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Plant-Based Nutraceuticals for Health: Current Trends and Future Perspectives

[1]Trupti. Y. Biradar, [1]Gaurav Mitkari, [1]Aditya. K. Tanpure,
[2]Mr. Vikas Mugale, [3]Dr. Dharashive V.M.
[1]Student, [2]Guide, [3]Principal
Shivlingshwar College of Pharmacy, Almala
Corresponding author: truptibiradar16@gmail.com

Abstract: *Background: Hair health is shaped by genetics, hormones, nutrition, general health, lifestyle and the scalp environment. Plant-derived ingredients are receiving attention because they contain polyphenols, fatty acids, phytosterols, polysaccharides and other bioactive constituents. These compounds are being investigated for antioxidant, anti-inflammatory, androgen-related and scalp-conditioning properties.*
Objective: To provide an expanded overview of selected plant-based ingredients associated with hair health, their major phytoconstituents, proposed mechanisms, available human evidence, safety concerns and future research needs.
Approach: This focused narrative review builds on the literature and references in the supplied manuscript, with additional background from peer-reviewed reviews and clinical literature. It distinguishes human clinical findings from laboratory, animal and traditional-use evidence. No formal meta-analysis or independent risk-of-bias assessment was conducted.
Overview: Amla, rosemary, green tea, onion, fenugreek, aloe vera, curry leaves, pumpkin seed and saw palmetto are discussed. Human studies have investigated particular preparations of amla, rosemary oil, onion juice and pumpkin seed oil. These results cannot automatically be applied to every product containing the same plant. Evidence for several other ingredients remains preliminary.
Conclusion: Plant-based nutraceuticals are scientifically interesting, but the strength of evidence is uneven. Reliable development requires correct botanical identification, chemical standardization, safety testing and well-designed clinical trials..

Keywords: Plant-based nutraceuticals; hair health; hair follicle; alopecia; phytochemicals; botanical extracts; hair growth..

I. INTRODUCTION

Hair is more than a cosmetic feature. It protects the scalp, contributes to sensory functions and can influence confidence and social well-being. Changes in hair density, texture or shedding may therefore cause concern. At the same time, hair loss is not one single disease. Androgenetic alopecia, telogen effluvium, alopecia areata, inflammatory scalp disorders and damage to the hair shaft have different causes and require different approaches [1,2].

The hair follicle is a living structure within the skin. It repeatedly moves through growth, regression, rest and shedding phases. This activity is influenced by genetic programming, hormones, local signalling molecules, nutrition and the general condition of the body. A period of illness, marked stress or a documented nutrient deficiency may disturb the normal cycle in some people [2,3,6].

Nutraceuticals are food-derived ingredients or products investigated for possible nutritional or physiological benefits. Plants are of interest because they naturally contain several classes of phytochemicals. For example, polyphenols may show antioxidant activity in laboratory systems, certain lipid fractions have been studied in relation to androgen

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pathways, and plant gels or oils may help condition the scalp or hair fibre. These are possible mechanisms, not guarantees of hair regrowth [4,5].

A useful distinction is the difference between improving the feel or appearance of hair and changing follicle activity. A conditioner may reduce friction and make hair feel smoother without increasing the number of active follicles. Similarly, an ingredient that affects cultured cells in a laboratory may not reach the human follicle at an effective concentration when used in a food or cosmetic product. This review keeps those outcomes separate.

II. REVIEW APPROACH AND SCOPE

This is a focused narrative review intended for educational and academic discussion. The supplied manuscript identified relevant literature through PubMed/PMC records and publisher pages using terms related to plant-based nutraceuticals, hair growth, alopecia and selected botanical names. Priority was given to human studies, reviews and primary experimental reports. The evidence was interpreted according to study design, population, plant part, preparation and route of administration.

Because this is not a systematic review, it does not claim to include every relevant study. No registered protocol, duplicate independent screening, formal quantitative risk-of-bias assessment or meta-analysis was performed. Studies involving different diagnoses or products were not treated as directly comparable. The purpose is to explain what has been studied and where uncertainty remains.

