www.ijarp.com ISSN 2456-9992 Page: 01-27

Research Article

International Journal Advanced Research Publications

Volume: 02
Issue: 10

FORMULATION, DEVELOPMENT, AND EVALUATION OF HERBAL HAIR SERUMS

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Article Received: 09 September 2026, Article Revised: 29 September 2026, Published on: 19 October 2026

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Doi: https://doi-doi.org/101555/ijrpa.5563

ABSTRACT

Herbal hair serums are leave-on cosmetic preparations intended to improve hair feel, manageability, shine, lubrication and resistance to everyday grooming friction through a suitable vehicle combined with selected botanical materials. Interest in plant-derived ingredients has encouraged the use of aloe vera, amla, bhringraj, hibiscus, neem, rosemary and fenugreek in hair-care products. However, a plant's traditional use or activity in a laboratory model does not establish that a finished serum improves hair growth or treats a scalp disorder. Product performance depends on botanical identity, extraction method, phytochemical variability, ingredient compatibility, vehicle composition, deposition on the hair shaft or scalp, preservation, packaging and storage. This narrative review discusses the scientific basis of herbal hair serums, hair structure and cosmetic damage, commonly used botanical ingredients, formulation components, development workflow, evaluation methods, stability and quality control, comparative formulation considerations, safety and Indian regulatory context. Physical and physicochemical tests such as appearance, homogeneity, pH where applicable, viscosity, rheology and spreadability are considered alongside botanical marker analysis, microbiological quality, preservative effectiveness, packaging compatibility and direct assessment of cosmetic performance. Evidence is appraised according to study type, distinguishing hair-fibre testing, in vitro and animal findings, small human studies,

traditional use and product-specific clinical evidence. Existing evidence supports rational design and quality testing, but direct comparative studies of standardized finished herbal serums remain limited. Future progress requires authenticated raw materials, reproducible extraction, transparent ingredient specifications, product-specific stability protocols and well-designed human-use studies that assess relevant outcomes without overstating medical claims. Herbal origin should not be treated as a guarantee of safety, stability or superiority. A scientifically developed serum should therefore be judged as a complete formulation whose quality, tolerability, claimed cosmetic performance and reproducibility are demonstrated for its intended use.

KEYWORDS: Herbal hair serum; herbal cosmetics; botanical extracts; hair-shaft conditioning; formulation development; cosmetic stability; quality evaluation.

1. INTRODUCTION

Hair contributes to appearance and personal identity, while cosmetic expectations vary with hair texture, styling practices, climate and cultural preferences. Hair-care products are therefore designed not only to cleanse but also to improve shine, softness, combability, static control and manageability. The visible hair shaft is biologically non-living, so many immediate cosmetic benefits are achieved by modifying its surface properties rather than by changing follicular biology. A formulation that coats the shaft and reduces friction can improve the feel and appearance of damaged hair even when it does not reverse the underlying structural damage [1,2].

The hair fibre consists mainly of keratin-rich structures arranged in cuticle and cortex, with a medulla present in some hair types. Grooming friction, ultraviolet exposure, repeated wetting and drying, heat styling, bleaching, dyeing and chemical straightening can disrupt cuticle scales and surface lipids, increase hydrophilicity and contribute to tangling, frizz and breakage. Conditioning ingredients can reduce friction and static, but cosmetic repair should be understood as improvement in surface behaviour or temporary reinforcement rather than biological regeneration of a dead shaft [1-3].

Conventional serums can contain silicones, oils, film-forming polymers, conditioning agents or combinations of these components. Their performance depends on molecular structure, deposition, viscosity, spreadability and sensory properties rather than whether ingredients are labelled natural or synthetic. Botanical extracts are attractive because they provide chemically diverse constituents and may support product positioning, but extract colour, odor, solids, pH

and solvent residues can complicate formulation. There is insufficient basis for a general claim that herbal products are safer or more effective than well-designed conventional formulations [1,2,25].

Herbal hair serums may be developed for the hair shaft, scalp surface or both, and these targets should not be conflated. A shaft-directed serum is typically evaluated for spreading, residue, shine, combing forces, friction and consumer-perceived feel. A scalp-directed product may require additional attention to irritation, exposure, microbial quality and compatibility with the intended application site. Claims about preventing alopecia or stimulating follicular growth require evidence that is specific to the final product and appropriate to the regulatory category; traditional use or evidence for an isolated extract is not sufficient [2,5,10].

The purpose of this narrative review is to summarize the formulation principles, botanical options, characterization methods, stability requirements, evidence gaps and regulatory considerations relevant to herbal hair serums. It emphasizes the relationship between ingredient quality and finished-product performance, and distinguishes cosmetic conditioning from medical treatment. The review also identifies practical research priorities for reproducible and defensible product development [1,2,6].

2. MATERIAL AND METHODS

A focused narrative literature search was undertaken on 14 October 2026 using web-accessible PubMed-indexed records, targeted scholarly search results and official sources from the World Health Organization (WHO), International Organization for Standardization (ISO) and Central Drugs Standard Control Organization (CDSCO). Search concepts included herbal hair serum, hair cosmetics, hair-shaft conditioning, Phyllanthus emblica, Eclipta prostrata, rosemary oil and hair growth, botanical extract standardization, cosmetic stability, preservation efficacy and Indian cosmetic regulation. Foundational hair-cosmetic sources were retained alongside relevant recent papers, while direct human evidence was distinguished from animal, in vitro and formulation-development studies [1-3,6-10].

The literature was synthesized thematically rather than through a systematic-review protocol. No claim is made that Scopus, Web of Science or every full-text publisher database was comprehensively searched, and no formal duplicate-removal process, registered protocol or quantitative risk-of-bias assessment was completed. Sources were prioritized for relevance, traceable bibliographic details and authority; official standards are cited as frameworks rather than as evidence that any specific serum complies with them. Because evidence specific to

finished herbal hair serums is limited and heterogeneous, this review avoids pooling results from products with different extracts, bases, test methods or intended claims [6,7,16-20].

3. OVERVIEW OF HERBAL HAIR SERUMS

3.1. Concept and formulation types

A hair serum is best understood as a leave-on preparation whose rheology, spreading behaviour and deposition are adjusted for the hair or scalp application. The term does not define one universal dosage form: market and research products may be water-based, hydroalcoholic, anhydrous oil-based, silicone-containing, gel-like, emulsion-based or solubilized systems. A clear liquid, a low-viscosity gel and an oil serum can differ substantially in ingredient compatibility, sensory feel, microbial risk and evaluation needs; the name ‘serum’ alone does not determine a product specification [1,2,25].

3.2. Difference from oils, conditioners, creams and lotions

Hair oils generally rely on lipid-phase spreading and lubrication, whereas rinse-off conditioners are designed to deposit conditioning materials during a relatively short contact period and then be removed. Creams and lotions commonly contain emulsified oil and water phases and may remain on skin or hair depending on the product. Serums are often positioned as lightweight leave-on preparations, but this is a product-design convention rather than a strict scientific category. A comparison should therefore focus on actual composition, application instructions, residue, washability and performance instead of the product name [1,2,25,26].

