IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Beyond Dye: A Comprehensive Review on Next-Generation Herbal Mehendi Formulations for Sustainable Hair Coloring and Scalp Care

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Abstract

Herbal-based hair color and scalp care systems have been developed more quickly in recent years due to the demand for sustainable and natural personal care products. With a focus on their dual function in hair coloring and scalp health, this paper examines the developing field of next-generation herbal "mehendi" (henna-based) products. In order to improve conditioning, antioxidant protection, and scalp-microbiome support, we first trace the historical use of traditional plant dyes like Lawsonia inermis (henna) and Indigofera tinctoria (indigo). Next, we examine recent innovations that incorporate botanical extracts (such as Emblica officinalis/amla, Eclipta alba/bhringraj, coffee, and shikakai). The overview summarizes research on performance measures (color absorption, retention, hair-shaft binding, coloring uniformity), formulation strategies (extraction techniques, pigment stabilization, carrier systems), and safety/scalp compatibility (irritation potential, allergenicity, microbiota influence). While highlighting the relative advantages of these herbal systems over synthetic hair dyes, such as decreased toxicological burden, enhanced scalp tolerance, and possible ancillary hair-care benefits, we also acknowledge enduring challenges, such as color intensity and shade variability, limited pigment longevity, batch-to-batch standardization problems, and a lack of long-term clinical data. Lastly, we address sustainability issues (plant sourcing, waste reduction, biodegradable carriers) and offer a research roadmap for the next generation of herbal hair color products, which includes sophisticated pigment engineering, actives that target the scalp microbiome, and thorough in-use consumer studies. Thus, this research presents herbal mehendi formulations as integrated hair-care systems that are in line with consumer wellness trends and sustainable product design, rather than only as cosmetic colorants.

Introduction

The human desire to appear beautiful is an age-old inclination that influences people of all generations. In today's world, appearance has become a major concern for many individuals. People pay close attention to every aspect of their physical presentation, and the market offers numerous products designed to enhance beauty. These cosmetic products may be synthetic, natural, or semi-synthetic in nature. Among the features that significantly affect a person's appearance, hair plays an essential role[1].Issues such as baldness and premature graying affect approximately 60–70% of the population. Hair graying often results from factors like vitamin B12 deficiency, thyroid disorders, and genetic predisposition. Early loss of hair pigment can also be triggered by stress, illness, UV radiation, alcohol consumption, certain medications, and shock. The frequent use of synthetic hair dyes to alter hair color can lead to hair damage due to their chemical composition and mechanism of action.As a result, herbal alternatives are gaining popularity for maintaining healthy hair. Herbal medicines are derived from various parts of plants such as stems, leaves, seeds, roots, flowers, and bark, and can be used in either raw or processed forms. They are incorporated into many personal care formulations, including herbal shampoos, hair dyes, toothpastes, and tablets. Common herbs used for these purposes include shikakai, henna, bhringraj, and reetha.Historically, natural dyes obtained from plant materials such as roots, bark, stems, leaves, berries, and flowers were used to color fabrics, carpets, and garments. Today, the growing preference for natural remedies is driven by their safety, eco-friendliness, and minimal side effects. Traditional Ayurvedic herbs like bhringraj, henna, reetha, and methi seeds are well known for their role in promoting hair growth and serving as natural colorants.Compared to synthetic alternatives, natural dyes are environmentally safer, less toxic, and cause fewer allergic reactions. Their active components—such as catechins, flavonoids, and ascorbic acid—possess strong antioxidant properties that benefit hair health. Herbal hair dyes are also effective against dandruff, lice, and premature graying. Because they use plant-based ingredients instead of harsh chemicals, natural dyes help preserve the scalp and hair structure while providing a safe coloring option. Pigments such as caramel and others are often used in these natural formulations[2,3].

