INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

OPEN ACCESS

Review Article

Development And Evaluation of Natural Hair Dye Formulations

Pooja Pisal*, Purva Kunjir, Shweta Koulage, Shweta Khenat, Viraj Kurpad

Department of Pharmaceutics, Poona District Education Association's Seth Govind Raghunath Sable College of Pharmacy, Saswad, Pune, Maharashtra, India.

ARTICLE INFO

Published: 21 May. 2026
Keywords:
natural hair dye, herbal hair colour, henna, indigo, amla, physicochemical evaluation, safety, sustainability.
DOI:
10.5281/zenodo.20322520

ABSTRACT

Growing concern over the health and environmental risks of synthetic oxidative hair dyes has accelerated research into natural or herbal hair-coloring agents.[1–3] Natural hair dyes are formulated from plant-derived pigments such as lawsone (henna, Lawsonia inermis), indigoid compounds (indigo, Indigofera tinctoria), tannins from catechu (Acacia catechu), and anthocyanins from beetroot (Beta vulgaris) or hibiscus (Hibiscus rosa sinensis), which primarily coat the hair surface rather than penetrating the cortex with strong oxidants.[3-4] Local irritancy, surfactants, and metal-based mordants used in some herbal products, however, can still influence safety and performance.[4–6]Recent studies report that well-formulated herbal blends exhibit near neutral pH (≈5.5–7.0), low ash content, good spreadability, and acceptable stability under variable storage conditions, with no significant acute irritation in patch tests or reconstructed skin models.4-6[–8] Multianalytes invitro approaches further demonstrate that plant based hydrogel dyes can produce viable colors on human gray hair, showing only slight-to-mild eye irritation potential and negligible skin irritation compared with many synthetic counterparts.7-9 Despite these advantages, plant based dyes still face limitations in shade range (especially ash blond and cool tones), consistency in application, and susceptibility to fading with repeated shampooing.[10–12] Some commercial "herbal" products are adulterated with metallic salts or synthetic dyes, which can compromise the perceived safety profile.[5-13] This review summarizes current scientific knowledge on natural hair dyes, describes typical formulation and evaluation methods, presents reported results on color performance and safety, and discusses future research directions for standardization, delivery systems, and long-term consumer acceptability.

INTRODUCTION

- **Background and rising demand for natural alternatives**

***Corresponding Author:** Pooja Pisal
Address: *Department of Pharmaceutics, Poona District Education Association's Seth Govind Raghunath Sable College of Pharmacy, Saswad, Pune, Maharashtra, India.*
Email ✉: virajkurpad22@gmail.com

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Hair coloring is one of the most common cosmetic practices worldwide, with synthetic oxidative dyes estimated to be used by a substantial proportion of adults, particularly women, at least once a year.[11-14] These dyes typically contain ammonia, hydrogen peroxide, and aromatic amines such as p-phenylenediamine (PPD), o-phenylenediamine, and related intermediates that are oxidized on the hair to generate colored compounds.[1-14] Mechanistically, they open the cuticle, oxidize both endogenous melanin and dye precursors, and polymerize within the cortex, resulting in broad shade ranges and high permanence.[11] However, the same chemical reactivity that makes synthetic dyes effective also underpins many adverse effects. Frequent use is associated with higher rates of scalp irritation, allergic contact dermatitis, hair dryness, and possible links to oxidative DNA damage and some cancers, especially in hairdressers and heavy users.[11-15] This has prompted both consumers and regulatory bodies to seek safer, more sustainable options.[1] Natural (herbal or plant based) hair dyes, which rely on plant pigments such as lawsone, indigoids, tannins, flavonoids, and anthocyanins, have thus gained prominence as "green" alternatives that avoid many synthetic oxidants and intermediates.[3-4]