3.3. Expected cosmetic functions and limits

Reasonable cosmetic objectives include improved combability, lubrication, gloss, softness, reduced static, easier detangling and a temporary film that decreases fibre-to-fibre friction. Results depend on the hair's original condition, application amount, humidity, washing frequency and how the formulation interacts with surface lipids and cuticle damage. Cosmetic products may reduce additional friction-related damage, yet they cannot permanently restore every damaged internal structure or create new follicles in areas affected by scarring alopecia [1-3].

Scalp-directed preparations raise different questions. The scalp is living skin and may respond to fragrance materials, essential oils, preservatives and botanical constituents with irritation or allergic contact dermatitis. Claims involving dandruff, fungal infection, inflammation or hair-loss disorders move beyond simple shaft conditioning and need

appropriate evidence and regulatory review. A formula intended to remain on the scalp should be assessed for that use rather than relying solely on a hair-tress test [14,20-22].

4. HAIR STRUCTURE, HAIR DAMAGE, AND RELEVANCE TO SERUM FORMULATION

4.1. Hair-fibre structure

The cuticle is the outer, overlapping scale layer that influences surface smoothness, friction and light reflection. Beneath it, the cortex provides most of the fibre's mass and contains keratin structures and pigment; a medulla may occur in thicker fibres but is not universally present. The lipid-rich surface, including 18-methyleicosanoic acid (18-MEA), helps maintain hydrophobicity. Repeated chemical treatments and weathering can remove or alter surface lipids and raise friction, making conditioning and lubricating films relevant formulation targets [1-3].

4.2. Scalp and hair-follicle relevance

The follicle is a living mini-organ that cycles through anagen (growth), catagen (regression) and telogen (resting) phases under genetic, hormonal and local signalling influences. This biology differs from the passive cosmetic behaviour of the emergent shaft. A product that improves shaft smoothness does not necessarily influence follicular cycling, and an ingredient that changes a marker in cultured cells or an animal model does not prove that a scalp serum induces clinically meaningful hair growth in humans [5,8-10].

4.3. Damage and the potential role of serums

Heat, ultraviolet radiation, aggressive brushing, repeated shampooing, bleaching and permanent waving can contribute to cuticle wear and changes in fibre mechanics. When the cuticle surface becomes rougher or more hydrophilic, wetting and drying may increase swelling, tangling and friction. Oils, silicones, cationic materials and film-forming polymers can modify surface behaviour, but the magnitude and durability of benefit depend on the particular material and the condition of the hair. A meaningful development programme should specify whether it seeks improved wet combing, dry combing, frizz control, breakage reduction or sensory acceptance [1-4,27].

5. HERBAL INGREDIENTS USED IN HAIR SERUMS

Botanical selection should begin with a specific product rationale and an identified material rather than a generic plant name. The scientific identity, accepted botanical name, plant part, origin, harvest conditions, processing, extraction solvent and batch traceability should be

documented. Botanical raw materials can vary by geography, season, maturity and storage, while extracts produced with different solvents may have different chemical fingerprints and biological activity. For that reason, the presence of a familiar plant name on a label does not ensure equivalence between extracts or finished products [6,7,23].

5.1. Aloe vera

Aloe vera leaf gel is rich in polysaccharide-associated material and is often incorporated for a soothing or moisturising product concept. In formulation terms, a suitably processed gel or extract may affect humectancy, viscosity, film feel and sensory characteristics; these effects depend on the ingredient grade and the rest of the formula. Aloe should not be treated as a universal hair-growth active, and evidence for topical skin applications cannot be transferred automatically to a leave-on serum or follicular outcome [2,14].

Processing is important because leaf latex and contamination with anthraquinone-containing fractions may influence tolerability. Although reported allergic reactions are uncommon, case reports of allergic contact dermatitis demonstrate that 'natural' materials can be sensitizers for some individuals. A serum developer should specify the plant part and processing grade, assess supplier documentation, and consider irritation or sensitization potential at the intended use concentration [14,15].

5.2. Amla (Phyllanthus emblica)

Amla fruit contains polyphenolic constituents, including tannins and reported gallic- and ellagic-acid-related compounds. These compounds make amla relevant to antioxidant-oriented formulations and allow consideration of analytical markers or chromatographic fingerprints. Nevertheless, high total phenolic content is not a validated stand-alone predictor of hair conditioning, scalp tolerability or clinical hair-growth effects; analytical and functional measures should therefore be treated as complementary rather than interchangeable [7,8].

A study of P. emblica extract-loaded transfersomes examined phytochemical composition, vesicle characterization and hair-related activity in laboratory models, including responses in human keratinocytes. Its findings are promising for research on delivery systems but should not be described as clinical proof for a conventional herbal hair serum. The study also illustrates that extraction solvent can change phenolic content and cytotoxicity, highlighting the need to select an extract based on both activity and tolerability [8].

5.3. Bhringraj (Eclipta prostrata; historically Eclipta alba)

Bhringraj is used traditionally in hair-care preparations and contains reported coumestans, flavonoids and other phytoconstituents. A frequently cited study evaluated a methanolic

extract of *Eclipta alba* in mice and reported dose-dependent changes in hair-growth-associated endpoints. This constitutes preclinical evidence, not direct confirmation that a finished leave-on serum produces hair growth in humans. The plant's accepted taxonomic name, extraction process, residual-solvent control and constituent profile should be clear when it is used as a formulation input [9].

5.4. Rosemary (Salvia rosmarinus; historically Rosmarinus officinalis)

Rosemary essential oil contains volatile terpenes, while rosemary extracts can contain non-volatile phenolic constituents depending on preparation. A randomized comparative study evaluated rosemary oil against 2% minoxidil in androgenetic alopecia over six months, reporting increased hair count from baseline at six months in both groups and no significant between-group difference. The trial is relevant but should be interpreted cautiously because it evaluated an oil regimen, not every rosemary-containing serum, and a single study is not sufficient to establish broad equivalence or a product-class claim [10].

5.5. Hibiscus (Hibiscus rosa-sinensis)

Hibiscus is used in traditional hair-care practices and contains mucilage-associated polysaccharides, anthocyanins and other phenolic constituents. Depending on extraction, it may contribute to product colour, texture or film feel. Direct evidence that hibiscus in a standardized finished serum changes clinically relevant hair growth remains limited; therefore, it is more defensible to describe its role as a botanical formulation candidate than as a proven treatment for hair loss. Colour variation, pH-dependent pigment changes and extract compatibility should be considered during product development [6,7,25].

5.6. Neem (Azadirachta indica)

Neem contains diverse limonoids, terpenoids, flavonoids and other compounds whose profiles vary across leaves, bark, seeds and oils. Published phytochemical and pharmacological reviews describe a broad range of biological activities, but these cannot establish the performance of a hair serum. In a topical cosmetic, neem may present challenges related to characteristic odour, colour, extract variability and constituent-specific tolerability. Plant part and extraction method should be recorded, and microbial or preservative performance must not be inferred from in vitro antimicrobial findings for a crude extract [11,29].