Hair

In humans, hair—especially that on the scalp, eyebrows, and eyelashes—performs several essential protective functions. These features are often considered distinctive and hold particular aesthetic importance, especially in women. Scalp hair shields the head and neck from sunlight, cold weather, and physical injury, while eyebrows and eyelashes act as natural barriers that protect the eyes from dust and other foreign particles. In this way, hair provides a layer of defense against various environmental and mechanical factors, supporting the skin's natural protection mechanisms [4].

Moreover, hair enhances the ability to sense tactile stimuli on the skin. Beyond its biological functions, it also carries social and sexual significance, influencing human interaction and perception. Hair disorders—such as excessive hair growth or hair loss—can have a profound psychological impact on an individual's self-esteem and overall quality of life. For example, people suffering from androgenetic alopecia often show a higher incidence of personality and emotional disturbances compared to the general population, demonstrating the strong emotional and social dimensions linked to hair conditions.

History of Hair Colouring

The practice of coloring hair dates back to ancient civilizations. Historical records suggest that Ramesses II, the pharaoh of Egypt's nineteenth dynasty, had his hair treated with henna even after his death, indicating the early use of natural dyes for cosmetic purposes. In ancient Greece, people lightened their hair by rinsing it with a potassium-based solution and then applying ointments prepared from pollen and flower petals. Throughout history, individuals have used a variety of colors—such as black, red, green, and gold—to dye their hair for aesthetic or cultural reasons.

The development of synthetic hair dyes began much later. The first artificial dye for hair was synthesized in 1856, marking a major advancement in cosmetic chemistry. In 1863, the German chemist August Wilhelm von Hofmann identified para-phenylenediamine (PPD), a compound that later became a key ingredient in modern hair dye formulations. By the late nineteenth century, the foundation for today's synthetic hair coloring products had been firmly established.

Anatomy and Physiology of Hair

Structure of Hair

Hair is composed of dead, keratinized cells that are tightly bound together. The visible portion of hair above the skin's surface is known as the shaft. The cross-sectional shape of the shaft varies—straight hair typically has a round cross-section, wavy hair tends to be oval, and curly or woolly hair is usually elliptical or kidney-shaped. The portion of the hair that extends downward into the dermis and sometimes into the subcutaneous tissue is called the root. Both the root and the shaft are organized into three concentric layers, forming a complex structural

The major parts of the hair structure include

Bulb

The bulb is the enlarged base of the hair located deep within the dermis. It plays a key role in hair growth and anchors the hair to the skin. The bulb is connected to the dermal papilla, a structure rich in blood vessels and nerve endings that supply essential nutrients and signals required for the growth and regeneration of hair

Root

Found beneath the epidermis, the root is the section of the hair between the bulb and the surface of the skin. It is firmly embedded within the hair follicle. The root and the lower portion of the shaft consist of three concentric layers — the medulla (innermost), cortex (middle), and cuticle (outermost).

Shaft

The shaft represents the exposed portion of the hair that extends above the skin surface. It is made up of the same three layers—cuticle, cortex, and medulla—and is responsible for the texture, strength, and color of the hair.