- **Conceptual framework: How natural dyes differ**

Natural hair dyes differ from conventional oxidative systems in three main ways: *mechanism of action, chemical composition, and user experience*. Mechanistically, most plant-based dyes rely on surface adsorption or weak covalent bonding between plant pigments and hair keratin, rather than deep oxidative penetration.[3-4] For example, lawsone from henna undergoes Michael type addition to nucleophilic amino and sulfhydryl side-chains in keratin, forming a thin, semi-permanent film on the cuticle rather than a deeply polymerized inner matrix.[3-13] This mode of action tends to produce reddish- brown to brown-black shades that build gradually with application time and subsequent washes, contrasting with the immediate, strong color response of synthetic PPD-based dyes.[3-4] In terms of composition, herbal formulations emphasize plant powders or extracts, water, mild buffers, and plant-based oils over ammonia, peroxide, and petroleum-derived surfactants.[3-4] In many published formulations, herbal blends include henna, indigo, amla, catechu, beetroot, hibiscus, and sometimes conditioning adjuncts such as shikakai, reetha, brahmi, and bhringraj.[3-4] Phytochemical screening of these herbs commonly reveals carbohydrates, proteins, tannins, anthraquinones, flavonoids, and mucilage, which support both coloration and ancillary benefits such as reduced frizz and improved scalp comfort.[3] User experience studies and consumer review compendia indicate that plant-based dyes often leave hair softer, shinier, and less prone to static like frizz, than conventional dyes, which frequently cause dryness and brittleness after repeated use. [11-1-7]Many users also report reduced scalp irritation and less offensive odor, attributes frequently highlighted by professional plant-based dye brands that market ammonia, PPD, and peroxide free formulas. [3-1-10]

- **Safety, environmental, and regulatory context**

Toxicological and epidemiological reviews consistently associate long-term exposure to synthetic oxidative dyes with increased risk of contact dermatitis, respiratory sensitization among hairdressers, and potential genotoxicity or carcinogenicity, although the magnitude of risk remains debated.[1-11-5] In contrast, carefully formulated natural dyes avoid many of these synthetic intermediates and strong oxidants, which

lowers immediate irritation potential and volatile chemical emissions.[4-6]

However, safety is not automatically guaranteed. Some "herbal" or "henna based" products have been found to contain undisclosed metallic salts or synthetic dyes added to intensify color, which can still provoke allergic reactions or lead to unexpected results.[5-1-3] Thermal degradation products and harsh extraction methods can also introduce impurities, underscoring the need for quality control, standardized testing, and transparent labeling.[1-6] Regulatory bodies in multiple regions now emphasize stricter requirements for all hair dye products, including ingredient listing, exclusion of prohibited allergens, and premarket safety assessment, particularly for products marketed to pregnant individuals, people with atopic skin, or those undergoing chemotherapy.[1-6] Recent guidance also encourages the use of invitro toxicological assays to reduce reliance on animal testing while still evaluating eye and skin irritancy potential.[7-1-6]

- **Aim and objectives of this review**

AIM: Development and Evaluation of Natural Hair Dye Formulation

OBJECTIVES:

- To identify and document the primary botanical sources and phytoconstituents, such as naphthoquinones (lawsone), indigoids, and tannins, that are effective for hair coloration.
- To analyze formulation strategies for natural hair dyes, including the selection of herbal blends, thickening agents, and pH-modifying buffers used to ensure stability and ease of application.
- To categorize standard evaluation parameters essential for quality control, covering organoleptic, physicochemical, rheological, and safety testing.
- To investigate the dyeing efficiency of herbal preparations, specifically their ability to provide uniform gray-hair coverage, color intensity, and shade durability.
- To compare the safety profiles of plant-based hair dyes with synthetic oxidative dyes, emphasizing the reduction in allergic reactions and scalp irritation.
- To outline future research needs in the areas of pigment stabilization, the use of advanced delivery systems like nanocarriers, and the development of standardized regulatory protocols.

- **Review Of Literature:**
- **Botanical Sources and Phytochemistry**

Natural hair dyes have gained considerable attention in recent years because of the increasing demand for safer, eco-friendly, and plant-based cosmetic products. Unlike synthetic hair dyes, which often contain harsh chemicals such as ammonia, paraphenylenediamine (PPD), and peroxide, herbal hair dyes utilize naturally occurring pigments extracted from different plant sources. These plant-derived pigments not only provide coloration but may also offer additional benefits such as antioxidant, antimicrobial, anti-inflammatory, and conditioning effects.[3–4] A wide variety of botanical materials have traditionally been used for hair coloring across different cultures; however, a few important plants dominate both scientific literature and commercial herbal dye formulations. The most used botanical sources include henna, indigo, catechu, amla, beetroot, and hibiscus, each contributing unique phytochemicals and coloring properties.[3–4] Lawsonia inermis, commonly known as henna, is one of the oldest and most extensively studied natural dyeing plants. The primary coloring compound present in henna leaves is lawsone (2-hydroxy-1,4-naphthoquinone), a quinone-based