5.7. Fenugreek (Trigonella foenum-graecum)

Fenugreek seeds contain galactomannan, proteins, saponins, trigonelline and other constituents. A polysaccharide-rich preparation could influence viscosity or film formation depending on its grade and solubility, but evidence for hair-growth claims is insufficient to

treat those effects as established. Botanical extracts and seed-derived proteins may also present allergenicity or tolerability considerations; the toxicology of oral consumption is not the same as that of a topical formula, yet it reinforces the need for exposure-specific safety review [12,13].

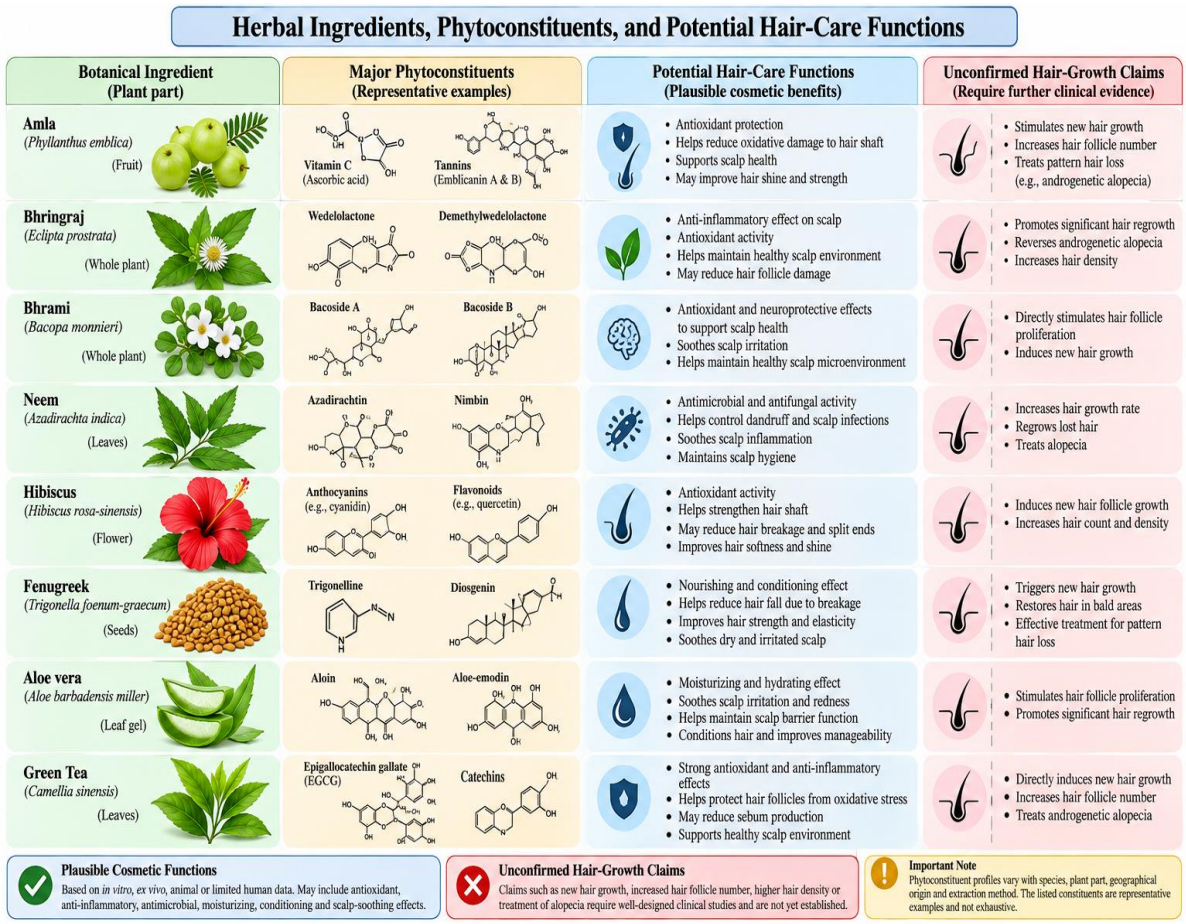


Figure 1. Herbal Ingredients, Phytoconstituents, and Potential Hair-Care Functions.

TABLE 1. SELECTED HERBAL INGREDIENTS AND THEIR POTENTIAL RELEVANCE IN HAIR SERUM FORMULATION.

Botanical name / part	Relevant constituents	Potential cosmetic / formulation role	Evidence level and limitations	Formulation / safety considerations
Aloe vera; processed leaf gel	Polysaccharides; organic acids; minor phenolics	Humectant feel, film contribution, soothing-positioning rationale	Traditional / cosmetic use; finished-serum efficacy not established	Specify processing and latex control; assess irritation and preservation

Botanical name / part	Relevant constituents	Potential cosmetic / formulation role	Evidence level and limitations	Formulation / safety considerations
Phyllanthus emblica; fruit	Tannins; gallic- and ellagic-acid-related polyphenols	Antioxidant-oriented formulation; potential analytical markers	Extract and delivery-system laboratory findings; no automatic transfer to serum efficacy	Solvent-dependent profile, colour, pH and marker consistency
Eclipta prostrata; aerial parts	Coumestans, flavonoids and other phenolics	Research candidate in scalp-directed formulations	Hair-growth-related endpoints reported in mice; human serum evidence limited	Authenticate taxonomic identity; standardize extract and residual solvent
Salvia rosmarinus; leaf / essential oil	Volatile terpenes; phenolic diterpenes in some extracts	Fragrance, antioxidant-oriented role; exploratory scalp active	One comparative human trial studied rosemary oil regimen, not all serums	Oxidation, fragrance sensitization, dose and chemotype control
Hibiscus rosa-sinensis; flower / leaf	Mucilage, anthocyanins, flavonoids	Texture / film feel and colour contribution depending on extract	Predominantly traditional and preclinical rationale; product-specific evidence limited	Pigment stability, extract variability and compatibility
Azadirachta indica; specified plant part	Limonoids, terpenoids, flavonoids	Exploratory botanical ingredient; sensory / formulation properties require testing	Phytochemistry is described; hair-serum effectiveness not established	Odour, colour, part-specific chemistry, tolerability and preservation
Trigonella foenum-graecum; seed	Galactomannan, saponins, flavonoids, trigonelline	Viscosity / film contribution where an appropriate extract grade is used	Hair-specific evidence weak; general plant pharmacology is not a finished-product claim	Protein/allergen assessment; viscosity drift and extract standardization

6. FORMULATION COMPONENTS AND THEIR FUNCTIONS

A serum is a complete formulation, so the choice of botanical material must be integrated with the vehicle, solubilization strategy, conditioning system, preservative and package. Ingredients that perform well separately may become incompatible when combined: a

phenolic-rich extract may shift pH or colour, an essential oil may separate without an appropriate solubilizer, and plant polysaccharides may change viscosity or feel. The formulation target should be expressed as quality attributes—appearance, clarity or acceptable dispersion, viscosity range, application feel, marker content where justified, microbial protection and stability—before trial batches are compared [16,25].