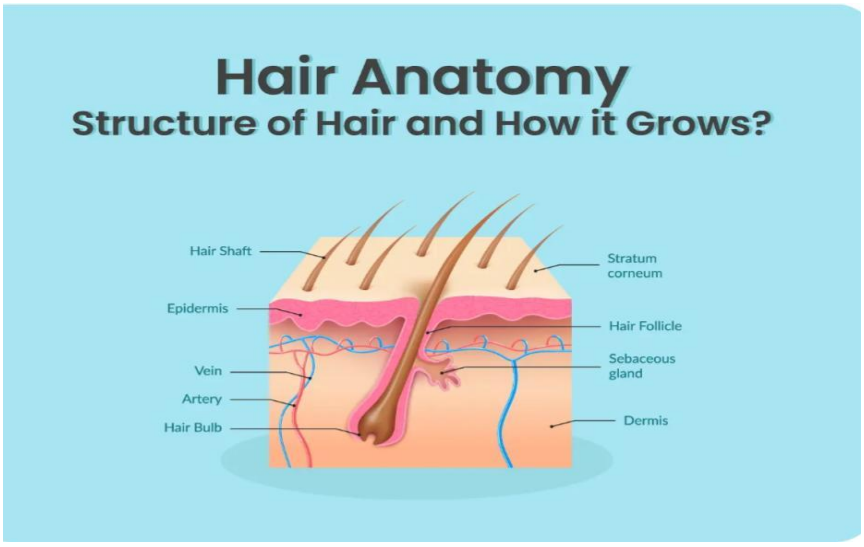
Cortex

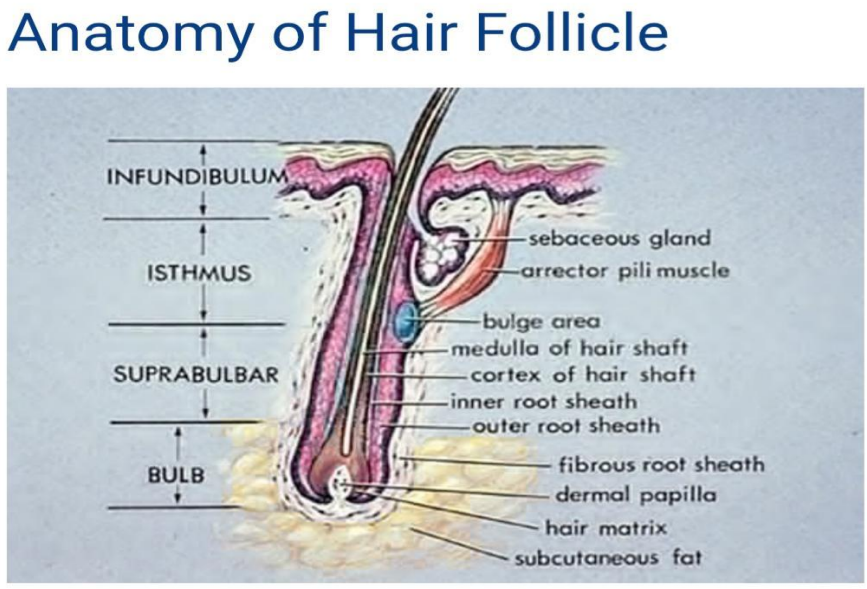
The cortex forms the largest portion of the hair shaft and surrounds the medulla. It is made up of elongated, spindle-shaped cells arranged lengthwise along the shaft. In dark hair, the cortex contains pigment granules that give color, while in white or gray hair, air spaces are present instead of pigment. The cortex is composed of densely packed cortical cells embedded in an amorphous matrix rich in sulfur-containing proteins and keratin filaments aligned parallel to the hair's longitudinal axis

Cuticle

The cuticle represents the outermost protective layer of the hair. It consists of a single layer of thin, flattened cells that overlap like roof shingles. These cells are highly keratinized, providing durability and protection to the inner layers. Structurally, the cuticle includes two main components: the endocuticle and the exocuticle. Smooth and intact cuticles help reduce friction between hair strands and reflect light, contributing to the hair's shine and smooth texture.

The principal protein found in hair is keratin, a tough, fibrous protein composed mainly of the amino acids tyrosine, glycine, and cysteine. These amino acids form long chains arranged in an α-helix structure, which contributes to the hair's strength and resilience. Keratin generally occurs in three types—basic, neutral, and acidic—each playing a specific role in maintaining the integrity of the hair fiber





Physiology of Hair

The growth and development of hair are influenced by multiple factors operating within the hair follicle, including hormones, cytokines, and various external stimuli. This process is highly dynamic and cyclical in nature. The duration of the hair growth cycle varies depending on factors such as the location of the hair on the body, age, nutritional status, developmental stage, and environmental influences like daylight exposure. Overall, hair health and growth are regulated by a complex interaction of biological, hormonal, and environmental components. Hair growth follows a continuous cycle composed of phases of active growth, regression, and rest

Anagen Phase (Growth Phase)

The anagen phase represents the active period of hair growth, during which the hair follicle undergoes significant enlargement and takes on a bulb-like or onion-shaped structure. This stage is further divided into six sub-stages (I–VI).

