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Herbal Shampoos for Protection Against Pollution-Induced Hair Damage: A Comprehensive Review

Aakash Bairagi[1], Dr. Shelesh Jain[2], Dr. Akhlesh Kumar Singhai[3]
[1] *M. Pharm (IV Semester) Student, School of Pharmacy, LNCT University, Bhopal (M.P.), India*
[2] *Professor, School of Pharmacy, LNCT University, Bhopal (M.P.), India*
[3] *Director, School of Pharmacy, LNCT University, Bhopal (M.P.), India.*
Corresponding Author: Aakash Bairagi

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ABSTRACT: Environmental pollution has emerged as a major external factor contributing to hair and scalp disorders such as oxidative stress, follicular inflammation, dandruff, premature greying, and alopecia. Continuous exposure of hair to particulate matter, toxic gases, and free radicals weakens hair structure and disrupts scalp homeostasis. This review highlights the role of herbal shampoos as safe and eco-friendly alternatives for protecting hair against pollution-induced damage. Medicinal plants such as *Sapindus mukorossi* (Reetha), *Acacia concinna* (Shikakai), *Phyllanthus emblica* (Amla), *Hibiscus rosa-sinensis*, *Moringa oleifera*, *Camellia sinensis* (Green tea), and *Aloe barbadensis* are discussed with respect to their phytochemical composition, antioxidant, cleansing, anti-inflammatory, and anti-alopecia activities. Natural surfactants and antioxidant-rich herbal constituents play a synergistic role in removing pollutants, neutralizing reactive oxygen species, and maintaining scalp and follicle health. The review also summarizes formulation perspectives, evaluation parameters, challenges, and future prospects of herbal shampoos. Overall, herbal shampoos represent sustainable and effective hair care solutions for mitigating pollution-related hair damage.

KEYWORDS: Herbal shampoo, Air pollution, Hair damage, Antioxidants, Polyherbal formulation, Scalp health.

I. INTRODUCTION

Hair is one of the most important appendages of the human body, serving both physiological functions (such as protection of the scalp against external factors) and psychological roles by contributing to an individual's appearance and confidence. In recent years, a significant rise in cases of alopecia (hair loss) has been observed worldwide, affecting both men and women across different age groups. Alopecia is commonly associated with genetic predisposition, hormonal imbalance, nutritional deficiencies, systemic diseases such as diabetes mellitus, and stress. However, one of the most concerning external contributors to alopecia in the modern era is environmental pollution.[1]

Air pollution has become one of the major health hazards of the 21st century due to rapid industrialization, urbanization, and vehicular emissions. Pollutants such as particulate matter (PM2.5 and PM10), volatile organic compounds, heavy metals, and nitrogen oxides directly interact with the skin, scalp, and hair. Unlike other body parts that can be protected by clothing, the hair and scalp remain continuously exposed to these environmental aggressors. Studies indicate that pollutants adhere to the hair shaft and penetrate scalp pores, resulting in oxidative stress, inflammation, alteration of the scalp microbiome, and weakening of hair follicles. These changes accelerate hair thinning, dandruff, premature greying, and alopecia.[2]

Furthermore, conventional hair care products available in the market are predominantly synthetic in nature, containing surfactants like sodium lauryl sulfate, parabens, silicones, and artificial fragrances. While these agents provide temporary cleansing, they are associated with long-term adverse effects such as scalp irritation, follicular damage, dryness, and hair breakage. In addition, synthetic surfactants are non-biodegradable,[3] thus adding further to environmental pollution. This creates a vicious cycle where not only does pollution cause hair damage, but synthetic products used to manage the problem contribute back to pollution.[4]

To overcome these challenges, there has been a growing interest in herbal and natural hair care formulations. Herbal extracts are rich in antioxidants, vitamins, essential oils, saponins, flavonoids, and polyphenols, which help in

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neutralizing reactive oxygen species (ROS)[5], reducing inflammation, blocking dihydrotestosterone (DHT), strengthening hair follicles, and restoring scalp health. Traditional herbs such as Reetha