III. HAIR STRUCTURE AND HAIR GROWTH CYCLE

The visible hair shaft is made mainly of keratinized cells. It is commonly described as having three layers: the cuticle, cortex and, in some hair types, a central medulla. The cuticle forms the outer protective covering. Its overlapping cells help reduce physical damage and protect the inner structure. The cortex makes up most of the shaft and contributes to strength, elasticity and colour. The medulla may be absent or discontinuous in fine hair [1,2].

The hair follicle is a small, complex organ embedded in the skin. At its base is the hair bulb, which contains rapidly dividing matrix cells. These cells differentiate and contribute to formation of the hair fibre. The dermal papilla is a specialized group of cells at the base of the follicle; it communicates with surrounding follicular cells and participates in regulating growth and cycling. The follicle also contains epithelial sheaths and stem-cell-associated regions that support renewal [1,2].

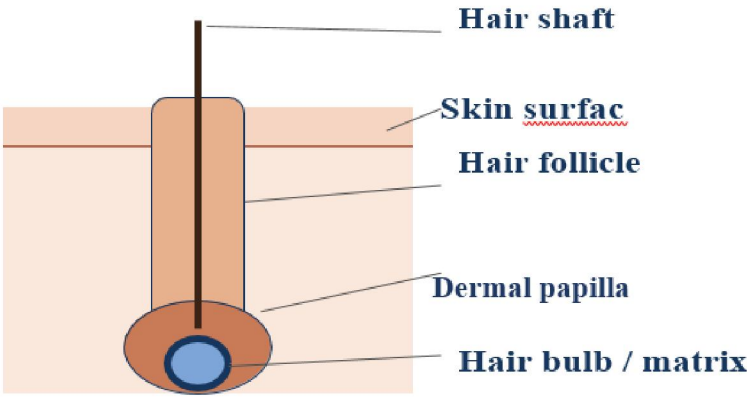


Figure 1. Simplified structure of a hair follicle and selected anatomical components.

3.1 Phases of the hair cycle

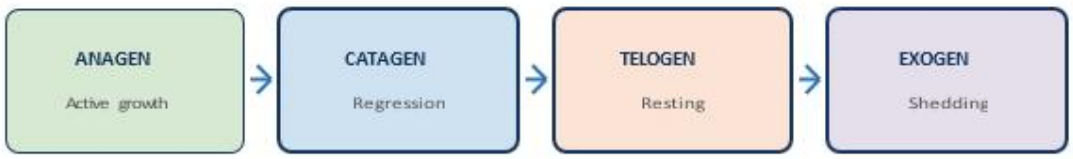
Anagen — active growth: Matrix cells divide and produce the growing hair shaft. Scalp follicles may remain in this phase for years. The length of anagen is an important factor in determining how long scalp hair can grow.

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Catagen — regression: Growth slows and the lower portion of the follicle undergoes controlled regression. This is a short transition phase rather than a period of active hair production.

Telogen — resting: The follicle is relatively inactive. The existing hair remains in place for a period before being released. The proportion of follicles in telogen can change with physiological or pathological influences.

Exogen — shedding: The old hair is released from the follicle. Shedding is a normal part of the cycle; concern arises when the amount, timing or pattern becomes abnormal.



The cycle repeats; phase duration varies with body site and individual.

Figure 2. The four commonly described stages of the hair growth cycle. The diagram is conceptual and phase durations are not to scale [2].

A healthy scalp does not keep every follicle in the same phase at the same time. This asynchronous cycling prevents all scalp hairs from being shed together. In some conditions, more follicles may enter the resting or shedding phases than usual, or the growth phase may become progressively shorter. This helps explain why the pattern and timing of hair loss matter during clinical assessment [2].

IV. NUTRITIONAL FACTORS RELEVANT TO HAIR HEALTH

Hair follicles are metabolically active, particularly during anagen. They need energy, amino acids and micronutrients to support cell division and keratin production. Protein provides amino acids for structural proteins. Iron participates in oxygen transport and cellular processes; zinc supports numerous enzymes; vitamin D, vitamin B12 and folate contribute to normal cellular functions. A clinically meaningful deficiency may contribute to shedding or poor hair quality in selected individuals [3,6].

However, the relationship between nutrients and hair loss is not as simple as taking a supplement and expecting thicker hair. A low nutrient level may be a cause, a contributing factor or an associated finding. Supplementation is most rational when a deficiency or specific risk is identified. In people who already have adequate nutritional status, extra vitamins or minerals are not automatically helpful and may sometimes be harmful at excessive doses [3,4].