pigment responsible for the characteristic orange-red coloration produced on hair and skin.[3–4] Lawsone exhibits a strong affinity toward keratin proteins found in hair fibers. When applied to hair, it reacts with amino and sulfhydryl groups of keratin to form stable bonds, resulting in shades ranging from reddish-orange to deep brown depending on the duration of application, concentration of paste, and the natural color of the hair.[3–4–13] Henna is also valued for its conditioning properties, as it can improve hair smoothness, impart shine, and slightly increase the thickness of the hair shaft by forming a protective coating over the cuticle surface.[3] In many traditional systems, henna is used either alone or in combination with other botanical ingredients to obtain different color tones and improved cosmetic effects. Another major botanical source used in herbal hair dye formulations is Indigofera tinctoria, commonly referred to as indigo. Indigo leaves contain indigoid compounds that produce blue pigments after oxidation.[3–4] Unlike henna, indigo alone generally imparts bluish tones that are not commonly desired for cosmetic hair coloring. Therefore, it is frequently used together with henna to achieve darker shades such as chestnut brown, dark brown, and black.[3–4] The final shade obtained depends greatly on the ratio of henna to indigo and the sequence in which they are applied. For example, applying henna first followed by indigo produces darker shades approaching black, whereas blending both powders together before application may yield softer brown tones.[4] Indigo-based formulations are highly popular among individuals seeking natural alternatives to black synthetic hair dyes because they provide comparatively better color depth and coverage.

Acacia catechu is another important botanical ingredient incorporated into herbal dye preparations. Catechu contains high levels of tannins and reddish-brown phenolic compounds that contribute to darker color intensity and improved adherence of pigments to the hair surface.[3–4] Tannins are polyphenolic compounds capable of interacting with hair proteins, thereby enhancing color fixation and durability. Because of these properties, catechu is commonly included in formulations intended for brown or dark brown shades.In addition to its coloring role, catechu also exhibits mild antimicrobial and antioxidant activities, which may help maintain scalp health.[3]

Phyllanthus emblica, commonly known as amla or Indian gooseberry, is another widely used herbal ingredient in traditional hair care preparations. Amla is rich in hydrolysable tannins, gallic acid derivatives, vitamin C, and various antioxidant compounds.[3] Although amla does not function as a strong primary coloring agent, it is extensively used as a supportive ingredient because it improves hair texture, reduces frizz, enhances shine, and acts as a natural conditioner.[3–4] The tannin content of amla may also contribute to mild color fixation and help maintain darker shades when combined with henna and indigo. Furthermore, the antioxidant properties of amla may help protect hair fibers from oxidative stress and environmental damage. Plant-derived anthocyanin pigments also play an important role in herbal hair coloration. Beta vulgaris and Hibiscus rosa-sinensis are two commonly used sources of anthocyanins that produce reddish-purple or magenta hues.[3–4] Anthocyanins are water-soluble flavonoid pigments whose color is highly influenced by pH and environmental conditions. Beetroot extracts are rich in betalains and anthocyanin-like pigments that can impart temporary reddish tones to hair, whereas hibiscus flowers provide deep pink to reddish-purple shades along with conditioning effects.[3–4] However, compared to lawsone and indigo pigments, anthocyanins are relatively unstable and sensitive to factors such as light exposure, oxidation, temperature, and pH changes. As a result, formulations based primarily on

anthocyanins often show faster fading and lower wash fastness.[3] Despite these limitations, beetroot and hibiscus remain popular in herbal cosmetic preparations because of their natural origin and additional benefits such as antioxidant and anti-inflammatory activities. Recent scientific reviews have systematically classified natural hair dye components according to their dominant phytochemical groups, including quinone-rich, tannin-rich, flavonoid-rich, anthocyanin-rich, and carotenoid-rich botanicals.[3–4] Quinone-containing compounds such as lawsone are mainly responsible for strong and relatively long-lasting coloration because of their ability to form stable interactions with hair proteins. Tannin-rich plants contribute to color enhancement and fixation, while flavonoids and anthocyanins provide lighter shades with added antioxidant activity.[3–4] Carotenoid-containing plants may impart yellow to golden hues, although they are less commonly used in commercial hair dye products. Besides their coloring functions, these phytochemicals may provide several therapeutic and cosmetic benefits including antioxidant protection, antimicrobial action against scalp microorganisms, reduction of inflammation, and improvement of hair texture.[3–4] Consequently, herbal hair dyes are increasingly being explored not only as coloring agents but also as multifunctional cosmetic products that support overall hair and scalp health.

