidants and anti-inflammatory agents that protect scalp keratinocytes from reactive oxygen species generated by UV radiation and environmental pollutants. Zingiberene exhibits inhibitory activity against *Malassezia restricta* and *Globosa*, the yeasts principally implicated in dandruff and seborrheic dermatitis [17].

Importantly, shogaols enhance local blood circulation through vasodilatory mechanisms, a property exploited in serum formulations aimed at stimulating follicular activity. An in vivo rabbit model study confirmed that topical ginger preparations increased hair shaft diameter and reduced telogen-phase follicle proportions compared to vehicle controls [11].

3.3 *Nigella sativa* L. (Black Seed)

Black seed oil and its aqueous extracts contain the isoquinoline alkaloid thymoquinone as the dominant bioactive, along with thymohydroquinone, dithymoquinone, thymol, carvacrol, and nigellimine. Collectively, these compounds impart potent antioxidant, antimicrobial, anti-inflammatory, and DHT-blocking properties [18]. The proposed mechanism of DHT inhibition involves the ability of the saponin fraction to interact physiologically with steroid biosynthesis pathways, reducing the concentration of bioavailable DHT at the follicular level. Multiple clinical case series have reported reduced hair shedding and improved scalp condition following regular application of *Nigella sativa*-containing topical preparations [19].

3.4 *Linum usitatissimum* L. (Flaxseed)

Flaxseed is an exceptionally rich source of α -linolenic acid (ALA), an omega-3 fatty acid that constitutes up to 57% of total seed oil. ALA is an essential precursor to anti-inflammatory eicosanoids; its topical application is believed to reduce scalp inflammation and suppress prostaglandin-mediated follicular regression [20]. Flaxseed also supplies lignans with phytoestrogenic and antioxidant activity, as well as a mucilaginous polysaccharide fraction that forms a smooth, film-forming gel when hydrated. This gel is an outstanding emollient and provides a physical coating over the hair shaft that reduces hygral fatigue — the repeated swelling and contracting that weakens the cortex during wetting and drying cycles [21].

3.5 *Trigonella foenum-graecum* L. (Fenugreek)

Fenugreek seeds are nutritionally dense, supplying B-vitamins (especially biotin and niacin), antioxidants, and trace elements that directly support hair matrix cell metabolism. The saponin fraction — principally diosgenin and yamogenin derivatives — accounts for fenugreek's proposed DHT-blocking activity: steroid saponins are thought to compete with DHT for follicular androgen receptors, reducing the miniaturisation signal [22]. A controlled clinical trial reported that subjects using a fenugreek seed extract-based hair tonic exhibited significantly greater new hair growth and a higher proportion of anagen follicles over a 16-week period compared to placebo [23].

3.6 *Cocos nucifera* L. (Coconut Oil)

Coconut oil is distinguished from most other plant oils by its extraordinarily high content of medium-chain saturated fatty acids, with lauric acid (C12:0) constituting 45–53% of total fatty acids. This molecular profile confers exceptional hair shaft penetrability: lauric acid has a high affinity for hair proteins and low molecular weight, enabling it to penetrate deep into the cortex rather than merely coating the cuticle surface. This trans-cortical penetration reduces swelling during water uptake, diminishes protein loss on combing, and provides mechanical protection against fatigue-induced breakage [24]. Coconut oil also moisturises and conditions the scalp, reducing the frequency of *Malassezia*-associated dandruff flares.

3.7 *Prunus dulcis* (Mill.) D.A. Webb (Almond Oil)

Sweet almond oil is characterised by a high oleic acid content (62–86%) that confers deep penetration and intense emollient activity, together with linoleic acid (omega-6), phytosterols including sitosterol, and naturally occurring α -tocopherol. The sitosterol fraction possesses anti-inflammatory properties relevant to managing scalp dermatitis, while the linoleic acid component helps maintain the scalp barrier and prevents transepidermal water loss [25]. Almond oil also contains biotin, which is known to be essential for fatty acid synthesis within the hair matrix, and zinc and magnesium, both of which are critical cofactors for hair follicle cell division. It is valued in serum formulations as the primary emollient phase, sealing moisture from aloe vera and rose water within the hair shaft [26].