A balanced dietary pattern should include adequate protein, pulses, nuts, seeds, vegetables, fruit and other foods that meet individual nutritional needs. Persistent, sudden, patchy or scarring hair loss should be assessed by a qualified healthcare professional. Depending on the history and examination, a clinician may consider investigations such as iron status or thyroid function; testing should be individualized rather than performed indiscriminately [2,6].

V. SELECTED PLANT-BASED INGREDIENTS

Plant composition is not fixed. It can change with species, variety, plant part, climate, soil, harvest time, storage and extraction method. Consequently, two products carrying the same plant name may not contain the same chemical profile or deliver the same exposure. This is one reason why results from a particular research preparation should not be generalized to all commercial products.

5.1 Amla (Phyllanthus emblica)

Amla, also known as Indian gooseberry, is a fruit used in traditional food and hair-care practices. It contains hydrolysable tannins and other polyphenolic constituents, including gallic-acid- and ellagic-acid-related compounds. These compounds have attracted attention because many polyphenols show antioxidant activity in experimental systems. Amla is also used in oral botanical mixtures and topical preparations.

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A randomized, triple-blind controlled trial evaluated a specific oral amla-containing product in 60 women with female androgenetic alopecia over 12 weeks [8]. The result is relevant to the tested preparation and study population. It does not prove that every amla powder, oil, shampoo or homemade preparation has the same effect. Larger independent studies with clearly reported product composition and longer follow-up would help establish how reproducible the finding is.

Research interpretation: Amla is a promising ingredient for further study, but claims should identify the exact preparation and should not promise a cure for hair loss.

5.2 Rosemary (Salvia rosmarinus; synonym Rosmarinus officinalis)

Rosemary leaves contain phenolic diterpenes and phenolic acids, including carnosic acid, carnosol and rosmarinic acid. Rosemary essential oil is chemically different from a water-based or alcohol-based leaf extract. The distinction matters because extraction method affects which compounds are present and in what concentration.

A randomized comparative study examined rosemary oil against 2% minoxidil in people with androgenetic alopecia over six months and reported an increase in hair count in both groups at the later assessment [9]. This is an interesting clinical signal, but a single comparative study cannot establish equivalence to a standard treatment. The product concentration, method of application, adherence and study population all influence interpretation.

Essential oils are concentrated materials and may irritate sensitive skin or cause allergic contact dermatitis. A product intended for topical use should be formulated appropriately; concentrated essential oil should not be applied casually or swallowed. More controlled trials are needed to clarify dose, tolerability and long-term outcomes.

5.3 Green Tea (Camellia sinensis)

Green tea leaves contain catechins, including epigallocatechin-3-gallate (EGCG). EGCG has been investigated in laboratory models involving dermal papilla cells and follicle-related biology [10]. Such work can help researchers identify possible biological pathways and decide which compounds deserve further study.

Cell-based experiments do not establish that drinking green tea or applying a green-tea cosmetic product will treat human hair loss. The amount reaching the follicle after oral consumption or topical application may differ substantially from the concentration used in a laboratory. Future work should examine formulation, skin delivery, stability and clinical outcomes.

5.4 Onion (Allium cepa)

Onion contains flavonoids such as quercetin and several organosulfur compounds. A small clinical study examined crude onion juice in people with patchy alopecia areata [11]. Alopecia areata is an immune-mediated condition and is biologically different from androgenetic alopecia or generalized shedding.

The study is therefore condition-specific. It should not be used as evidence that onion juice treats all types of hair loss. Raw onion juice may also irritate the scalp or cause contact reactions. Standardized preparations and larger controlled trials are needed before reliable recommendations can be made.

5.5 Fenugreek (Trigonella foenum-graecum)

Fenugreek seeds contain saponins, flavonoids, alkaloids, mucilage and steroidal sapogenins such as diosgenin. The seed mucilage may contribute to a conditioning or film-forming feel in topical preparations, while the phytochemical profile has encouraged laboratory investigation. Traditional use in hair masks and oils is common in some communities.

Traditional use is valuable as a source of research questions, but it is not the same as proof of clinical benefit. Robust human studies measuring hair density, shedding or follicle outcomes are insufficient. Fenugreek preparations may cause irritation or allergy in susceptible people, and oral products require attention to dose, interactions and intended use.