In the initial stages (I–V), known as proanagen, progenitor cells in the follicle multiply rapidly, surrounding the developing dermal papilla, extending deeper into the skin, and beginning the formation of the hair shaft.

By stage VI, or metanagen, the follicle reaches full maturity as the epithelial bulb organizes around the dermal papilla, leading to the production of a new hair shaft that eventually emerges from the skin surface. The anagen

phase is the longest stage of the hair cycle and can persist for several years, depending on genetic and physiological factors

Catagen Phase (Transitional Phase)

The catagen phase marks a brief transitional period between growth and rest. During this stage, the hair follicle begins to shrink, and the connection between the follicle and the dermal papilla gradually detaches. This regression phase prepares the follicle for the resting stage that follows.

Telogen Phase (Resting Phase)

The telogen phase is characterized by a period of dormancy in which the follicle remains inactive and no new hair growth occurs. The hair fiber stays anchored within the follicle until it eventually sheds. Afterward, the cycle recommences with the onset of a new anagen phase

In summary, hair growth is a cyclic and continuous process involving three primary phases—anagen (growth), catagen (transition), and telogen (rest)—each regulated by intricate physiological and molecular mechanisms that ensure the renewal and maintenance of healthy hair Hair graying can occur due to several factors, including genetic predisposition, nutritional deficiencies, stress, and certain medical

Hair daye

Studies suggest that nearly half of the global population experiences some degree of hair graying before the age of fifty, with heredity being the most significant contributing factor. To cover or modify gray hair, many individuals rely on chemical-based hair dyes, which, despite their effectiveness, can sometimes lead to allergic reactions, skin irritation, and other adverse effects. As a result, natural and herbal dyes have gained widespread popularity as safer and more sustainable alternatives. With increasing emphasis on personal grooming and appearance, maintaining healthy and aesthetically pleasing hair has become an important aspect of self-care [14].Historically, plant-based dyes have been used for centuries to color textiles such as carpets and fabrics. Today, the same principle is being applied in the cosmetic field, as herbal hair dyes are preferred for their natural origin, lower toxicity, and minimal side effects compared to synthetic products. In contrast, conventional hair dyes containing harsh chemicals can cause scalp sensitivity and other dermatological issues.The growing interest in herbal formulations stems from their perceived safety, biocompatibility, and nourishing properties. In Ayurvedic medicine, numerous plant-based remedies have long been used to promote hair growth, restore natural color, and improve overall hair health [15].Hair remains one of the most defining features of human appearance, and with age, approximately 70% of individuals over fifty experience either graying or thinning of hair. This rising awareness of hair's aesthetic and psychological importance continues to drive the demand for natural hair care and coloring solutionsAge plays a significant role in the onset of hair graying, though genetics largely determine when the process begins. However, several external and internal factors—such as certain illnesses, medications, and psychological stress—can accelerate the loss of hair pigmentation, leading to premature graying. In India, the traditional use of natural colorants like henna for hair and hand decoration during festivals reflects a long-standing cultural practice. These plant-derived dyes are popular due to their safety, affordability, easy accessibility, and minimal side effects.In today's era of environmental consciousness, the use of natural and eco-friendly hair colorants aligns well with global sustainability efforts. Beyond their physical function, hair also serves as an important symbol of personality, identity, and self-expression. Based on their longevity and the depth of color they impart, hair dyes are generally categorized into three main types: temporary, semi-permanent, and permanent.