6.1. Vehicle and solvent systems

Water-based systems can feel light and are suitable for water-soluble extracts, but they require careful microbial risk management and may not readily dissolve lipophilic constituents. Hydroalcoholic vehicles can improve solubilization for selected materials and modify drying time, yet alcohol may affect skin tolerability, volatility and package compatibility. Oil-based systems can dissolve lipophilic ingredients and provide lubrication but may feel heavier and are vulnerable to oxidation if unsaturated oils or volatile components are present. Silicone-containing systems can provide slip and gloss, while emulsions, microemulsions or solubilized systems may incorporate components with different polarities at the cost of greater formulation complexity [1,2,25].

6.2. Humectants, emollients and conditioning agents

Humectants such as glycerol or propanediol can influence water retention and application feel, although excess levels may contribute to tackiness depending on the vehicle and ambient humidity. Emollients and oils reduce friction and improve sensory characteristics through surface lubrication. Cationic conditioning agents and selected polymers may reduce static and improve combability by modifying the surface charge and deposition characteristics of the fibre. Ingredient choice should be matched to the target: a fine-hair serum may need low residue, whereas a product for highly textured or chemically treated hair may prioritize lubrication and detangling [1-3,27].

6.3. Solubilizers, emulsifiers, gelling agents and film formers

Solubilizers and emulsifiers are selected according to the polarity and required loading of the botanical material, not simply to achieve a visually clear formula. A transparent formulation is not necessarily more stable than a slightly opalescent one, and clarity may be lost with temperature or dilution. Gelling agents and viscosity modifiers control flow, pourability and spread; their performance may be altered by salts, pH, extract solids, alcohol or electrolytes. Film-forming polymers may improve hold or reduce friction but can create stiffness, flaking or residue when over-deposited [25].

TABLE 2. FORMULATION COMPONENTS AND THEIR FUNCTIONS.

Component class	Primary function	Selection considerations	Frequent development risk
Herbal extract / oil	Provides botanical constituents and sensory or positioning rationale	Authenticated species and part; extraction solvent; marker profile; colour and odor	Batch variability; insolubility; oxidation; unsubstantiated biological claim
Vehicle / solvent	Dissolves or disperses ingredients; determines feel and drying	Polarity, evaporation, skin tolerability, compatibility, application target	Precipitation, phase separation, tack or irritation
Humectant	Adjusts water-related feel and product sensorial profile	Concentration, tackiness, ambient humidity, interactions	Sticky residue or altered rheology
Emollient / conditioning agent	Lubrication, shine, reduced friction and static	Deposition, washability, hair type, residue and compatibility	Greasy feel, buildup or reduced volume
Solubilizer / emulsifier	Incorporates otherwise incompatible phases	Required solubilization, surfactant system, clarity and irritancy	Haze, separation, excessive surfactant or sensory change
Gelling / film-forming agent	Controls flow, film and spreadability	Polymer chemistry, pH, electrolytes, extract solids	Stringiness, flaking, viscosity drift
Preservative system	Controls microbial growth during manufacture and use	Formula pH, water phase, package and microbial risk	Preservative failure or tolerability issue
Antioxidant / chelator	May reduce selected oxidation pathways or metal-catalysed changes	Mechanism, solubility, compatibility and evidence of benefit	No measurable protection; interaction with botanical markers
Fragrance / colour / pH adjuster	Consumer acceptability and controlled product properties	Need, allergen risk, pH target, label and claim requirements	Sensitization, colour drift, pH instability

7. FORMULATION DEVELOPMENT OF HERBAL HAIR SERUMS

7.1. Raw-material selection and authentication

Development should start by defining the intended user, application site, desired cosmetic benefit, intended frequency of use and principal product constraints. Botanical identity should be authenticated by a qualified source and supported by documentation such as voucher information where available, scientific name, plant part, origin, batch and supplier. These controls are particularly important when a plant material is sold as a powder or crude extract with variable composition [6,23,32].

7.2. Extraction and standardization

The extraction method should be selected based on the target constituent groups, intended solvent residues, compatibility with the formulation and process reproducibility. Aqueous extracts may be suitable for hydrophilic polysaccharides or polar constituents, while hydroalcoholic extraction can yield a different phenolic profile.. A single colorimetric value should not be presented as proof of efficacy or purity [6-9].

7.3. Preformulation and compatibility

Preformulation studies should determine solubility or dispersibility of each extract and identify likely incompatibilities with the vehicle. Useful preliminary observations include pH, colour, odour, sedimentation, turbidity, phase behaviour and viscosity over time and temperature. Potential interactions between botanical polyphenols, polymers, surfactants, preservatives and container materials should be explored. If an ingredient's solubility is low, options include changing the solvent system, lowering the loading, using a compatible solubilizer, selecting a standardized alternate extract or considering a delivery technology; each option must be validated in the finished product [16,25].

7.4. Trial batches and optimization

Trial formulations should vary a limited number of meaningful factors rather than changing many ingredients simultaneously without a design rationale. Examples include polymer level, extract loading, solvent ratio, solubilizer-to-oil ratio or humectant content. Where resources permit, factorial or response-surface design can identify interactions and reduce trial numbers; however, the chosen model must be supported by enough experiments and relevant responses. Sensible responses include viscosity at defined conditions, pH where relevant, spreadability, phase stability, marker recovery, residue or hair-tress performance. The preferred formulation should meet pre-established criteria instead of being selected from visual appeal alone [16,25].

7.5. Manufacturing controls and scale-up

The manufacturing procedure should specify mixing order, temperature, mixing intensity, addition rate, hydration time, hold times and in-process checks. Scale-up can change shear history, mixing efficiency, heat transfer, aeration and cooling rate, producing a different viscosity or dispersion even when nominal composition is unchanged. Batch records and ingredient specifications support reproducibility, while good manufacturing practice provides a framework for personnel, equipment, hygiene, documentation and quality responsibilities. No hypothetical batch can be described as optimized or validated without appropriate data [19,25].