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5.6 Aloe Vera (Aloe vera)

Aloe vera gel contains water and polysaccharides, including acemannan-related components. It is widely used in skin-care and cosmetic products because it can provide a soothing, moisturizing or conditioning feel. These properties may be useful when the goal is to improve scalp comfort or the feel of the hair shaft.

Scalp conditioning should not be confused with follicular regrowth. Direct human evidence that aloe vera increases hair density or reverses alopecia is limited. Product quality also matters: the inner gel and whole-leaf preparations are not identical, and processing influences the composition. Topical products should be selected for the intended use and stopped if irritation occurs.

5.7 Curry Leaves (Murraya koenigii)

Curry leaves contain carbazole alkaloids and other phenolic constituents. They are used in traditional hair oils and household preparations. Their chemical constituents provide a basis for laboratory investigation, but clinical trials establishing an effect on hair density, hair-cycle duration or diagnosed alopecia are lacking.

A research-grade preparation would require authenticated plant material, a defined extraction method, a reproducible chemical fingerprint and appropriate safety testing. Without these details, it is difficult to compare products or know whether a reported effect can be repeated.

5.8 Pumpkin Seed (Cucurbita pepo)

Pumpkin seed oil contains unsaturated fatty acids, phytosterols and tocopherols. These constituents have prompted interest in its nutritional and possible androgen-related effects. A randomized, double-blind, placebo-controlled study in men with androgenetic alopecia reported improved hair-growth outcomes after oral pumpkin seed oil supplementation over 24 weeks [12].

The result is promising but should be interpreted in context: it relates to the preparation, dose, participants and duration used in that trial. It does not establish that all pumpkin seed oils or topical products produce the same outcome. Replication in larger and more diverse populations is important.

5.9 Saw Palmetto (Serenoa repens)

Saw palmetto fruit extracts contain fatty acids and phytosterols. They have been investigated for possible influence on 5-alpha-reductase-related androgen pathways. This pathway is relevant to androgenetic alopecia, in which genetically susceptible follicles respond to androgen signalling.

Clinical evidence for saw palmetto in hair loss remains limited and heterogeneous [4,5]. Extract composition can vary, and products may differ in dose and standardization. Potential interactions and safety considerations should be reviewed, particularly for people taking medicines or managing other health conditions. It should not be assumed to be a substitute for established treatment.

VI. COMPARATIVE SUMMARY OF SELECTED BOTANICALS

Botanical	Key reported constituents	Evidence interpretation
Amla	Tannins; polyphenols; gallic-/ellagic-acid-related compounds	One specific oral product studied in a randomized trial; replication needed.
Rosemary	Rosmarinic acid; carnosic acid; carnosol	One comparative clinical study; not proof of equivalence to standard therapy.
Green tea	Catechins, including EGCG	Mainly experimental evidence for follicle-related effects.
Onion	Quercetin; organosulfur compounds	Small, condition-specific study in alopecia areata.

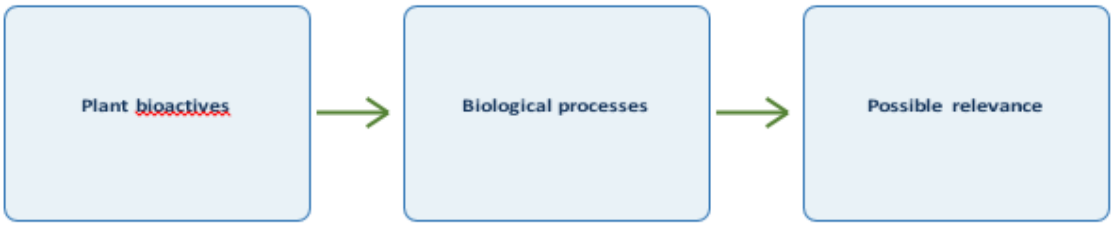
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Fenugreek	Saponins; flavonoids; diosgenin; mucilage	Traditional and preclinical interest; clinical evidence insufficient.
Aloe vera	Polysaccharides; acemannan-related compounds	Scalp-conditioning interest; direct hair-growth evidence limited.
Curry leaves	Carbazole alkaloids; phenolics	Traditional and preclinical interest; human trials needed.
Pumpkin seed	Fatty acids; phytosterols; tocopherols	One placebo-controlled trial in men; replication needed.
Saw palmetto	Fatty acids; phytosterols	Limited and heterogeneous clinical evidence.