- **Interaction of Plant Pigments with Hair Keratin**

The effectiveness of natural hair dyes largely depends on the interaction between plant- derived pigments and the keratin structure of hair fibers. Human hair is primarily composed of keratin, a fibrous structural protein rich in amino acids such as cysteine, lysine, arginine, and histidine.[3] These amino acids contain reactive functional groups, including amino, sulfhydryl, and carboxyl groups, which serve as binding sites for natural pigments. The mechanism through which herbal dyes interact with hair differs significantly from that of synthetic oxidative dyes. While synthetic dyes penetrate deep into the cortex and undergo oxidative polymerization reactions, most herbal pigments primarily bind to the outer layers of the hair shaft through covalent bonding, hydrogen bonding, electrostatic interactions, or surface deposition.[3–4] Lawsone, the active pigment present in henna, possesses an electrophilic quinone structure that readily reacts with nucleophilic groups in keratin proteins.[3–4–13] Specifically, lawsone undergoes 1,4-Michael addition reactions with sulfhydryl and amino groups present in hair keratin, resulting in the formation of relatively stable covalent bonds.[3–4] This reaction produces a thin colored film over the hair shaft that contributes not only to coloration but also to improved hair smoothness and shine. Repeated application of henna may gradually increase the apparent thickness and volume of hair because of the cumulative deposition of pigment layers over the cuticle surface.[3–4–13] The stability of these covalent interactions explains why henna-based dyes generally show better durability compared with many other plant-derived pigments. Tannins present in catechu and amla interact with hair keratin mainly through hydrogen bonding and weak cross-linking interactions.[3–4] These polyphenolic compounds can associate with protein chains and help stabilize pigment deposition on the hair surface. Although the interactions are weaker than the covalent bonding observed with lawsone, tannins still contribute significantly to initial color fixation and enhancement of color depth.[3–4] In addition, tannin-rich formulations may improve the mechanical strength of hair fibers by forming temporary cross-linked structures around the cuticle. However, because these interactions are comparatively less

stable than the oxidative polymerization reactions involved in synthetic hair dyes, herbal colorants are generally considered semi-permanent and gradually fade with repeated shampooing, sunlight exposure, and mechanical wear.[3–4] Indigo pigments exhibit a distinct mechanism of action compared with henna. During preparation, indigo compounds are converted into a reduced and soluble form known as leuco-indigo under alkaline conditions.[3–4] This soluble intermediate can diffuse into the outer layers of the hair shaft. Upon exposure to atmospheric oxygen, leuco-indigo undergoes oxidation to form insoluble blue-black pigments that become trapped within and around the hair surface.[3–4] When indigo is applied after henna treatment, the blue-black indigo pigments combine with the reddish-orange henna layer to produce dark brown or black shades. This sequential application creates a composite pigment coating that is more durable than henna alone, although it still does not achieve the permanence of synthetic oxidative dyes.[3–4] Anthocyanins obtained from beetroot and hibiscus primarily bind to the hair surface through electrostatic attractions and hydrogen bonding interactions.[3–4] These pigments provide attractive reddish-purple tones but are highly sensitive to pH changes, oxidation, and ultraviolet light exposure. Consequently, anthocyanin-based shades tend to fade more rapidly than quinone- or indigo-based systems.[3–4] Some studies have reported that the use of metal mordants such as iron(II) salts can improve color intensity and wash fastness by forming coordination complexes with anthocyanin molecules.[4–7–9] However, the concentration and use of such mordants must be carefully controlled because excessive metallic compounds may cause scalp irritation, hair dryness, or concerns related to long-term metal accumulation.[4–7–9] Overall, the interaction of plant pigments with hair keratin determines the shade, durability, and cosmetic performance of herbal hair dye formulations, making this an important area of research in the development of safer and more effective natural cosmetic products.