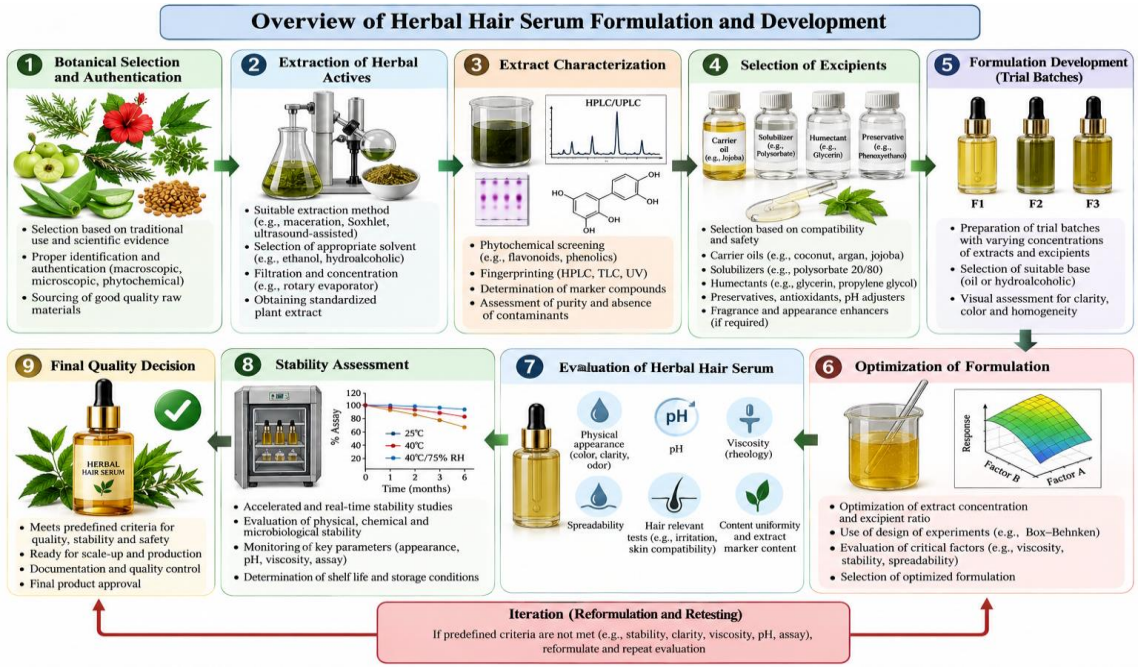


Figure 2. Overview of Herbal Hair Serum Formulation and Development.

8. EVALUATION AND CHARACTERIZATION OF HERBAL HAIR SERUMS

Evaluation should answer a defined product question. Not every assay is needed for every serum: a clear water-based scalp serum, an anhydrous oil serum and a silicone-rich shaft serum have different quality risks. Test methods should be described sufficiently for reproducibility, including sample conditioning, instrument, speed or shear conditions, temperature, replicate number and acceptance criterion. Where methods lack standardization, the limitation should be stated rather than implying that one laboratory procedure is universal [16-18,25].

8.1. Appearance, homogeneity and phase behaviour

Visual inspection can document colour, odour, clarity or intended opalescence, visible particles, sedimentation and phase separation. Homogeneity is relevant to dosing consistency and consumer acceptance, particularly when extracts are dispersed rather than dissolved. Visual testing is inexpensive but subjective; use defined lighting, containers, observation conditions and terminology, and support it with instrumental or chemical tests when the formulation warrants them [16,25].

8.2. pH, viscosity, rheology, spreadability and density

pH is relevant primarily to aqueous or partly aqueous products and should be measured with an appropriate calibrated method; it is not meaningful in the same way for an anhydrous oil. Viscosity depends on temperature, shear rate, instrument geometry and sample history, so reporting a single value without measurement conditions can mislead. Rheology may reveal

shear-thinning, thixotropy or flow behaviour relevant to dispensing and application. Spreadability tests can compare how easily a defined amount spreads under a defined force, but simple glass-slide tests may not represent application to real hair or scalp. Density or specific gravity is useful only where it supports a manufacturing, fill-volume or product-quality decision [16,25].

8.3. Botanical marker content and phytochemical characterization

Where a marker compound or fingerprint can be justified, validated chromatographic or spectroscopic methods can help assess identity, extract consistency and stability. Total phenolic or flavonoid assays may be useful as broad descriptive measures but are nonspecific and can be affected by other reducing substances, matrix colour or solvent composition. Extraction yield alone is also insufficient because a high yield can include inactive or undesirable material. Marker recovery should be evaluated after formulation, since a vehicle may affect extraction, detection or analyte stability [6-9].

8.4. Antioxidant assays and release or permeation studies

Antioxidant assays such as radical-scavenging tests may describe the chemical capacity of an extract under the specific test conditions, but they do not establish protection of hair, scalp or finished product during use. A claim of product protection should be supported by a formulation-relevant oxidation study, while a biological claim needs appropriately selected biological evidence. In vitro release or permeation studies may be relevant for a scalp-directed delivery research question, but they are not automatically required for an ordinary shaft-conditioning serum and do not alone establish clinical benefit [7-10,25].

8.5. Hair-tress and cosmetic-performance testing

Direct testing on standardized hair tresses can be more relevant to shaft-directed claims than an unrelated antioxidant assay. Depending on the claim, endpoints may include wet and dry combing force, friction, tensile properties, breakage during grooming, gloss, static, volume, residue and sensory assessment. Hair source, damage history, fibre type, humidity, wash protocol, amount applied and comparator should be specified. A small uncontrolled user survey may help refine sensory design but should not be treated as equivalent to a blinded controlled clinical study [1-3,27].

8.6. Microbial quality, preservative effectiveness and safety

Water-containing serums require a microbial risk assessment that considers water activity, raw-material burden, manufacturing hygiene, package design and expected consumer handling. Microbiological limits and preservative-effectiveness testing address different questions: the former assesses the product's microbial quality at a point in time, while a

challenge test evaluates how well the preservative system controls defined microorganisms under the test conditions. ISO documents provide useful frameworks, but the appropriate method and acceptance criteria depend on the product and current standards [17,18].

Skin or scalp compatibility should be assessed using ethically appropriate and scientifically justified methods matched to foreseeable exposure and ingredients. Ingredient safety dossiers, exposure assessment, literature review and validated non-animal methods, including appropriate reconstructed-human-epidermis approaches, may contribute to a safety rationale; any human-use testing should have suitable ethics, informed consent and adverse-event handling. Essential oils and fragrances deserve particular attention because oxidation products and individual sensitization can alter risk. A product should not be described as 'hypoallergenic' or universally safe without substantiation [14,30].

TABLE 3. EVALUATION PARAMETERS FOR HERBAL HAIR SERUMS: PURPOSE, GENERAL METHOD, AND INTERPRETATION.

Parameter	Purpose	General method / reporting needs	Interpretation and limitation
Appearance / odour / colour	Detect visible change and assess acceptability	Defined lighting, transparent container and observation conditions; record sediment / separation	Subjective; use consistent descriptors
Homogeneity / phase behaviour	Check distribution and physical integrity	Inspect at rest and after suitable stress; microscopy if justified	Does not prove chemical or microbial stability
pH	Assess aqueous-phase acidity where relevant	Calibrated pH meter; state temperature and sample preparation	Not applicable to neat anhydrous oils; no universal target for all products
Viscosity / rheology	Understand flow, dispensing and sensory behaviour	State geometry, shear rate / RPM, temperature and equilibration	Values from different test conditions may not be comparable
Spreadability	Compare application-related flow / spreading	Defined sample amount, substrate, force and time	In vitro surrogate; may not predict real hair use
Density / specific gravity	Support fill and process consistency where needed	Appropriate calibrated density method and temperature	Include only when relevant to quality specification