(Sapindus mukorossi) and Shikakai (Acacia concinna) are natural cleansers due to their saponin content, while Amla (Emblica officinalis) provides vitamin C and antioxidants that protect against oxidative stress. Moringa oleifera[6] contains β-sitosterol, a natural DHT blocker, and Green Tea (Camellia sinensis) catechins inhibit 5-α reductase activity. Similarly, Hibiscus rosa-sinensis nourishes hair follicles and prolongs the anagen (growth) phase of hair. These herbs, when combined in a shampoo base, provide a synergistic action that can help in cleansing pollutant residues, preventing alopecia, and maintaining scalp health without harmful side effects.[7]

Considering the rising burden of pollution-related scalp disorders and the limitations of synthetic shampoos, there is a need to develop an eco-friendly, herbal-based shampoo formulation that not only provides effective cleansing but also offers protection against pollution-induced damage and alopecia. Such a formulation would address the dual concerns of human health and environmental sustainability, aligning with the growing consumer demand for safe, natural, and biodegradable personal care products.

S. No.	Plant (Botanical Name)	Major Phytochemicals	Pharmacological Role	Solubility Characteristics
1	*Sapindus mukorossi* (Reetha)	Saponins, sugars, fatty acids	Natural surfactant, antimicrobial, cleansing agent	Saponins – water soluble; fatty acids – soluble in ethanol and oils
2	*Acacia concinna* (Shikakai)	Saponins, tannins, flavonoids, vitamins (A, C, D, E, K)	Mild cleanser, conditioner, anti-dandruff	Saponins – water soluble; flavonoids & tannins – soluble in ethanol/methanol
3	*Phyllanthus emblica* (Amla)	Vitamin C, gallic acid, ellagic acid, flavonoids, tannins	Antioxidant, strengthens hair follicles, prevents greying	Vitamin C – water soluble; tannins/flavonoids – soluble in ethanol/methanol
4	*Moringa oleifera*	β-sitosterol, flavonoids, vitamins (A, C, E), linoleic & oleic acids	Anti-alopecia, antioxidant, anti-inflammatory	β-sitosterol – soluble in ethanol/acetone; vitamins – partially water soluble
5	*Camellia sinensis* (Green Tea)	Catechins (EGCG, ECG), polyphenols, caffeine	Antioxidant, 5-α reductase inhibitor, scalp protection	Catechins – soluble in water, ethanol, and DMSO
6	*Aloe barbadensis* (Aloe vera)	Polysaccharides, amino acids, enzymes, vitamins	Moisturizing, soothing, anti-inflammatory	Polysaccharides – water soluble; amino acids – water soluble
7	*Hibiscus rosa-sinensis*	Flavonoids, anthocyanins, mucilage, amino acids	Promotes hair growth, antioxidant, scalp protection	Anthocyanins – soluble in water/alcohol; mucilage – water soluble

Table 1: Major Phytochemicals of Selected Plants and Their Solubility Characteristics. [7-13]

II. REVIEW OF LITERATURE:

1. **Kumar et al**. (2025) reported that *Hibiscus rosa-sinensis* extract promotes the anagen phase of hair follicles and inhibits 5-α-reductase activity. Its antioxidant and anti-inflammatory properties protect follicles from oxidative stress, although lack of standardized extraction methods remains a limitation.[14]
2. **Tupe et al. (2025)** developed a herbal shampoo containing hibiscus extract and observed satisfactory pH, viscosity, foamability, and stability. The formulation showed mild antimicrobial activity and good consumer acceptability, supporting the safety of herbal shampoos.[15]
3. **Wankhade et al. (2025)** formulated a *Moringa oleifera* based herbal shampoo and reported significant antimicrobial activity along with good cleansing and conditioning effects. The study highlighted moringa's potential as a sustainable alternative to synthetic shampoos.[16]