3.8 *Tocopherol* (Vitamin E)

Vitamin E — the α -tocopherol vitamer being the most biologically active — plays a dual role in herbal hair serums: it acts as a physiological antioxidant within the lipid film coating the hair shaft, neutralising reactive oxygen species that would otherwise degrade keratin and melanin; and it functions as a pharmaceutical preservative, preventing the oxidative rancidity of the polyunsaturated fatty acids present in herbal oils, thereby extending shelf life [27]. Applied topically, vitamin E has been demonstrated to enhance peripheral capillary blood flow in the scalp, a property attributed to its capacity to dilate arteriolar smooth muscle. A randomised controlled trial found that tocotrienol supplementation increased hair count by 34.5% over 8 months compared to a 0.1% increase in the placebo group, representing strong clinical evidence for vitamin E's hair-stimulating potential [28].

3.9 *Rosa damascena* Mill. (Rose Water)

Rose water — produced by steam distillation of fresh Damask rose petals — functions as the primary aqueous vehicle in many herbal serum formulations. Its pH typically falls between 5.0 and 6.0, perfectly matching the scalp's natural acidity and obviating the need for additional pH-adjusting agents. Rose water contains phenolic compounds including gallic acid and quercetin, both potent antioxidants; trace volatile oils including geraniol, citronellol, and linalool that collectively contribute antimicrobial properties; and tannins that act as mild astringents, regulating sebum production on oily scalps [29]. Its characteristic fragrance eliminates the need for synthetic fragrances, a further advantage for sensitive scalps.

3.10 *Citrus sinensis* L. (Orange Peel)

Orange peel extract is rich in vitamin C (ascorbic acid), carotene, flavonoids (particularly hesperidin and narirutin), and a complex mixture of antimicrobial essential oils dominated by limonene and linalool. Vitamin C is an essential cofactor for collagen synthesis in the dermal papilla, and its antioxidant activity protects follicular melanocytes from oxidative damage — a mechanism linked to the prevention of premature greying [30]. The

flavonoid fraction promotes local scalp microcirculation, nourishes follicular cells, and provides clinically meaningful antidandruff protection through its anti-Malassezia antimicrobial activity.

3.11 *Piper betle* L. (Betel Leaf)

Betel leaf extract contains hydroxychavicol, eugenol, chavicol, and caryophyllene as its principal bioactive phenols. Hydroxychavicol is among the most potent antimicrobial and antifungal phenylpropanoids found in any botanical source, with demonstrated inhibitory activity against *Candida albicans*, *Malassezia* spp., and a broad spectrum of bacteria implicated in scalp infections [31]. Eugenol contributes additional anti-inflammatory and local analgesic properties that soothe an irritated scalp. A serum formulated with *Piper betle* extract was found to produce significantly larger inhibition zones against *Candida albicans* in well-diffusion assays compared to a vehicle control, confirming its antifungal utility [32].

3.12 *Ixora coccinea* L. (Jungle Geranium)

Ixora coccinea flowers, leaves, and roots contain anthocyanins, flavonoids, tannins, saponins, triterpenoids including oleanolic acid, and aromatic sterols. The anthocyanin fraction provides potent antioxidant coverage, scavenging the free radicals generated by UV exposure and air pollution that otherwise damage the hair cuticle. Tannins supply astringent activity, improving scalp firmness and tightening follicular ostia, which may reduce shedding. Saponins act as natural mild surfactants, facilitating even serum distribution across the scalp surface. *Ixora coccinea*'s anti-inflammatory activity is supported by *ex vivo* data showing marked inhibition of pro-inflammatory cytokines in stimulated keratinocyte cultures [33].

4. Formulation Design Principles

4.1 Classification of Hair Serums

Hair serums are broadly classified by their base vehicle: oil-based serums (e.g., argan, coconut, jojoba, or avocado oil bases) provide intensive moisture and penetrate the cortex; water-based serums use aqueous extracts as the continuous phase and deliver water-soluble actives; silicone-based serums coat the cuticle to reduce friction and add shine but do not penetrate; and emulsion-based serums — the most common category in herbal research — combine aqueous and lipid phases stabilised by an emulsifier to deliver both hydrophilic and lipophilic actives simultaneously [34].

Herbal serums typically employ an emulsion architecture with aloe vera gel or rose water providing the aqueous phase and a blend of plant oils providing the lipid phase. Tween 80 (polysorbate 80) is the most commonly reported emulsifier in the academic literature because it is non-ionic, compatible with a wide range of herbal extracts, and Generally Recognised as Safe (GRAS) for cosmetic use [35].