Temporary Hair Dyes

Temporary hair dyes are water-soluble colorants with relatively high molecular weights, which prevent them from penetrating deeply into the hair shaft. Instead, they coat the outer surface of the hair to provide color. Many of these dyes are derived from natural sources, such as henna, and can be easily removed through routine washing. They are primarily used to enhance existing shades, create highlights, or refresh faded tones rather than permanently alter the hair's natural color.These dyes are particularly effective on light-colored, bleached, or white hair, as the lighter background makes the applied color more visible. Temporary dyes can help mask small areas of gray hair, add subtle color reflections, or neutralize yellowish tones in white hair. Because they

remain on the surface, they are suitable for individuals with up to 15% gray hair coverage.Chemically, temporary dyes typically have acidic properties and large molecular structures that ensure minimal penetration into the hair cortex. Their anionic nature provides good water solubility and facilitates easy removal during the first wash. Application can be done in two ways—either gradually (progressive application) or in a single session, followed by rinsing to remove any unbound pigment. These dyes are available in various cosmetic forms, including shampoos, gels, emulsions, and liquid solutions [17].

Semi-Permanent Hair Dyes

Semi-permanent dyes are often synthetic compounds derived from coal-tar-based intermediates with lower molecular weights compared to temporary dyes. Due to their smaller size, they can partially penetrate the hair cortex and are more resistant to washing and friction. Unlike permanent dyes, semi-permanent formulations do not rely on an oxidation reaction; instead, they involve a simple application process lasting 10–40 minutes, after which the hair is rinsed thoroughly.To ensure proper adhesion during application, these formulations are designed with an optimal viscosity that allows even coverage on the hair surface. Because of their slightly alkaline pH, the hair cuticle opens slightly, allowing limited dye penetration. As a result, semi-permanent dyes can last through approximately 15–20 washes before fading.Many modern semi-permanent products combine direct-acting dye molecules with oxidation dye precursors that react mildly with hydrogen peroxide (H_2O_2) to enhance color intensity and durability. These dyes are often used for tone enhancement, color correction, and temporary experimentation with hair shades.

Permanent Hair Dyes

Permanent hair dyes are primarily used to achieve long-lasting color changes that withstand multiple washes and environmental exposure. The coloring process generally begins with bleaching or lightening the natural pigment of the hair to prepare it for dye absorption. The key components involved in this oxidative coloring system include primary intermediates, couplers, and oxidizing agents such as hydrogen peroxide or ammonium/sodium persulfates.During the coloring process, the primary intermediates react with the couplers in the presence of an oxidizing agent, producing complex colored molecules that become trapped within the hair cortex. This chemical reaction alters the natural pigment permanently, resulting in the desired hair shade. The newly formed color molecules are large and insoluble, making them resistant to washing, sunlight, and friction, thus providing durable, long-term color retention.In simple terms, a dye is a colored compound that has a strong binding affinity for fibers, making it capable of imparting long-lasting color. Hair dyes are particularly valued for their ability to darken or modify natural hair color while maintaining durability over time.Before applying color, bleaching is often necessary to achieve the desired shade, especially when transitioning from dark to lighter tones. This process involves the use of specific chemical lightening agents that remove or reduce the natural pigment (melanin) within the hair shaft. Approximately 80% of the hair color products available in the market belong to the permanent dye category, which can produce a wide range of shades and effectively cover up to 100% of gray or white hair.The interaction between ammonium hydroxide and oxidizing agents enables both lightening and coloring effects, allowing for the creation of diverse hair tones—from very light blondes to deep browns and blacks. In contrast, semi-permanent dyes generally contain monoethanolamine (MEA) as an alkalizing agent, which has a gentler action and lower lightening ability compared to ammonia-based formulations used in permanent dyes.The process of color formation in oxidative hair dyes is based on a chemical reaction between precursors and oxidizing agents. These precursors are classified into two main groups: primary intermediates and couplers (also known as secondary intermediates). When these compounds react together in the presence of an oxidant, they form large, colored molecules that become trapped within the hair cortex, producing a stable and long-lasting color result.