International Journal of Pharmaceutical research and Applications
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4. **Thakur et al. (2025)** evaluated a soapnut-based herbal shampoo and found effective cleansing and dandruff control. However, higher concentrations of herbal surfactants caused scalp dryness, emphasizing the need for formulation optimization.[17]
5. **Son and Kwon (2025)** systematically reviewed the effects of air pollution on hair and scalp health and concluded that particulate matter induces oxidative stress and follicular inflammation, leading to hair loss and scalp disorders.[18]
6. **Tran et al. (2024)** demonstrated that antioxidant-rich formulations containing EGCG significantly reduce pollution-induced oxidative stress in skin models, supporting the role of antioxidants in anti-pollution cosmetic products.[19]
7. **Alnuqaydan (2024)** reviewed the toxicological risks associated with synthetic cosmetic ingredients and emphasized the need for safer, herbal-based alternatives to reduce long-term health hazards.[20]
8. **Cheyasak et al. (2024)** compared a herbal extract formulation with minoxidil in androgenetic alopecia and reported comparable efficacy with no adverse effects, highlighting the clinical potential of herbal therapies.[21]
9. **Wan et al. (2024)** optimized *Sapindus mukorossi* extract for use in shampoos and demonstrated effective sebum control and improved stability after decolorization, making it suitable for cosmetic applications.[22]
10. **Pailwan et al. (2024)** reviewed the cosmetic importance of *Acacia concinna* and concluded that its natural surfactant and antimicrobial properties make it a valuable ingredient in herbal shampoos.[23]
11. **Bhojane et al. (2023)** formulated an anti-dandruff herbal shampoo and observed favorable physicochemical properties with effective microbial control, supporting the efficacy of polyherbal formulations.[24]
12. **Chaudhary et al. (2023)** reviewed *Camellia sinensis* and highlighted its strong antioxidant and anti-inflammatory activities, although poor bioavailability remains a challenge.[25]
13. **Godeto et al. (2023)** demonstrated that herbal shampoos prepared from plant extracts showed comparable cleansing and conditioning effects to marketed shampoos with added antimicrobial benefits.[26]
14. **Akbarnejad (2023)** reported that green tea catechins inhibit 5-α-reductase and stimulate dermal papilla cells, suggesting a natural alternative for managing androgenetic alopecia.[27]
15. **Sochacki and Vogt (2022)** emphasized that *Sapindus mukorossi* saponins act as biodegradable natural surfactants with antimicrobial properties suitable for cosmetic formulations.[28]
16. **Sun et al. (2022)** reviewed natural polyphenols and confirmed their role in protecting hair follicles from oxidative damage, although stability issues limit their application.[29]
17. **Wang et al. (2022)** reviewed the nutritional composition and bioactive metabolites of Camellia sinensis and highlighted its antioxidant, antimicrobial, and cosmetic applications. The study emphasized the potential use of tea-derived polyphenols in hair care formulations, while noting the need for improved extraction and standardization techniques.[30]
18. **Korassa et al. (2022)** concluded that *Moringa oleifera* seed oil exhibits anti-alopecia activity through DHT inhibition and antioxidant mechanisms.[30]
19. **Roberts (2020)** highlighted air pollution as a major environmental factor contributing to dermatological and scalp disorders via oxidative stress pathways.[32]
20. **Ezekwe et al. (2020)** reported limited but promising evidence for natural ingredients in alopecia management, emphasizing the need for well-designed clinical trials.[33]

IV. DRUG / PLANT PROFILE

- **Sapindus mukorossi (Reetha)**

  Sapindus mukorossi (Family: Sapindaceae) is widely used as a natural cleansing agent due to its high saponin content. The fruit pericarp contains triterpenoid saponins that act as natural surfactants, producing foam and effectively removing dirt and oil from hair and scalp. Reetha also exhibits antimicrobial and anti-dandruff activity, making it suitable for herbal shampoo formulations.[34,35]

- **Acacia concinna (Shikakai)**

  Acacia concinna (Family: Fabaceae) is traditionally used in Ayurvedic hair care preparations. It contains saponins, flavonoids, tannins, and vitamins that provide mild cleansing without stripping natural oils.