Table 1. Selected plants, reported constituents and broad evidence status. Chemical composition varies with plant identity, part, cultivation and extraction.

VII. PROPOSED MECHANISMS OF ACTION

Several biological explanations have been proposed for plant-derived ingredients. These mechanisms are useful for planning experiments, but they should not be presented as established clinical effects unless human studies demonstrate a meaningful outcome.



Proposed research framework — not proof of clinical efficacy.

Figure 3. Conceptual relationship between plant bioactives, biological processes and possible relevance to follicle or scalp biology. This is a research framework, not proof of clinical efficacy.

Antioxidant activity: Polyphenols and related compounds may neutralize reactive species or influence cellular antioxidant pathways in experimental systems. Oxidative stress is one area of interest in follicle biology, but the clinical importance of a particular botanical antioxidant depends on exposure, stability and the condition being studied.

Inflammatory signalling: Some plant extracts show anti-inflammatory activity in laboratory models. This may be relevant to research on scalp irritation or inflammatory pathways. However, a product that soothes the scalp is not necessarily treating an immune-mediated or scarring hair disorder.

Androgen-related pathways: Saw palmetto and certain lipid-rich preparations have been studied for possible effects on androgen-related signalling, including 5-alpha-reductase pathways. These effects require confirmation in well-controlled human studies and should not be assumed from the presence of phytosterols alone.

Scalp and hair-shaft conditioning: Oils and polysaccharide-rich gels can change lubrication, moisture retention, friction and manageability. These cosmetic effects may reduce breakage or improve feel, but they do not necessarily increase the number of growing follicles.

VIII. HUMAN CLINICAL EVIDENCE AND ITS INTERPRETATION

The strongest practical question is not simply whether a plant has been studied, but what exact preparation was tested, in whom, for how long and against what comparator. The amla trial involved a particular oral product and women with female androgenetic alopecia. The rosemary study compared a topical oil preparation with 2% minoxidil in androgenetic alopecia. The onion study concerned patchy alopecia areata. The pumpkin seed oil trial involved men with androgenetic alopecia [8,9,11,12].

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These studies cannot be combined into one general conclusion that herbal products treat hair loss. They involve different diagnoses, routes of administration, durations and outcome measures. A change in hair count, a participant's impression of improvement and a change in scalp comfort are also different outcomes. Independent replication is needed to determine whether the results are reliable and clinically meaningful.

A systematic review of nutritional supplements noted that some products have promising signals, while also emphasizing the limitations of the available studies, including differences in design and product composition [4]. A later review of herbal remedies likewise highlights the need to interpret efficacy and safety ingredient by ingredient [5].

IX. CURRENT TRENDS AND FORMULATION OPPORTUNITIES

Current product development includes oral supplements, topical oils, serums, shampoos and combined products containing botanical extracts with vitamins or minerals. The choice of dosage form should follow the intended purpose. An oral product is evaluated for ingestion, systemic exposure and interactions, whereas a topical product is assessed for local tolerability, stability, skin delivery and cosmetic performance.

Standardized extracts are important because a plant name alone does not define the chemical content. Researchers can specify the botanical species, plant part, extraction solvent, drug-to-extract ratio and marker compounds. Analytical techniques such as high-performance liquid chromatography (HPLC) and high-performance thin-layer chromatography (HPTLC) can help create chemical fingerprints and support batch-to-batch consistency.

Advanced delivery systems such as liposomes and nanoemulsions may be explored to improve the stability or delivery of selected compounds. However, a more sophisticated carrier is not automatically better. It must be shown to be safe, stable, reproducible and capable of improving a meaningful outcome. Computational tools, including artificial intelligence, may help prioritize compounds or formulation variables, but predictions require laboratory and clinical validation [16].

X. SAFETY, QUALITY AND REGULATORY CONSIDERATIONS

The word “natural” should never be treated as a synonym for “risk-free”. Botanical products may cause irritation, allergic reactions, contamination-related problems or interactions with medicines. Essential oils are concentrated and may be unsuitable for direct application without appropriate formulation. Oral supplements may have different risks from topical cosmetics, and the two categories should not be treated as interchangeable.