Herbal Hair Dye

Since ancient times, plants such as henna, chamomile, indigo, and others have been used to naturally color gray or silver hair, often giving it darker shades. However, achieving true black hair with these natural dyes is challenging, and users frequently end up with reddish or coppery tones instead. The natural variation in hair color can be influenced by several factors, including genetic background, environmental exposure, the use of chemical products, and other physiological conditions, which may limit the range of achievable shades with herbal dyes.While synthetic hair colors provide long-lasting shades and help maintain natural shine, they carry a significant risk of allergic reactions in some individuals. Even products marketed as "natural" may contain chemicals such as phenylenediamine (PPD), which can irritate the skin or stain clothing during application [22].Recognizing these risks, there is growing interest in developing hair dyes made entirely from plant-based compounds that provide rich, natural color without causing irritation, allergic responses, or scalp damage. Combining different plant extracts can produce naturally dark shades, such as those derived from henna, which also protect the hair cuticle and scalp from harm. Unlike chemical dyes, these natural formulations are generally safe and do not cause skin discoloration, itching, or allergic reactions.The use of natural dyes dates back to the Bronze Age, when primitive techniques evolved into more sophisticated methods for coloring textiles and hair. Up until the mid-nineteenth century, most fabrics and materials were dyed with natural plant-based colors [23]. The later rise of synthetic dyes was driven by their low cost, ease of manufacturing, wide color range, and better colorfastness. Consequently, by the early twentieth century, the use of natural dyes had declined sharply.It is important to note, however, that "natural" does not always mean safe. While toxicological data and safety records are available for synthetic dyes, similar comprehensive studies for natural dyes are limited. Although most herbal dyes are safe, some can be harmful depending on the mordants or preparation methods used. For example, logwood can produce a range of colors—from violet and blue-grey to deep natural black—depending on the mordant applied [24].Today, herbal hair dyes are increasingly preferred as an alternative to chemical-based products, which may contribute to skin disorders and other health issues [25]. While genetics play a primary role in determining the onset of hair graying, other factors—including illness, medications, stress, and environmental influences—can lead to premature depigmentation. Historically, natural dyes have been used for various purposes, including coloring textiles, carpets, and rugs, derived from plant parts such as roots, bark, leaves, stems, berries, and flowers. In general, any substance, natural or synthetic, that imparts color or alters an existing color is classified as a dye. For instance, a "blond hair dye" refers to a product formulated specifically to color blonde hair, and most natural dyes are derived from plant sources

Objective of hair dye

1. To consolidate various natural dye extraction techniques into a single reference.
2. To evaluate the fastness properties of different natural dyes, assessing how well the color persists over time.
3. To describe extraction methods suitable for a variety of plant sources.
4. To analyze multiple parameters, including patch tests, phytochemical content, physico-chemical properties, sensory (organoleptic) characteristics, rheological behavior, and other tests to determine overall efficacy

Advantages of Herbal Hair Dyes

1. Chemical-Free and Natural: Primarily composed of natural ingredients, these dyes avoid harsh chemicals.
2. Safe Gray Coverage: Effectively covers gray hair without causing adverse effects such as irritation or allergic reactions.
3. Deep Conditioning and Nourishment: Penetrates hair strands to provide nourishment and conditioning from within [29].
4. Addresses Hair Concerns: Can help improve existing hair problems, such as dryness, breakage, or dullness.
5. Natural Look with Human Hair Fibers: When combined with natural human hair fibers, it creates a realistic appearance.
6. Styling Flexibility: Allows for natural hairstyles without compromising the hair's texture.
7. Lower Heat Vulnerability: Hair treated with herbal dyes is less prone to damage from heat styling tools.
8. Compatibility with Coloring and Perming: Supports additional hair treatments, including coloring and perming.
9. Natural Movement: Hair retains its natural flow and movement, enhancing overall appearance [30, 31].