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Shikakai acts as a natural conditioner, improves hair texture, reduces dandruff, and promotes scalp health. [34,36]

- **Phyllanthus emblica (Amla)**

  Phyllanthus emblica (Family: Phyllanthaceae) is rich in vitamin C, tannins, and polyphenols. It possesses strong antioxidant activity, strengthens hair follicles, prevents premature greying, and enhances hair growth. Amla protects hair from oxidative stress induced by environmental pollutants. [34,37]

- **Moringa oleifera**

  Moringa oleifera (Family: Moringaceae) contains β-sitosterol, flavonoids, and essential fatty acids. It exhibits antioxidant, anti-inflammatory, and anti-alopecia activities by inhibiting dihydrotestosterone (DHT). Moringa helps in nourishing the scalp and protecting hair follicles from pollution-induced damage. [34,38,39]

- **Camellia sinensis (Green Tea)**

  Camellia sinensis (Family: Theaceae) leaves are rich in catechins such as epigallocatechin gallate (EGCG). These compounds exhibit potent antioxidant and anti-inflammatory properties and inhibit 5-α reductase activity, thereby reducing hair fall and protecting the scalp from oxidative stress. [34,40]

- **Aloe barbadensis (Aloe vera)**

  Aloe barbadensis (Family: Asphodelaceae) gel contains polysaccharides, amino acids, enzymes, and vitamins. It provides moisturizing, soothing, and anti-inflammatory effects on the scalp. Aloe vera helps in reducing irritation, dandruff, and dryness associated with pollution exposure. [34,41]

- **Hibiscus rosa-sinensis**

  Hibiscus rosa-sinensis (Family: Malvaceae) is known for its hair growth–promoting activity. It contains flavonoids, anthocyanins, and mucilage that nourish hair follicles, improve hair strength, and protect the scalp. Hibiscus also exhibits antioxidant and antimicrobial properties.[34,42]

IV. DISCUSSION

Environmental pollution has emerged as a major extrinsic factor responsible for hair and scalp damage in urban populations. Pollutants such as particulate matter (PM2.5 and PM10), heavy metals, nitrogen oxides, and polycyclic aromatic hydrocarbons adhere to the hair shaft and penetrate scalp pores, resulting in oxidative stress and inflammation. These pollutants generate reactive oxygen species (ROS), which damage hair cuticle proteins, weaken hair follicles, disrupt the scalp microbiome, and accelerate conditions such as dandruff, hair thinning, premature greying, and alopecia. Conventional synthetic shampoos primarily focus on cleansing action but often contain harsh surfactants and preservatives that strip natural oils, irritate the scalp, and may aggravate pollution-induced damage. In contrast, herbal shampoos offer a dual advantage by combining gentle cleansing with protective and therapeutic effects. Natural surfactants such as saponins from Sapindus mukorossi and Acacia concinna effectively remove dirt and pollutants without damaging the scalp barrier. The presence of antioxidant-rich herbs such as Phyllanthus emblica, Camellia sinensis, Hibiscus rosa-sinensis, and Moringa oleifera plays a crucial role in neutralizing free radicals generated due to pollution exposure. These herbs contain polyphenols, flavonoids, catechins, and vitamins that protect hair follicles from oxidative stress and inflammation. Additionally, bioactive constituents such as β-sitosterol from Moringa oleifera and catechins from green tea inhibit 5-α reductase activity, thereby reducing dihydrotestosterone (DHT)-mediated hair loss. Hydrating and soothing agents such as Aloe barbadensis help restore scalp moisture, reduce irritation, and improve overall scalp health. The synergistic action of cleansing agents, antioxidants, anti-inflammatory compounds, and hair growth promoters in polyherbal shampoos makes them effective alternatives to synthetic formulations for managing pollution-induced hair damage.

V. CHALLENGES AND LIMITATIONS

Despite the increasing popularity and therapeutic potential of herbal shampoos, several challenges and limitations restrict their large-scale acceptance and scientific validation. One of the major challenges is the variability in phytochemical composition of herbal ingredients. Factors such as geographical origin, climatic conditions, soil quality, harvesting season, and post-harvest processing significantly influence the concentration of active constituents, leading to batch-to-batch variation in efficacy and quality of herbal formulations.

Another important limitation is the comparatively lower stability of herbal shampoos when compared to synthetic formulations. The

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absence of strong synthetic preservatives may result in microbial contamination, reduced shelf life, and changes in color, odor, or consistency during storage. Although natural preservatives are available, their effectiveness and compatibility with polyherbal formulations require further optimization and validation.

Standardization and quality control of herbal shampoos also remain challenging due to the complex nature of plant-based ingredients. Identification of suitable marker compounds and establishment of validated analytical methods are essential but often lacking. Additionally, the lack of extensive clinical studies evaluating the long-term safety and efficacy of herbal shampoos limits their acceptance in evidence-based cosmetic and pharmaceutical practice.