4.2 Excipient Selection

Beyond the active botanical ingredients, serum formulation involves careful excipient selection to achieve the desired product characteristics. Sodium benzoate (typically 0.1–0.5% w/v) serves as a preservative with antifungal properties that complement the inherent antimicrobial activity of the herbal ingredients. Distilled water or rose water acts as the vehicle, contributing to spreadability and solvating water-soluble actives. Vitamin E, beyond its pharmacological role, serves a formulation-stabilising function by preventing lipid peroxidation and extending shelf life — a classic example of an ingredient that is both active and excipient [36].

4.3 Preparation Methodology

The most widely employed preparation sequence, validated across the reviewed studies, proceeds as follows: (1) herbal raw materials are authenticated and subjected to appropriate extraction (decoction for water-soluble materials, cold pressing or solvent extraction for oils); (2) the aqueous phase is prepared by dissolving water-soluble extracts in aloe vera gel or rose water; (3) the lipid phase is prepared by combining plant oils with vitamin E at low heat; (4) the emulsifier (Tween 80) is incorporated into the lipid phase; (5) the aqueous phase is gradually added to the lipid phase under continuous mechanical stirring with gentle heat; (6) the preparation is cooled, preservative added, pH adjusted if needed, volume made up to the target volume with distilled water, and the finished serum transferred to an appropriate container [37, 38].

5. Representative Formulation Profiles from Recent Literature

Study / Year	Key Actives	Base Vehicle	Notable Feature
Yenurkar & Ingle, 2024 [1]	Aloe vera, Vit E, Sandalwood oil, Coconut oil	Aloe vera gel	3 batches; pH 5.5–5.7; all batches easily spreadable
Anusha R. et al., 2023 [2]	Ginger, Orange peel, Flaxseed, Black seed, Fenugreek, Coconut oil, Almond oil, Vit E	Aqueous decoction	4 formulations; rabbit hair growth model
Shende D. & Indurkar P., 2026 [3]	Aloe vera, Vit E, Rose water, Almond oil, Ginger	Rose water	pH 5; milky off-white; stable solution
Nandhakumar J. et al., 2026 [4]	Piper betle, <i>Ixora coccinea</i> , Aloe vera gel, Vit E, Lavender oil, Rose water, Tween 80	Rose water / Aloe vera	Antifungal activity vs <i>Candida albicans</i> confirmed
Singh V. et al., 2024 [5]	Ginger, Orange peel, Flaxseed, Black seed,	Distilled water	Comprehensive review formulation;

Study / Year	Key Actives	Base Vehicle	Notable Feature
	Fenugreek, Coconut oil, Almond oil, Vit E		sterility tested
Patel T. et al., 2025 [6]	Aloe vera, Ginger, Vit E, Flax, Rosemary, Neem, Almond oil	Aqueous	Polyherbal; anti-grey + anti-loss focus
Bhalerao P. et al., 2024 [7]	Aloe vera, Vit E, Rose water, Coconut oil	Rose water / Distilled water	3 batches; pH 6.7; viscosity 1110 cP
Saini L. et al., 2023 [8]	Aloe vera, Rose petals, Almond oil, Black pepper, Vit E	Aqueous	Spread $S = M \times L / T$ formula; stability at 4°C and 30°C
Choughule A. et al., 2025 [9]	Flaxseed extract, Aloe vera, Almond oil, Vit E, Rose water, Liquid paraffin	Rose water	5 formulations (F1–F5); F5 optimal; pH 4.80

6. Evaluation of Herbal Hair Serums

6.1 Physicochemical Parameters

6.1.1 Physical Appearance

Visual assessment of colour, odour, texture, and consistency is the first evaluation step and provides rapid information about formulation homogeneity. Across the reviewed studies, herbal serums most commonly presented as pale yellow to milky off-white liquids with a mild oily texture and a characteristic herbal or floral scent. The presence of any visible particulates, phase separation, or unusual discolouration at baseline or during storage serves as a primary stability flag [39].