Disadvantages of Herbal Hair Dyes

1. Higher Cost: Typically more expensive than synthetic hair dyes.
2. Increased Maintenance: Requires more care and attention to maintain color and hair health.
3. Styling Effort: Additional styling may be necessary to achieve the desired look
4. Susceptibility to Sunlight and Environmental Damage: Herbal or natural hair treatments may be more prone to fading when exposed to sunlight and other environmental factors.
5. Potentially Greater Weight: Wigs or hair extensions made from natural hair or plant-based fibers may be heavier compared to synthetic alternatives, which can affect comfort during wear.

Fenugreek Methiconsist of dried seeds of plant Trigonella foenum.		Hair growth promoter[45]
Orange peel It consists of fresh fruits of plant Citrus aurantarium. Family: Rutaceae		Hair growth promoter[45]
Peppermint Mentha piperata is a strongly scented perennial herb Family-Labiatae		Hair growth promoter, improve scalp[46]
Marigold (Genda) It consists of flowers and petals of Tagetes erecta Family - Asteraceae		Improve hair health, boost hair growth[46]
Custard apple seeds Sharifa, sitaphal, sugar apple It consists of dried seeds of Annona squamosa Family- Annonaceae		Anti-lice agent, prevent premature graying[47]
Banana peel It consist of fruit of Musa acuminata Family- Musaceae		Provide shine to hair and strengthen hair and improve hair health[48]
Coffee It consists of dried ripe seeds of Coffea arabica Family- Rubiaceae		Reduce hair loss and encourage hair growth, darken hair[49]
Beetroot It consist of Beta vulgaris Family- chenopodiaceae		Reduces hair breakage, nourishes hair follicles, and helps to delay premature graying.[49]

Cinnamon It consists of dried inner bark of shoot of tree Cinnamomum zeylanicum Family- Lauraceae		Possess anti fungal properties, stimulate circulation, encourage hair growth and reduce hair loss[50]
Black sesame Kaale til It consists of seeds of Sesamum indicum Family- Pedaliaceae		Strengthen hair follicles, improve hair health , promote hair growth , stimulate melanocyte activity[50]
Black seed It consists of seeds of Nigella sativa Family- Ranunculaceae		Minimizes dandruff, moisturizes hair, soothes scalp dryness, and prevents graying.[51]
Turmeric It consists of dried rhizomes of Curcuma longa Family- Zingiberaceae		Thickens hair, stimulate hair growth, anti bacterial in nature ,promote hair growth[52]
Rose It consists of flowers and petals of Rosa hybrida Family- Rosaceae		Conditions hair, nourishes the scalp, reduces dandruff , promotes hair growth[53]

Comparison Between Marketed Synthetic Formulations and Herbal Formulations

In both rural and urban regions, many people continue to rely on herbal ingredients for traditional cosmetic applications. The demand for herbal-based, natural products is growing due to their inherent safety, minimal side effects, and nutritional benefits for hair. Commonly used herbal ingredients include amla, indigo, methi (fenugreek), henna, tea, curry leaves, lemon juice, beetroot juice, bhringraj, honey, and shikakai. These plants have been traditionally employed as hair colorants and to promote hair growth, in contrast to chemical-based hair dyes, which often cause skin irritation or other dermatological issues due to the synthetic chemicals they contain [54].Natural dyes are also eco-friendly. For example, turmeric—one of the brightest natural sources of yellow dye—possesses antiseptic properties and can promote hair growth, while indigo provides a cooling effect on the scalp. The advantages of using herbal colorants are numerous: they are generally safe for the body, environmentally compatible, and derived from renewable natural sources. Furthermore, the preparation of herbal dyes involves minimal risk of adverse chemical reactions, making them a gentler alternative to synthetic formulations. The colors obtained from natural dyes are typically subtle, harmonious, and provide a natural appearance, enhancing hair health while avoiding the harmful effects associated with chemical dyes.Natural dyes are visually appealing and generally safe for human health, and in some cases, they may