Regulatory challenges further complicate the development of herbal cosmetic products, as regulatory guidelines for herbal formulations are less uniform across different regions. This may result in variations in product quality, labeling, and consumer trust. Moreover, large-scale production of herbal shampoos requires sustainable sourcing of raw materials, which may pose economic and environmental challenges if not properly managed.

VI. FUTURE PROSPECTS

The growing awareness regarding the harmful effects of environmental pollution on hair and scalp health has created significant scope for the development of advanced herbal hair care formulations. Future research should focus on the standardization of herbal raw materials to ensure consistency in phytochemical composition, quality, and therapeutic efficacy. Variations due to geographical origin, seasonal changes, and extraction methods can be minimized through the adoption of validated cultivation practices and optimized extraction techniques.

Advanced analytical tools such as High Performance Liquid Chromatography (HPLC), Gas Chromatography–Mass Spectrometry (GC–MS), and Fourier Transform Infrared Spectroscopy (FTIR) may be employed for phytochemical profiling, quality control, and identification of marker compounds in herbal shampoos. Such approaches will enhance scientific validation and regulatory acceptance of herbal formulations.

Further preclinical and clinical studies are required to establish the long-term safety, efficacy, and anti-pollution potential of herbal shampoos in diverse populations. Controlled clinical trials can provide strong evidence regarding their antioxidant, anti-alopecia, and scalp-protective effects. Additionally, incorporation of novel delivery systems such as herbal extracts in nano- or micro-encapsulated forms may improve stability, bioavailability, and sustained release of active constituents.

From an industrial perspective, the use of green extraction technologies, biodegradable excipients, and eco-friendly packaging materials can significantly enhance the sustainability and market appeal of herbal shampoos. With increasing consumer preference for natural and environmentally responsible products, herbal anti-pollution shampoos hold strong commercial potential. Integration of traditional Ayurvedic knowledge with modern pharmaceutical and cosmetic sciences can pave the way for innovative, effective, and sustainable hair care solutions in the future.

VII. CONCLUSION

Environmental pollution has become an unavoidable part of modern life and is increasingly recognized as a significant contributor to hair and scalp disorders. Continuous exposure of hair to particulate matter, toxic gases, heavy metals, and free radicals results in oxidative stress, follicular inflammation, disruption of the scalp microbiome, and weakening of hair follicles. These pathological changes manifest as dandruff, hair thinning, premature greying, and various forms of alopecia, highlighting the urgent need for protective and preventive hair care strategies.

Herbal shampoos offer a promising and holistic approach for managing pollution-induced hair damage by combining gentle cleansing with therapeutic benefits. Natural surfactants derived from plants such as *Sapindus mukorossi* and *Acacia concinna* effectively remove pollutants without stripping natural oils or irritating the scalp. In addition, antioxidant- and polyphenol-rich herbs including *Phyllanthus emblica*, *Camellia sinensis*, *Hibiscus rosa-sinensis*, and *Moringa oleifera* play a crucial role in neutralizing reactive oxygen species, reducing inflammation, and protecting hair follicles from environmental stress. The presence of bioactive compounds that inhibit 5-α reductase further supports the role of herbal shampoos in reducing hair fall and promoting follicular health.

Furthermore, soothing and moisturizing agents such as *Aloe barbadensis* help restore scalp hydration, reduce irritation, and improve overall scalp condition, making herbal formulations suitable for long-term use. The synergistic

interaction of cleansing agents, antioxidants, anti-inflammatory constituents, and hair growth promoters in polyherbal shampoos provides a comprehensive protective effect against pollution-induced hair damage.

In conclusion, herbal shampoos represent safe, eco-friendly, and sustainable alternatives to conventional synthetic hair care products. With appropriate standardization, scientific validation, and quality control, herbal shampoos have strong potential to meet the growing consumer demand for natural and environmentally responsible personal care solutions. Future research integrating traditional herbal knowledge with modern pharmaceutical and cosmetic sciences may further enhance the efficacy, acceptability, and commercial viability of anti-pollution herbal hair care formulations.

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