6.1.2 pH Measurement

pH is measured using a calibrated digital pH meter immersed in the serum for 3–5 minutes until a stable reading is obtained. Buffer calibration at pH 4.0 and 7.0 before each session is standard practice. The universally accepted target range for hair and scalp products is pH 4.5–6.5, reflecting the natural scalp pH; formulations outside this range risk cuticle swelling, scalp irritation, or follicular disruption [40]. Across the reviewed literature, reported pH values ranged from 4.8 to 6.7, all within acceptable limits.

6.1.3 Homogeneity

The homogeneity test detects the presence of undissolved particles, flocculates, or aggregates within the serum matrix. A thin film of serum is spread between a glass slide and a cover slip, and examined visually or under low-power magnification. A homogeneous preparation is expected to show uniform distribution of all components with no coarse particles. Studies reporting good to excellent homogeneity across all tested batches suggest that the magnetic stirring and slow-addition emulsification procedures employed adequately disperse the herbal extracts [41].

6.1.4 Viscosity

Viscosity determines the ease of serum application, its ability to spread evenly without dripping, and its sensory acceptability. Two methods are reported in the literature: Brookfield rotational viscometry (spindle no. 6 at 10, 20, 50, and 100 rpm), which provides absolute viscosity values in centipoise (cP); and the glass plate flow test, in which the serum is allowed to flow under gravity and the time to travel a fixed distance recorded. Herbal serums typically exhibit pseudoplastic (shear-thinning) behaviour, becoming less viscous under the shear forces of application — a desirable property that facilitates spreading but prevents dripping from stationary hair [42]. Reported viscosities in the reviewed studies ranged from 225 to 1,124 cP, with moderate flow rates (3–6 seconds per 10 cm on a glass plate) considered optimal for scalp application.

6.1.5 Spreadability

Spreadability quantifies how readily the serum distributes across the application surface and is calculated using the parallel-plate method. One gram of serum is placed between two 20×20 cm glass plates; a 125 g weight is applied to the upper plate for one minute and the spread diameter recorded. The spreadability index $S = (M \times L) / T$, where M = applied mass, L = spread length, and T = time in seconds [43]. All herbal serum formulations reviewed reported satisfactory spreadability (classified as 'easily spreadable'), which is expected given the low-viscosity, oil-in-water emulsion architecture.

6.1.6 Transparency and Consistency

Transparency and overall consistency complement the homogeneity assessment. Most herbal serums described in the literature are translucent to mildly opaque, reflecting the presence of suspended plant extract particles. High oil concentrations tend to produce a mildly oily consistency — reported in several studies as 'mild oily' and 'thickened' — while higher rose water or distilled water proportions yield a more fluid, serum-like texture [44].

6.2 Safety Testing

6.2.1 Skin Irritation (Draize Skin Test)

The Draize skin test is conducted by applying the serum to shaved rabbit skin divided into 4×4 cm zones at concentrations of 2.5%, 5%, and 10% w/v alongside untreated and placebo controls. Application sites are observed at 24 and 48 hours for erythema, oedema, and epidermal peeling. All herbal serum formulations reviewed in this article produced no erythema or oedema scores above zero at any concentration, confirming non-irritant status [45].

6.2.2 Draize Eye Sensitivity Test

One drop of serum is instilled into the conjunctival sac of rabbit eyes with the contralateral eye serving as control. Corneal opacity, iris inflammation, and conjunctival redness scores are assessed at 30, 60, 120, and 240 minutes and at 1, 2, 3, and 4 days post-instillation. Zero scores across all parameters

at all time points are the expected outcome for properly formulated herbal serums, consistent with findings reported in the reviewed studies [46].

6.2.3 Skin Sensitivity Test

Two to three drops of the finished serum are applied to a sensitive skin area (inner forearm or retroauricular region) and observed for 24–48 hours for redness, itching, burning, swelling, or blistering. The absence of any of these responses confirms that the product is appropriate for routine topical use. All reviewed formulations satisfied this criterion [47].

6.3 Efficacy Testing

6.3.1 Hair Growth Activity (In Vivo)

Hair growth studies are performed in rabbits or guinea pigs using a depilatory cream to remove hair from demarcated zones. Treatment and control serums are applied twice daily for 21 days; hair length is measured at days 7, 14, and 21 using digital calipers. Qualitative hair growth scoring records the time to first visible darkening of the treated skin (indicating early anagen) and the time to complete hair coverage. Quantitative outcomes include average hair length and, in some studies, hair density calculated from photographs [48]. Studies incorporating fenugreek and ginger extracts consistently reported earlier onset of hair growth and greater final hair length compared to vehicle controls.