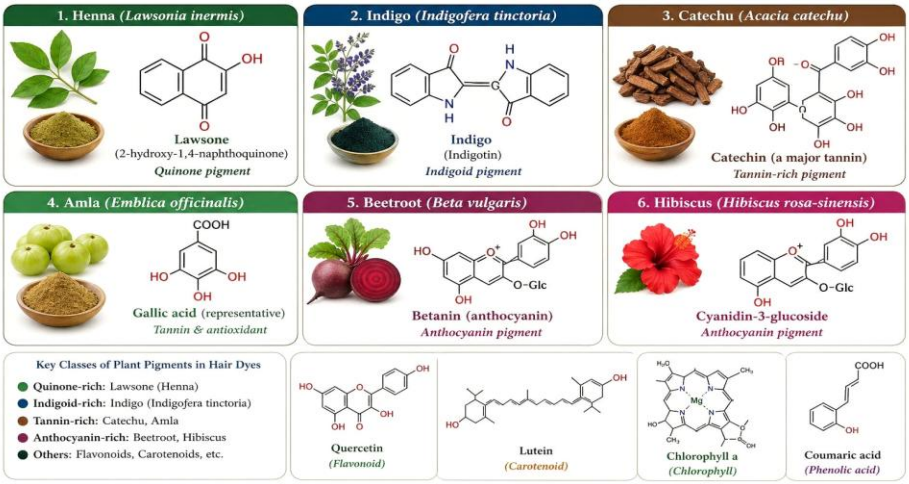

Fig. 1. Plant Pigments used in Natural Hair Dye.

- **Comparative efficacy: natural vs synthetic dyes**

Aspects	Synthetic dyes	Natural dyes
Shade Range	Broader spectrum (e.g., very light/ash-cool tones) [11]	Limited versatility; can be engineered with mordants

		for better intensity[7]
Permanence	Higher color permanence[1-11-5]	Lower without mordants; iron (II) mordant boosts strength with subtle hue shifts[7]
Irritation Potential	High (ammonia, peroxide, PPD allergens cause scalp irritation, hair damage, systemic toxicity) [11]	Low (slight-to-mild eye irritants in assays; no significant skin irritation; mordant non-irritant) [1-6]
Hair-Conditioning Effects	Oxidative damage from chemicals[1-5]	Milder profile, potentially conditioning; comparable color strength to some synthetics[7]
Overall Suitability	Effective but risky for long-term/sensitive use	Viable low-irritant alternatives for short-term, especially with formulation tweaks[6-7]

- **Safety, adulteration, and regulatory trends**

Patch test and irritancy evaluations of herbal hair dye formulations generally report no or minimal erythema, edema, and burning, indicating low acute irritation potential under controlled conditions.[4-6] Comprehensive review of plant based cosmetic products further emphasize that irritation risk is highly formulation dependent and that herbal blends can be safer than synthetic alternatives when purified, standardized ingredients are used.[1-6] However, some marketed "herbal" or "henna based" products have been analyzed and found to contain undisclosed metallic salts or synthetic dyes, added to intensify color or to mask the presence of prohibited pigments.[5-13] Such adulterants may still trigger allergic reactions or produce unexpected color shifts, thereby undermining the safety profile consumers expect from "natural" labeling.[5] In response, regulatory authorities in several regions now require clear ingredient listing, prohibition of specified allergens, and documentation of safety data, including in vitro toxicological testing, particularly for products used by pregnant women, infants, or individuals with compromised skin.[1-6] Guidance documents also encourage manufacturers to avoid undocumented mordants, heavy metals, and synthetic dyes in products labeled as "plant-based" or "herbal."[1-6]

- **Formulation strategies, stability, and user experience data**

Modern research on herbal hair dyes focuses on optimizing ratios, base systems, and processing methods to improve color performance and stability.[3-4] Common formulations combine henna, indigo, amla, catechu, and plant based oils in powder or paste form, with pH and viscosity adjusted using mild buffers and thickeners.[3-4] Commercial plant based kits often include ready-to-mix powders and gloves, emphasizing ease of application and reduced chemical exposure.[10-7] Stability studies under different temperatures (5–40°C) over one month or longer periods show that herbal blends generally retain color, odor, and pH within acceptable limits, although some anthocyanin rich preparations exhibit gradual fading under light and high humidity conditions.[4-6] This suggests that plant based dyes can be stable for short to medium-term use if stored in opaque, airtight containers and protected from prolonged sun exposure.[4-6] Consumer-survey-style reports and brand compiled user reviews indicate that plant-based dyes tend to fade slowly and

gracefully, often blending gray regrowth more naturally than harsh synthetic lines. [10-11]

Many users highlight softer, shinier hair and reduced scalp irritation after switching from synthetic to plant-based dyes, although some note that application time and rinsing protocols are more demanding than with conventional products.[10-7] Standardization of these protocols—application duration, temperature, and post color care remains a key barrier to consistent consumer outcomes.[12]