even provide therapeutic benefits. Their use also produces minimal environmental waste, making them eco-friendly alternatives to synthetic dyes. However, natural dyes do have certain limitations, including restricted availability, lower color yield, variable stability, and the complexity of the dyeing process. Additionally, they cannot fully replace synthetic dyes in all applications, but they hold a valuable and unique position in the market [55].The development of the first synthetic dyes by William Henry Perkin in 1856 revolutionized the field, offering faster and more versatile coloring options across industries such as textiles, cosmetics, food, photodynamic therapy, and non-linear optical applications. Synthetic dyes became popular due to their ease of application, wide color range, and lower cost [56].In recent decades, however, the use of synthetic dyes has declined due to growing environmental awareness and recognition of their harmful effects. Many synthetic dyes are toxic and non-biodegradable, and their use has been associated with serious health risks, including allergic reactions and potential carcinogenicity [57].Commercial synthetic hair dyes typically contain a combination of peroxide and ammonia, which can alter the hair structure, causing damage and increasing the risk of allergic reactions. Paraphenylenediamine (PPD), a common ingredient in many hair dyes, is known to trigger allergic skin reactions, including dermatitis around the lips, redness, and swelling of the scalp and face. Market surveys in India have revealed that some products labeled as herbal or natural hair dyes may actually contain significant amounts of PPD—sometimes 20–25% by concentration—posing health risks despite their "natural" claims. The development of the first synthetic dyes by William Henry Perkin in 1856 revolutionized the field, offering faster and more versatile coloring options across industries such as textiles, cosmetics, food, photodynamic therapy, and non-linear optical applications. Synthetic dyes became popular due to their ease of application, wide color range, and lower cost [56].In recent decades, however, the use of synthetic dyes has declined due to growing environmental awareness and recognition of their harmful effects. Many synthetic dyes are toxic and non-biodegradable, and their use has been associated with serious health risks, including allergic reactions and potential carcinogenicity [57].

Sr no.	Synthetic hair dyes	Marketed hair dye	Chemical ingredients
1-	Godrej expert rich crème		p-phenylenediamine
2-	L'Oreal Paris Excellence Creme Hair color		p-phenylenediamine
3-	Garnier `hair color		Resorcinol,p-phenylenediamine
4-	L'Oreal Paris casting crème gloss Hair color		Hydrogen peroxide

Problems Associated with Chemical-Based Hair Dyes

Most synthetic hair dyes contain chemicals such as para-phenylenediamine (PPD), parabens, hydrogen peroxide, sorbates, and ammonia, which are essential for achieving lasting color effects. While PPD is commonly used for dark hair shades, prolonged or frequent use can be hazardous. PPD is a toxic compound that may lead to severe side effects, including rhabdomyolysis, kidney failure, and respiratory complications.Other chemicals in hair dyes, such as ammonia, hydrogen peroxide, parabens, and resorcinol, also pose health risks. Ammonia is used to open the hair cuticle, allowing color to penetrate the shaft, but it can cause lung irritation, hair cortex damage, and frizz or brittleness. Hydrogen peroxide, while effective in bleaching, can contribute to dryness, hair breakage, and chemical burns. Parabens and resorcinol have been linked to hormonal disturbances, scalp irritation, dandruff, and hair loss, and in some cases, may carry carcinogenic potential

Side Effects of Hair Dye Use

Excessive Chemical Exposure: Permanent hair dyes often contain peroxide and ammonia. Repeated use can strip the hair of its natural pigment, resulting in dull, brittle hair and potentially causing hair loss.Allergic Reactions: PPD is a common allergen. Individuals with dermatitis, eczema, or psoriasis may experience severe reactions, including redness, swelling, itching, and skin irritation.Impact on Pregnancy: Hair coloring during pregnancy may pose risks to the fetus, including potential exposure to carcinogenic compounds.Respiratory Issues: Inhalation of chemicals such as persulfates present in hair dyes can aggravate conditions like asthma, and prolonged exposure may lead to lung irritation, coughing, and breathing difficulties.Overall, while chemical hair dyes are effective for altering hair color, their frequent use carries multiple health risks affecting the skin, hair, and respiratory system, highlighting the importance of safer alternatives such as herbal or plant-based dyes.

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