Parameter	Purpose	General method / reporting needs	Interpretation and limitation
Botanical identity / marker	Check extract identity and batch consistency	Fingerprint and validated HPLC / TLC / spectroscopic method as justified	Total phenolics alone is nonspecific
Antioxidant capacity	Describe chemical activity under assay conditions	Validated assay, controls and matrix blanks	Not proof of efficacy on hair or preservation in product
Hair-tress performance	Test claimed conditioning benefit	Combing force, friction, gloss, static or residue as relevant; matched controls	Specify hair type, damage history, humidity and protocol
Microbial limits / preservative efficacy	Assess microbial quality and protection	Risk assessment; suitable limits and challenge approach	Not replaceable by crude extract antimicrobial data
Safety / tolerability	Evaluate intended scalp or skin exposure	Ingredient assessment and justified, ethical methods	Evidence must be formulation- and exposure-specific
Stability / pack compatibility	Monitor time-dependent change and container interactions	Justified stress and real-time studies; trend key attributes	Accelerated results do not alone establish shelf life

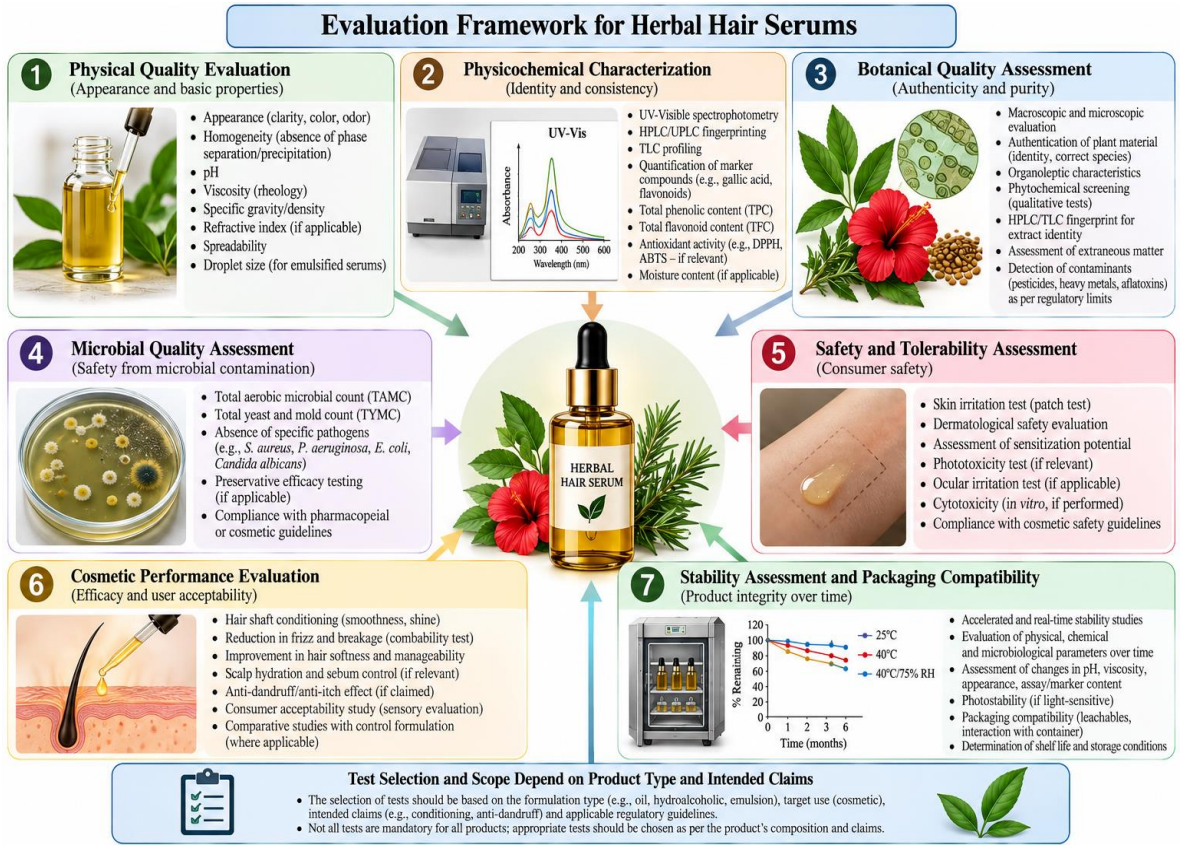


Figure 3. Evaluation Framework for Herbal Hair Serums. Placement.

9. STABILITY STUDIES AND QUALITY CONTROL

Stability is the ability of a product to remain within justified specifications during manufacture, storage and intended use. For herbal serums, relevant changes include colour darkening, odour shift, precipitation, phase separation, pH drift, viscosity change, loss or transformation of markers, oxidation of oils or volatile constituents, package interaction and microbiological failure. A stability programme should therefore combine physical, chemical and microbiological endpoints selected for the formulation rather than relying on a single visual check [16-18].

9.1. Environmental and matrix-related influences

Temperature can accelerate chemical reactions, change solubility and reduce viscosity or promote polymer changes. Light and oxygen can affect oxidation-sensitive plant constituents, pigments and unsaturated oils. The relevant stress conditions should reflect the product's plausible distribution and use environment [16,25].

9.2. Protocol design and packaging

ISO/TR 18811 describes a framework for selecting and justifying cosmetic stability procedures rather than prescribing one universal test condition or shelf life. Tests should be performed in the intended market pack when possible because container opacity, closure quality, adsorption, leachables and repeated opening may influence performance. Acceptance criteria should be set before reviewing the results [16].

9.3. Microbiological preservation and contamination control

Preservation should be considered across the product life cycle. Risk depends on water content, raw materials, manufacturing hygiene, packaging and the way consumers use the product; dispensers that limit finger contact may reduce some contamination routes but do not automatically make a product low risk. ISO 11930 provides approaches for interpreting preservation-efficacy data and microbiological risk assessment, while ISO 17516 addresses microbiological limits. The current status of standards should be checked at submission because ISO 17516 is undergoing replacement work as of the search date [17,18].

9.4. Quality-control strategy

A product specification should connect critical attributes to user-relevant quality: appearance, viscosity or flow, pH when meaningful, extract marker or fingerprint, microbiological quality, packaging performance and appropriate cosmetic endpoints. Change control is important when switching botanical suppliers, changing extraction solvents, altering preservatives or modifying the packaging; each change can affect the established stability and performance profile [6,16-19].

TABLE 5. KEY STABILITY CHALLENGES AND QUALITY-CONTROL STRATEGIES FOR HERBAL HAIR SERUMS.