6.3.2 Antifungal Activity

Serums designed to combat dandruff are evaluated against *Malassezia* spp., *Candida albicans*, and other scalp-borne fungi using the agar well diffusion method. Petri dishes inoculated with 72-hour fungal cultures are loaded with serial dilutions of the test serum; inhibition zone diameters are measured after incubation at 37°C for 72 hours. Serum formulations containing Piper betle and *Ixora coccinea* extracts produced inhibition zones of 18–22 mm against *Candida albicans*, comparable to the positive control fluconazole disc, confirming clinically meaningful antifungal activity [32].

6.4 Stability Testing

Accelerated stability testing subjects the serum to freeze-thaw cycling (typically three cycles between 4°C and 28°C) and elevated temperature storage (30°C/65% RH and 40°C/75% RH for three months), with evaluation of pH, viscosity, colour, and phase separation at predetermined intervals [49]. The incorporation of vitamin E as an antioxidant preservative, together with sodium benzoate, has been shown to maintain product stability throughout a three-month accelerated protocol without significant changes in pH ($< \pm 0.3$ units) or viscosity ($< \pm 10\%$ of initial values).

6.4.1 Sterility Testing

For serums intended for scalp application where the epidermal barrier may be compromised, sterility testing on nutrient agar at 32°C for 24 hours confirms the absence of viable microbial contaminants at the point of manufacture. The inherent antimicrobial activity of ingredients such as Piper betle, *Nigella sativa*, and tea tree oil (when present) contributes to self-preserving capacity, reducing reliance on synthetic preservatives [50].

7. Comparative Analysis of Evaluation Data

Parameter	Acceptable Range	Typical Reported Value	Test Method	Significance
pH	4.5–6.5	4.8–6.7	Digital pH meter	Scalp compatibility
Viscosity	Moderate flow	225–1124 cP	Brookfield / Glass plate	Application ease
Spreadability	Easily spreadable	S = 2.5–8.0 g·cm/s	Parallel plate method	Coverage efficiency
Homogeneity	No coarse particles	Good to Excellent	Visual / Microscopic	Active distribution
Skin irritation	Non-irritant	0 erythema score	Draize skin test	Consumer safety
Antifungal (Candida)	IZ > 10 mm	18–22 mm	Well diffusion / PDA	Dandruff efficacy

8. Safety Considerations and Regulatory Framework

In most jurisdictions, hair serums are regulated as cosmetics rather than drugs, which means they do not require pre-market approval but must comply with labelling regulations, restricted substance lists, and Good Manufacturing Practice (GMP) guidelines. However, where manufacturers make specific hair growth or anti-hair-loss claims, regulatory agencies may reclassify the product as a cosmeceutical or drug, triggering more stringent requirements [51].

From a safety standpoint, the non-irritant and non-sensitising profiles reported across the reviewed studies are reassuring but must be contextualised. Rabbit Draize models, while standard, do not fully predict human sensitisation rates, particularly for individuals with compromised scalp barriers or pre-existing dermatoses such as atopic dermatitis or psoriasis. Future safety dossiers should incorporate human repeat insult patch testing (HRIPT) and, where possible, photosafety evaluation given that several herbal ingredients (e.g., citrus peel extracts) contain furanocoumarins with phototoxic potential [52].

Formulators should also be mindful of botanical adulteration and batch-to-batch variability in raw material composition, both of which can undermine reproducibility of safety and efficacy outcomes. Standardisation of extracts to defined marker compounds — acemannan content in aloe vera gel, thymoquinone in black seed oil, gingerol concentration in ginger extract — is an essential quality assurance step that remains incompletely implemented in published herbal serum research [53].

9. Advantages and Limitations of Herbal Hair Serums

9.1 Advantages

- Broader bioactivity spectrum: botanical extracts offer simultaneous antioxidant, antimicrobial, anti-inflammatory, and hair-growth-stimulating activities in a single ingredient, reducing the number of synthetic actives required.
- Superior tolerability: the absence of parabens, sulphates, artificial fragrances, and silicones significantly lowers the incidence of contact dermatitis and scalp sensitivity reactions.
- pH compatibility: many herbal ingredients (aloe vera gel, rose water) are naturally acidic and require minimal adjustment to match scalp pH.
- Consumer acceptability: growing consumer preference for 'clean beauty' and sustainably sourced ingredients drives market demand for herbal formulations.
- Multifunctional utility: a single serum formulation can address hair growth, scalp health, frizz control, moisturisation, and UV protection simultaneously.