- **MATERIALS:**

- **Plant materials and chemicals:**
- Typical raw materials used in herbal hair-dye research include:
- *Lawsonia inermis* leaf powder (henna, lawsone rich).
- *Indigofera tinctoria* leaf powder (indigo, indigoid pigments).
- *Emblica officinalis* fruit powder (amla, tannins, and antioxidants).
- *Acacia catechu* heartwood powder (catechu, tannins, and reddish-brown pigments).
- *Beta vulgaris* root powder or extract (beetroot, anthocyanins).
- *Hibiscus rosa-sinensis* flower powder or extract (anthocyanins).
- Conditioning adjuncts such as shikakai, reetha, brahmi, and bhringraj are used in published formulations targeting black or dark-brown shades. [3-4]

These ingredients are typically authenticated botanically, screened for heavy metals and microbial contamination, and stored in airtight containers under controlled temperature and humidity. [3-4]

- **Equipments:**

- **Digital pH meter:** Used to measure the pH of the herbal hair dye formulation accurately. It helps confirm whether the product is mild enough for a scalp application. [3-4]
- **Rotational viscometer or Brookfield viscometer:** Used to determine viscosity and flow properties of the formulation. This equipment is important for checking whether the dye has the proper thickness for easy application. [3-4]
- **Hot air oven:** Used in moisture content analysis by drying the sample until a constant weight is reached. This gives an estimate of how much water is present in the formulation. [3-4]
- **Muffle furnace:** Used for ash content determination by burning the sample at hot temperature and measuring the remaining inorganic residue. [3-4]
- **Colorimeter or spectrophotometer:** Used to measure color strength, shade, and dye uptake on hair tresses. This provides objective data on how well the dye performs.[7-11]
- **Hair tresses or hair swatches:** Used as test samples for dyeing experiments. They help assess gray coverage, shade development, and overall coloring efficiency. [7-11]

- **Glassware set:** Beakers, measuring cylinders, conical flasks, spatulas, and stirrers are used for weighing, mixing, and preparing the herbal dye formulation. These are basic but essential tools in the formulation process. [3-4]
- **Patch test materials/irritation test setup:** Used for safety evaluation of the formulation on skin or in vitro models. These materials help identify any potential irritant reactions. [7-14]
- **Storage containers:** Airtight containers are used to store the prepared formulation during stability testing. They protect the product from moisture, contamination, and environmental changes. [4-6]

- **Temperature-controlled storage conditions:** Used to keep samples at different temperatures during stability studies. This helps evaluate how the product behaves under real storage conditions. [4-6]

METHODOLOGY:

- A standard laboratory scale procedure for herbal hair dye pastes or powder involves:
- **Blending ratios:** Raw powders are weighed in predetermined ratios (e.g., henna:indigo 2:1 for brown, henna:amla:catechu 4:1:1 for reddish-brown, or more complex blends including 2–5% each of shikakai, reetha, brahmi, and hibiscus for dark black formulations).[3-4]
- **Paste preparation:** Powders are mixed with water or plant-based hydrosol to form a smooth paste, avoiding lumps and entrapped air; gentle stirring or light mechanical mixing is used if necessary. [3-4]
- **pH and viscosity adjustment:** pH is adjusted to 5.5–7.0 using mild buffers such as citrate or phosphate systems; viscosity may be modified with plant-based thickeners or hydroxypropyl cellulose to improve spreadability and adherence on hair. [3-4]
- **Optional mordanting or oil addition:** For studies examining mordant effects, a small quantity of iron (II) salt or similar mild metal complex may be introduced in controlled amounts in cosmetic oriented formulations. Plant oils (e.g., coconut or almond oil) are added for conditioning. [4-7]
- The final paste is degassed, packaged in airtight containers, and stored protected from light until evaluation.