Stability challenge	Potential quality consequence	Control / monitoring strategy	Interpretation and limitations
Botanical variability	Marker or fingerprint drift; differences in colour, odour or solids	Authenticate species and plant part; qualify supplier; specify markers/fingerprint; retain batch samples	A marker alone does not guarantee cosmetic performance or safety.
Temperature and light	Degradation, pigment changes, viscosity drift or phase changes	Justified stress and real-time studies; assess light exposure and final market pack where relevant	Conditions and acceptance criteria must suit the product; no universal shelf life follows from a single test.
Oxidation	Off-odour, rancidity or transformation of susceptible oils and constituents	Limit unnecessary oxygen/light exposure; select compatible packaging; consider an antioxidant only where justified	The benefit of an antioxidant or barrier pack requires confirmation in the finished formula.
Extract–excipient incompatibility	Precipitation, pH shift, haze, viscosity change or separation	Preformulation solubility screening; monitor pH, rheology, appearance and marker recovery over time	Initial compatibility does not establish long-term stability.
Microbial exposure	Contamination or inadequate preservative performance	Raw-material and GMP controls; product-specific microbial risk assessment; suitable microbial-limit and preservation-efficacy testing	Use current applicable standards and justify the chosen test for the product.
Packaging and consumer use	Leakage, adsorption, evaporation, leachables or contamination after opening	Evaluate the intended pack, closure, compatibility and foreseeable repeated-use conditions	Testing should represent the actual packaging system and instructions for use.

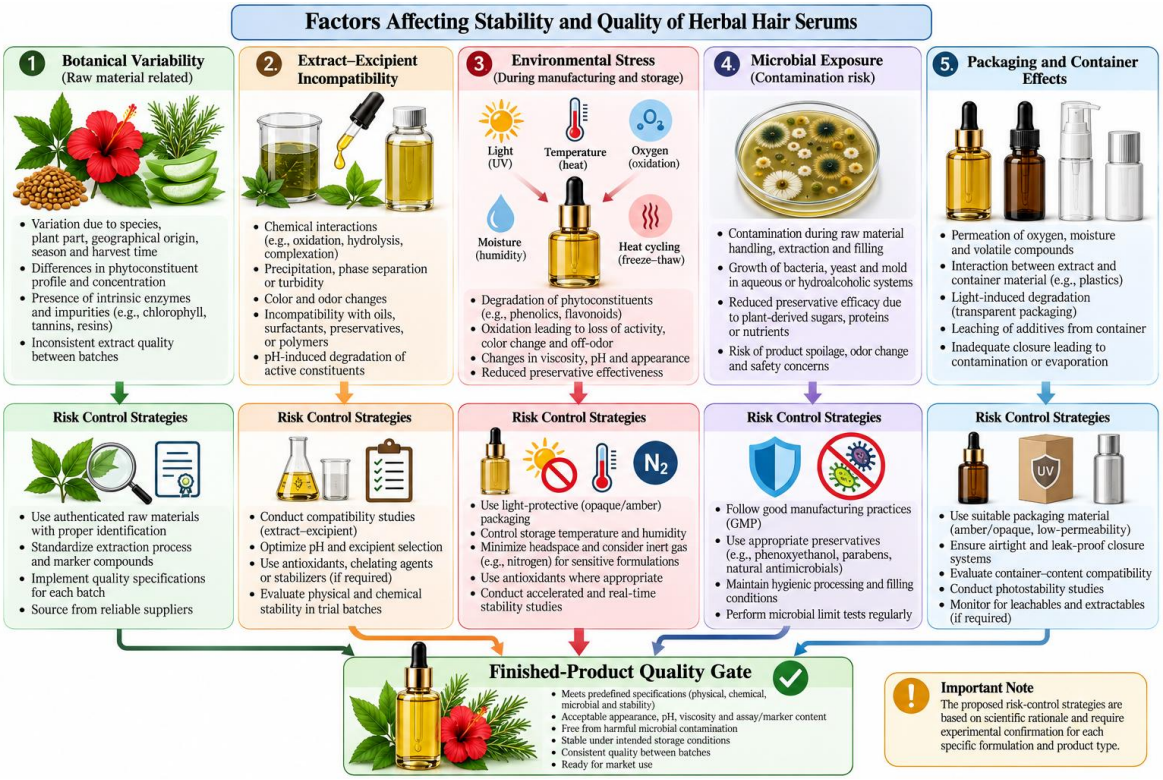


Figure 4. Factors Affecting Stability and Quality of Herbal Hair Serums. Placement.

10. MECHANISM AND SCIENTIFIC BASIS OF HERBAL HAIR SERUMS

For a shaft-directed serum, the most defensible mechanisms are physicochemical: lubricating ingredients can reduce fibre-to-fibre friction, some polymers can form a thin film, and selected conditioning materials can reduce static and improve the cuticle's sensory smoothness. These effects can improve combing and shine without changing hair-follicle activity. A serum may also reduce some mechanical stress during grooming if it measurably lowers combing force or friction under relevant test conditions; the size of that effect must be demonstrated for the product [1-3,27].

Botanical ingredients may contain polyphenols or other constituents with antioxidant activity in chemical assays, but the relationship among assay response, deposition on hair, oxidative protection during real-world use and consumer-perceived outcomes is not straightforward. An antioxidant assay should be interpreted as a test-specific characteristic, not as proof that the serum prevents hair ageing or damage. Similarly, a botanical extract's antimicrobial activity in vitro does not prove that the whole formulation is adequately preserved or treats dandruff [6-8,25].

Potential effects on follicular signalling or the hair cycle should be discussed as hypotheses unless supported by appropriate biological and human studies. The *Eclipta* mouse study and

Phyllanthus delivery-system work provide exploratory evidence, while the rosemary-oil trial provides limited human evidence for a particular regimen. None establishes that every extract, dose, vehicle or marketed serum has the same effect. Product identity, concentration, deposition, exposure and tolerability remain essential determinants of translation [8-10].

The ingredient-to-constituent-to-function map is shown in Figure 2. Its links are formulation rationales and should not be interpreted as proof of a validated hair-growth mechanism [6-15,29].

11. COMPARISON WITH CONVENTIONAL HAIR-CARE FORMULATIONS

Herbal serums and conventional serums should be compared on performance and quality attributes, not on an assumption that one class is inherently safer. Conventional materials such as silicones, synthetic polymers, oils and cationic conditioning agents have well-described roles in lubrication, deposition and sensory modification. Botanical inputs may provide consumer-relevant differentiation and chemical diversity, but they can increase batch variability, colour or odour drift, solubility constraints and analytical complexity. An appropriately designed herbal serum can be effective as a cosmetic product, yet superiority must be demonstrated with a valid comparator and relevant outcomes; the label “natural” is not a performance standard [2,24,27].

A fair comparison should keep the vehicle, dose, application amount, hair-tress source, washing conditions and endpoints as similar as possible. A product-level study might compare wet combing force, gloss, frizz, residue and user preference under controlled conditions, while a scalp-directed product would need endpoints relevant to scalp tolerability and its stated purpose. Comparing a complex herbal formula against an unrelated commercial product without composition and protocol details makes it difficult to attribute differences to the botanical ingredient [1-3,25].

TABLE 4. COMPARISON OF SELECTED HAIR-CARE FORMULATION TYPES.