Quality begins with correct identification. Substitution or misidentification of plant material can change the chemical profile and safety of a product. Good manufacturing practice, controlled sourcing, hygienic processing and suitable packaging help reduce avoidable variation. Testing may include microbial limits, heavy metals, pesticide residues, residual solvents, stability and marker-compound content.

A well-described research product should report: (i) accepted botanical name and plant part; (ii) source and authentication method; (iii) extraction solvent and ratio; (iv) marker compounds or chromatographic fingerprint; (v) dose and route; (vi) dosage form and excipients; (vii) storage conditions and stability; and (viii) adverse-event monitoring. These details allow another research group to reproduce the work.

In India, products marketed as foods or health supplements, cosmetics or drugs may fall under different regulatory frameworks depending on composition, intended use and claims. The relevant classification and current requirements should be checked before manufacture, marketing or submission. Claims should be evidence-based and must not imply treatment or cure of a disease without the appropriate regulatory basis.

XI. RESEARCH GAPS AND FUTURE PERSPECTIVES

The field needs better clinical evidence, not simply a larger number of products. Many published studies are small, use different preparations and follow participants for limited periods. Hair growth is slow, so short studies may not capture durable changes. Research should use clearly defined diagnoses, adequate sample sizes, appropriate control groups and

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objective outcomes such as standardized hair counts, hair density, shaft diameter and phototrichogram-based measurements.

Priority areas include:

- Larger, adequately powered randomized controlled trials with transparent protocols and independent replication.
- Standardized botanical extracts with authenticated species, defined plant parts and reproducible chemical profiles.
- Longer follow-up to assess durability, tolerability and delayed adverse effects.
- Studies in diverse populations and in clearly defined hair disorders rather than mixing different causes of hair loss.
- Direct comparison of oral and topical routes when scientifically justified, with clear reporting of dose and exposure.
- Investigation of possible interactions between botanical ingredients and conventional medicines.
- Better distinction between cosmetic conditioning, reduced hair breakage and actual changes in follicle activity.

Future research should also report funding sources, conflicts of interest, protocol deviations and negative findings. Publishing only positive outcomes can create an exaggerated impression of benefit. A balanced evidence base is essential for clinicians, pharmacists, consumers and product developers.

XII. PRACTICAL FRAMEWORK FOR EVALUATING A HAIR NUTRACEUTICAL

Before accepting a product claim, a reader or researcher can ask five straightforward questions:

1. Identity: Is the plant correctly identified, and is the plant part stated?
2. Composition: Are the extraction method and marker compounds reported?
3. Evidence: Is the claim supported by a human study of the same preparation and diagnosis, or only by traditional use or laboratory findings?
4. Safety: Are adverse effects, interactions, contaminants and route-specific risks addressed?
5. Outcome: Does the study measure hair density or another objective outcome, or only subjective appearance and scalp comfort?

This simple framework helps separate a plausible research idea from a product claim that is ready for clinical use.

XIII. LIMITATIONS OF THIS REVIEW

This article is a narrative review and not a systematic review with a registered protocol. The selected literature is illustrative rather than exhaustive. Differences in plant species, plant parts, extraction methods, product composition, study populations, diagnoses and outcome measures limit direct comparisons. Some mechanisms discussed are based on experimental or preclinical findings and should not be interpreted as proof of benefit in humans. The search strategy and reference list should be expanded and checked against the requirements of the intended journal before submission.

XIV. CONCLUSION

Plant-based nutraceuticals are an active and developing area of hair and scalp research. Amla, rosemary, green tea, onion, fenugreek, aloe vera, curry leaves, pumpkin seed and saw palmetto contain a range of phytochemicals that provide scientific reasons for further investigation. A small number of specific preparations have been evaluated in human studies, but the findings differ by plant, preparation and type of hair disorder.

The most responsible conclusion is therefore balanced: some botanicals are promising, but the evidence is not strong or uniform enough to support broad claims that herbal products prevent or cure hair loss. Correct diagnosis, correction of documented nutritional deficiencies, botanical standardization, safety assessment and well-designed clinical trials remain essential. Plant-based products should not replace professional assessment or evidence-based treatment when these are needed.

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