EVALUATION PARAMETERS:

- **Organoleptic evaluation:** The herbal hair dye should be assessed for its appearance, color, odor, consistency, and spreadability.This step helps determine whether the formulation is visually acceptable, easy to handle, and suitable for application on hair. [3-4]
- **pH determination:** The pH of the formulation should be measured to check whether it is scalp friendly. A near neutral or slightly acidic pH is preferred because it reduces the chance of irritation and supports compatibility with hair and skin. [3-4]
- **Viscosity evaluation:** The viscosity should be measured to understand the thickness and flow behavior of the dye. This is important because a properly viscous formulation spreads evenly on hair and stays in place during application. [3-4]
- **Moisture content analysis:** Moisture content should be determined because water level influences product stability, texture, and shelf life. Excess moisture can promote microbial growth or reduce storage stability. [3-4]
- **Ash content analysis:** Ash content should be measured to estimate the amount of inorganic matter present in the formulation. A low ash value usually indicates better purity and fewer unwanted residues. [3-4]
- **Phytochemical screening:** The formulation should be tested for active phytochemical constituents such as tannins, flavonoids, anthraquinones, proteins, carbohydrates, and mucilage. These compounds contribute to dyeing ability, conditioning effect, and overall product performance. [3-4]
- **Dyeing performance on hair:** The dye should be applied to hair tresses or swatches to observe its coloring ability. This evaluation helps determine shade development, color intensity, and coverage of gray hair. [711]
- **Color strength measurement:** The depth and intensity of the color should be measured instrumentally to provide objective data. This

is more reliable than only visual inspection because it allows comparison between formulations. [7-11]

- **Safety and irritation testing:** Patch tests or in-vitro irritation studies should be conducted to check whether the dye causes redness, swelling, burning, or discomfort. This is essential because even herbal products can cause irritation if improperly formulated or adulterated. [7-14]
- **Stability evaluation:** The formulation should be stored under different conditions and observed for changes in color, odor, pH, and texture over time. Stability testing helps determine whether the product remains effective and acceptable during storage. [4-6]

RESULT & DISCUSSION:

- **Physicochemical and safety findings**

- Reported herbal hair-dye formulations consistently show:
- pH values in the range 5.5–7.0, which is compatible with the scalp's natural acid mantle and associated with low irritation risk. [3-4-14]
- Low ash content, indicating acceptable levels of inorganic residues when genuinely plant-based, nonadulterated materials are used. [3-4]
- Moderate viscosity and good spreadability, enabling even application without excessive dripping or lump formation. [3-4]
- Phytochemical screening commonly reveals the presence of carbohydrates, proteins, tannins, anthraquinones, flavonoids, and mucilage, confirming that these herbs deliver not only color but also conditioning agents and mild antioxidants. [3-4]
- In-vitro irritation and patch-test studies generally report no or minimal erythema, edema, and burning, indicating low acute irritation potential for many plant-based formulations when applied correctly.[7-14] Multi-analytical in-vitro work on plant-based hydrogel dyes further demonstrates that these systems can produce viable colors on human gray hair with only slight-to-mild eye-irritation and negligible skin-irritation, whereas mordanting with iron(II) salts significantly increases color strength without notably worsening irritation.[7]

- **Color performance and user-experience**

- Color strength measurements from experimental studies indicate that optimized herbal blends can achieve color intensities comparable to many commercial synthetic products, especially when mordanting or synergistic blending is employed.[3-4-7] For example, henna indigo combinations at appropriate ratios provide chestnut brown to near black tones, whereas henna-amla-catechu blends yield rich red-brown shades suitable for a broad consumer base.[3- 4]

Anthocyanin rich dyes based on beetroot or hibiscus deliver vivid reddish-purple to magenta hues, although these tend to fade more quickly with shampooing and light exposure.[3-4] Compiling consumer-review-style data, plant- based dyes generally last 4–6 weeks (about 1 and a half months) on average, with gradual fading that many users describe as "soft" or "blended," especially in gray-hair coverage.[10-11] User experience reports compiled by brands and review platforms emphasize reduced scalp irritation, softer and shinier hair, and less offensive odor compared with synthetic oxidative dyes, although some consumers note that preparation and application protocols are more time-consuming and require careful attention to ratios and timing. [10-17]

- **Stability and durability considerations**

Stability studies under 5–40 °C for 1–3 months show that most herbal blends retain acceptable color, odor, and pH, with only minor changes in viscosity or texture.[6] Anthocyanin rich preparations, however, often show measurable fading under light and high humidity conditions, underlining the need for protective packaging and clear storage instructions.[4-6] When mordanted with iron(II) salts, plant-based dyes can achieve markedly higher color strength and somewhat improved wash-fastness, but the trade-off may be a slightly darker or cooler shade and a need for careful control of metal concentration to avoid potential scalp-safety concerns.[7] Studying these systems in more-realistic usage scenarios (repeated shampooing, heat-styling, UV exposure) will help refine formulations for long-term consumer satisfaction.[12]