Formulation type	Potential strengths	Limitations / risks	Typical priority tests
Water-based serum	Light feel; suited to water-soluble extracts; easy dispensing	Microbial protection; limited solubility for oils; possible tack	pH, viscosity, marker recovery, microbial limits, preservative efficacy, stability

Formulation type	Potential strengths	Limitations / risks	Typical priority tests
Hydroalcoholic serum	Can solubilize selected extracts; relatively quick drying	Volatility, flammability during manufacture, sensory sting / dryness and pack compatibility	Solvent content, evaporation behaviour, compatibility, tolerability, stability
Anhydrous oil serum	Good lubrication; may suit lipophilic constituents; generally lower water-related microbial risk	Greasy residue; oxidation; essential-oil sensitization; viscosity and dosing issues	Oxidation indicators where justified, sensory tests, viscosity, pack compatibility
Silicone / polymer-rich serum	Slip, gloss, lower friction and residue control can be engineered	Buildup or flaking if poorly balanced; ingredient preferences and compatibility vary	Combing force, friction, gloss, residue, application / washability
Emulsion / solubilized system	Can combine ingredients with differing polarity and tailor feel	Higher complexity; separation, surfactant interactions and preservation challenges	Phase stability, rheology, marker content, microbial protection, pack compatibility
Botanical-rich serum	Allows plant-derived constituents and differentiated product rationale	Botanical variability, colour / odour changes, uncertain activity, sensitization potential	Authentication, fingerprint / marker, tolerability, direct cosmetic performance, stability

12. SAFETY, LIMITATIONS, AND REGULATORY CONSIDERATIONS

12.1. Ingredient and finished-product safety

Potential safety issues include irritant effects, allergic contact dermatitis, essential-oil sensitization, contamination, adulteration, pesticide residues, heavy metals and microbial load. Risk depends on ingredient identity, plant part, concentration, impurity profile, oxidation state, application site, dose, frequency and user susceptibility. Case reports and toxicity reviews for Aloe and reviews of fenugreek or neem demonstrate why safety should be assessed at the ingredient and exposure level instead of inferred from long-standing traditional use [11-15,23].

A finished-product safety assessment should consider all ingredients together and examine reasonably foreseeable use, including application to an irritated scalp, accidental eye exposure and use by people with known fragrance or botanical sensitivities. For a leave-on product, exposure can be longer than for a rinse-off preparation. Safety substantiation should be proportionate to product type and claims, and human testing must be designed ethically.

The absence of reported adverse events in a small formulation study is not equivalent to evidence that a product cannot cause irritation or sensitization [14,28].

12.2. Botanical quality, contamination and manufacturing

Botanical quality management requires more than supplier reputation. Raw materials should have clear identity and part specifications, traceability, appropriate contaminant testing, and documented storage conditions. WHO methods for herbal materials provide relevant principles for sampling, macroscopic and microscopic assessment, foreign matter, ash, moisture and analytical quality; cosmetic manufacturers should adapt controls to the material and product rather than blindly applying medicinal-herbal monograph tests. Good manufacturing practice, cleaning controls, process records and supplier qualification reduce avoidable sources of variability [6,19,23].

12.3. Indian cosmetic regulatory context and claims

In India, the Cosmetics Rules, 2020 and associated provisions under the Drugs and Cosmetics Act frame manufacturing, import, quality and labeling obligations for products that meet the legal definition of a cosmetic. The CDSCO's public information page states that cosmetics may not make false or misleading claims and summarizes registration and quality requirements for imported products. The specific classification, licensing, labeling and standards applicable to a proposed product should be checked against the latest official text and the manufacturer's actual business situation before commercialization [20,21].

Claims such as ‘smooths hair’, ‘improves manageability’ or ‘adds shine’ are different in nature from claims to treat alopecia, cure dandruff or alter a disease-related process. Claim classification depends on wording, intended use, product composition and applicable law; the United States FDA's claims guidance is informative as a general example but is not the governing law in India. For a submission or launch in India, claims should be truthful, substantiated, non-misleading and checked against current Indian requirements by a competent regulatory professional [20-22].

13. CURRENT CHALLENGES AND FUTURE PERSPECTIVES

The first challenge is botanical reproducibility. Species names, plant part, region, extraction process and storage can change the chemical fingerprint and sensory profile. A practical improvement is to define a minimum raw-material dossier, use identity confirmation and establish marker or fingerprint acceptance criteria that are linked to stability and finished-product performance. Standardization does not mean that one marker explains every activity; it is a tool to reduce variability and increase transparency [6-9,23].

The second challenge is formulation compatibility. Standardized extracts may still differ in polarity, solubility, colour, pH, solids, odour or interactions with polymers and preservatives. Future studies should connect physicochemical characterization with product-relevant outcomes rather than evaluating only appearance, pH and viscosity. Experimental design can help reveal interacting variables and optimize responses, while clear reporting of comparator formulas and test protocols would make studies more comparable [16,25].

Encapsulation, liposomes, transfersomes, nanoemulsions and other delivery systems may improve solubilization or change deposition for selected constituents, but these systems bring additional questions about scale-up, ingredient compatibility, analytical characterization, safety and long-term stability. The *P. emblica* transfersome study illustrates an emerging research path, not a blanket guarantee of improved clinical performance. Advanced systems should be justified by a specific problem and compared with an appropriate conventional vehicle [8,25].

Packaging and sustainability will remain important. Light-protective containers can be useful for photosensitive ingredients, while suitable closures can reduce evaporation and consumer contamination. Refillable or recycled packaging introduces its own compatibility and contamination considerations; environmental advantage should be substantiated rather than assumed. Sustainable sourcing is most credible when paired with traceability, responsible harvesting, reproducible quality and transparent communication about the extract [6,16,23].

CONCLUSION

Herbal hair serums represent a useful area of cosmetic formulation development, but their quality and performance depend on much more than the inclusion of plant extracts. Rational design begins with an identified product purpose, authenticated botanical materials, a reproducible extraction process, compatible excipients and a vehicle matched to the hair shaft or scalp application. A well-designed serum may improve lubrication, combability, shine, manageability or sensory feel, while claims of hair growth or disease treatment require separate and substantially stronger evidence.

Evaluation should be selected according to the formulation and its intended claims. Physical appearance, homogeneity, pH where relevant, rheology, spreadability, marker analysis, microbial quality, preservative effectiveness, package compatibility, safety and product-specific performance provide complementary information. Stability protocols should be justified, and shelf life should not be inferred from short-term or accelerated observations

without suitable data. Botanical origin does not guarantee safety, compatibility or superiority over conventional hair-care materials.

The main research priorities are better extract standardization, direct measurement of cosmetic performance, harmonized evaluation methods, transparent reporting, robust preservation and stability data, and controlled studies of finished products. Emerging delivery systems may solve specific formulation problems, but their value must be demonstrated rather than assumed. A publication-ready evidence base will depend on reproducible methods, proportionate claims and clear separation between preliminary biological activity and validated finished-product outcomes.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to **Ms. Pritam Ghadge** Assistant Professor, Department of Pharmaceutics for their valuable guidance, constructive suggestions, and continuous support throughout the preparation of this review article. The authors also gratefully acknowledge **Dr. Tushar Shelke** Principal, for providing the necessary institutional support, encouragement, and facilities required for the completion of this work. The authors sincerely appreciate their valuable contributions and support.

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