9.2 Limitations

- Standardisation challenges: the phytochemical composition of botanical raw materials varies with geography, season, harvest conditions, and storage, making batch-to-batch consistency difficult to guarantee.
- Limited clinical data: the majority of published efficacy studies rely on animal models or in vitro assays; large-scale, randomised, double-blind human trials are scarce.
- Shorter shelf life: the absence of strong synthetic preservatives means herbal serums may have a shorter functional shelf life than conventional products unless robust antioxidant systems (e.g., vitamin E, rosemary extract) are incorporated.
- Potential photosensitivity: citrus-derived furanocoumarins and certain essential oil components may sensitise the scalp to UV radiation.
- Risk of overuse: daily application of oil-heavy serums can lead to product build-up, weighing hair down and potentially occluding follicular ostia.

10. Future Directions

Several promising avenues remain underexplored in the herbal hair serum literature. Nanoencapsulation — particularly the use of phytosomes, solid lipid nanoparticles, and nanosomes — offers the potential to enhance follicular penetration of polar herbal actives that would otherwise remain on the hair surface. Preliminary studies with nanostructured lipid carriers loaded with fenugreek and saw palmetto extract have reported follicular delivery efficiencies two to three times greater than conventional topical application [54].

The microbiome dimension of scalp health is an emerging area. The scalp harbours a diverse resident microbial community whose composition correlates with scalp condition; disruption of this community — through either dysbiosis or aggressive antimicrobial treatments — may paradoxically worsen dandruff and promote inflammation. Future herbal serum research should consider how botanical ingredients modulate not only pathogenic species but also commensal populations, with the goal of supporting rather than disrupting the overall scalp microbiome [55].

Artificial intelligence-assisted formulation optimisation is beginning to permeate cosmetic science; predictive models trained on large datasets of ingredient combinations, HLB values, and rheological outcomes could accelerate the identification of optimal herbal serum compositions without the need for exhaustive empirical screening. This approach would be particularly valuable for multi-ingredient polyherbal formulations where interaction effects between actives are difficult to predict manually [56].

11. Conclusion

The body of research produced over the past decade demonstrates convincingly that herbal hair serums can be formulated to deliver a comprehensive package of hair benefits — growth stimulation, moisture retention, frizz control, antifungal protection, and scalp conditioning — within a single, consumer-friendly product. The physicochemical evaluation data reviewed here show consistent alignment with safety and performance benchmarks: pH values between 4.8 and 6.7, satisfactory spreadability, excellent homogeneity, and stable viscosity over accelerated storage conditions. Safety profiles across multiple animal and human sensitisation models are uniformly positive.

The botanical ingredients that appear most consistently and with the strongest evidence base are aloe vera gel, vitamin E (tocopherol), ginger rhizome extract, flaxseed mucilage, fenugreek seed extract, coconut oil, and almond oil. Newer additions to the formulation toolkit — particularly Piper betle and *Ixora coccinea* leaf extracts — show considerable promise as antifungal agents deserving of further clinical investigation.

The principal gaps that remain are a shortage of well-designed human clinical trials with appropriate controls and validated endpoints, inadequate standardisation of botanical raw materials, and limited mechanistic data relating in vitro bioactivities to observable in vivo outcomes. Addressing these

gaps through collaborative, multidisciplinary research — combining pharmacognosy, cosmetic science, dermatology, and clinical trial methodology — will be essential to fully realise the potential of herbal hair serums and to earn them the regulatory recognition they are increasingly approaching.

Acknowledgments:

I would like to acknowledge the Tamil Nadu chemists and druggist educational trust (TNCDE) and Pallavan pharmacy college for their extended support.

Disclosure of conflict of interest:

There is no conflict of interest.

Author contribution:

RAGHUL. P had principal responsibility for the conception, design of the study and drafting of manuscript. Santhosh Kumar.G was responsible for the revision of the manuscript for important intellectual content, S. Mohan Kumar, Dr. J. Karthi, Dr. S. Swarnalatha contributed towards reviewing of the literature. All authors agreed on the final version of manuscript.

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