Sr. No.	Evaluation Parameters	Observations
1.	Organoleptic properties	Smooth paste, pleasant herbal odor, uniform color
2.	pH determination	5.5 - 7.0
3.	Viscosity	Moderate, smooth flow
4.	Phytochemical screening	Presence of tannins, flavonoids, and anthraquinones
5.	Dyeing performance	Good grey coverage, brown to black shade.
6.	Color strength	Moderate to high intensity
7.	Stability Study	No major change in color, pH & texture

Table 1. Evaluation of Natural Hair Dye

CONCLUSION & FUTURE SCOPE:

Natural plant-based hair dyes offer a promising, relatively safer alternative to conventional synthetic oxidative dyes, combining decent color performance with good scalp compatibility and improved hair conditioning effects.[3-4-7] Carefully formulated blends of henna, indigo, amla, catechu, and other plant-based adjuncts can achieve market-relevant chestnut-brown to near black shades, with mild to moderate anthocyanin rich red-purple tones, all while avoiding many of the harsh oxidants and aromatic amines associated with health concerns.[3-4- 11] However, limitations remain in shade range (especially for ash blond and cool tones), consistency of application, and susceptibility to fading with repeated shampooing.[10-12] Some marketed "herbal" products are adulterated with metallic salts or synthetic dyes, which can compromise safety and consumer trust.[5-13] Future research should therefore focus on:

- Developing standardized ratios, particle size specifications, and extraction methods to improve reproducibility and batch-to-batch consistency. [12]
- Exploring nanocarriers, microencapsulation, and inorganic nanocarriers to stabilize plant pigments and enhance wash fastness without synthetic oxidants.[8]
- Conducting larger scale clinical trials and longitudinal follow-up to assess long-term safety, color retention profiles, and user satisfaction, particularly in gray hair management and sensitive skin populations. [7-14]

Regulatory harmonization and transparent labeling will further support the development of reliable plant-based hair dyes, paving the way for a more sustainable, consumer-centric hair-coloring industry.

REFERENCES

1. Gupta AK: Future directions in natural and plant-based hair dyes: consumer and science trends. Int J Cosmet Sci. 2021;43(3):247–258.

2. Kaur S, et al. Recent advancements in natural plant colorants used for hair dyes: a comprehensive review. Phytochem Rev. 2022;21(6):1423–1441.
3. Suchita G, et al. A review: natural ingredients as hair dye. IJPPR. 2021;13(1):1–10.
4. Gupta S, et al. Formulation and evaluation of herbal hair dye. Pharmacognosy Res. 2014;6(3):294–298.
5. Elsadek M, et al. A review of the natural herbal hair dye for hair colour. Int J Sci Res Eng Manag. 2026;10(3):1–15.
6. Kumar S, et al. Formulation and evaluation of natural hair colour. IJPRAS. 2024;14(1):1–9.
7. Sturm R, et al. Assessing the dyeing efficiency and irritation potentials of plant hair dyes: a multi-analytical invitro approach. J Cosmet Dermatol. 2019;18(4):1120–1127.
8. Mishra R, et al. Formulation and evaluation of herbal hair dye. IRJMETS. 2019;7(6):127247.
9. Kumar V, et al. Safety considerations of natural plant hair dyes: a consensus-based review. Dermatol Pract Concept. 2025;15(3): e2025153.
10. Deyga. How long does plant-based hair color last? Real-world longevity and user reviews. 2023.
11. Refresh Your Life. I tried natural hair color for the first time—honest insight and user-experience data. 2025.
12. Tresse Paris. Plant-based hair color: safe or not? Cosmetic and dermatological perspective. 2026.
13. Sturm R, et al. Local irritancy, and surfactant effects in plant-based hair dyes: mechanistic insights. J Cosmet Sci. 2020;71(2):145–158.
14. Open Dermatology Journal. Synthesis and evaluation of herbal based hair dye. 2018; 12:90–98.

HOW TO CITE: Pooja Pisal*, Purva Kunjir, Shweta Koulage, Shweta Khenat, Viraj Kurpad, Development and Evaluation of Natural Hair Dye Formulations, Int. J. of Pharm. Sci., 2026, Vol 4, Issue 5, 5354-5365. https://doi.org/10.5281/zenodo.20322520