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Review Article

Phytoconstituents in Herbal Toothpastes: Mechanisms for Plaque Control and Gingival Health

Rajveer Bhaskar¹, Monika Ola², Sonali Matkar^{1*}

1. Department of Industrial Pharmacy, R C Patel Institute of Pharmaceutical Sciences & Research, Shirpur, Maharashtra, India

2. Department of Pharmaceutics, R C Patel Institute of Pharmacy, Shirpur, Maharashtra, India

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For Correspondence:

Sonali Matkar, Department of Industrial Pharmacy, R C Patel Institute of Pharmaceutical Sciences & Research, Shirpur, Maharashtra, India

Abstract

The global rise in interest toward herbal oral care products has brought significant focus on the phytoconstituents present in herbal toothpastes. Unlike conventional formulations containing fluoride, triclosan, and chlorhexidine, herbal preparations utilize natural bioactive compounds such as flavonoids, tannins, terpenoids, alkaloids, and essential oils derived from plants like neem, clove, licorice, and miswak. These phytoconstituents exert antibacterial, anti-inflammatory, antioxidant, and plaque-inhibiting actions that contribute to maintaining gingival health. This review summarizes the mechanisms of plaque formation, the role of active phytoconstituents, their pharmacological actions, and compares them with conventional agents. Safety aspects, current evidence from clinical and laboratory studies, and future research prospects are also discussed to highlight the therapeutic potential of herbal-based oral care products.

Keywords: Herbal toothpaste; Phytoconstituents; Dental plaque; Gingival health; Antimicrobial activity

INTRODUCTION

Oral health is crucial to overall wellbeing since it directly affects nutrition, quality of life, and systemic health outcomes. Dental plaque, a complex biofilm that develops on tooth surfaces, is the primary cause of gingivitis, periodontitis, and dental cavities. In the past, plaque has been treated and gingival health has been maintained by mechanical brushing and the use of chemical adjuncts like fluoride, triclosan, and chlorhexidine. These conventional drugs have side effects, such as tooth discolouration, diminished taste sensitivity, and in rare cases, mucosal irritation, despite their efficacy. Increased awareness of chemical misuse has also sparked a hunt for better, sustainable alternatives.¹

Inspired by traditional medical systems like Ayurveda, Siddha, and Unani, where medicinal herbs have long been utilised for oral hygiene, herbal toothpastes have become a competitive alternative. Plant extracts and essential oils with antibacterial, anti-inflammatory, antioxidant, and analgesic qualities are frequently used in these compositions. By regulating microbial growth, preventing biofilm development, scavenging free

radicals, and promoting tissue repair, the phytoconstituents found in these herbal remedies are essential for controlling plaque and protecting gingiva.²

These active molecules may now be isolated, characterized, and assessed thanks to recent developments in phytochemistry and pharmacology. While clove (*Syzygium aromaticum*) includes eugenol, which has antimicrobial and analgesic properties, neem (*Azadirachta indica*) offers limonoids and nimbidin with strong antibacterial action against *Streptococcus mutans*. Rich in silica, tannins, and fluoride-like ions, miswak (*Salvadora persica*) helps build enamel and remove plaque. Similar to this, phytoconstituents from licorice, aloe vera, tulsi, and tea tree oil have shown great promise in preserving dental hygiene via a variety of pharmacological mechanisms.^{3,4}

The function of phytoconstituents in herbal toothpastes is critically examined in this review, with an emphasis on their mechanisms for gingival health and plaque management. After describing the process of plaque formation and its clinical implications, the study goes into great detail into the main phytoconstituents and

their pharmacological effects. To illustrate relative benefits and drawbacks, comparisons with traditional agents are given. In order to provide a comprehensive understanding of the therapeutic potential of herbal formulations in contemporary dental care, safety profiles, clinical evidence, and future research prospects are also examined.^{5,6}

MECHANISM OF PLAQUE FORMATION

Dental plaque is a persistent, organized biofilm that sticks to the gingival border and tooth surface. Salivary proteins, dietary substrates, and host immunological responses all have an impact on the series of microbial colonization events that lead to its development. Understanding how phytoconstituents work to interfere with or alter plaque development is crucial.⁷



Figure 1: Mechanism of Dental Plaque Formation⁸

The production of an acquired pellicle marks the start of the first stage of plaque development. Within minutes of tooth cleaning, this thin proteinaceous film—which is mostly made up of salivary glycoproteins, enzymes, and immunoglobulins—covers the enamel surface. The pellicle offers receptor sites for bacterial adhesion in addition to providing protection against demineralization. Through the interaction of certain adhesins with pellicle proteins, early colonizers—primarily Gram-positive facultative anaerobes including *Streptococcus sanguinis*, *Streptococcus mitis*, and *Actinomyces* spp.—attach.⁹

Microcolonies are created as colonisation advances due to extracellular polysaccharide synthesis and microbial multiplication. Aciduric species like *Streptococcus mutans* and *Lactobacillus* spp. benefit from the metabolism of dietary carbohydrates by these bacteria, which produce lactic acid and other metabolites that decrease the local pH. The acidic environment causes carious lesions and speeds up the demineralisation of enamel. Gingival irritation and bleeding result from the host's inflammatory reactions being triggered concurrently by the buildup of lipopolysaccharides, proteases, and other bacterial products.¹⁰

Gram-negative anaerobes such *Porphyromonas gingivalis*, *Fusobacterium nucleatum*, and *Prevotella intermedia* are incorporated into plaque as it matures. Virulence factors secreted by these pathogens deteriorate host tissues, weaken immunological responses, and prolong chronic inflammation.

Extracellular polymeric substances (EPS) unite a complex microbial community to build a protective biofilm matrix that is resistant to chemical antimicrobials and mechanical removal.¹¹

Plaque turns into calculus if left untreated, producing a rough surface that encourages bacterial colonisation even more. Gingivitis is mostly caused by biofilms that persist around the gingival border, but periodontitis is caused by deeper penetration into periodontal pockets.¹²

Herbal toothpastes' phytoconstituents have an impact on plaque development at several stages. Some impede receptor-ligand interactions to prevent bacterial adherence, while others inhibit the glucosyltransferase enzymes that produce EPS. While anti-inflammatory substances lessen host tissue damage, antimicrobial phytochemicals lower the bacterial load. Therefore, the basis for knowing how natural substances support oral health is an understanding of plaque development.¹³

Types, Features, and Management of Plaque and Plaque Control. Dental plaque is a durable and well-organised biofilm that forms on the gingival border and tooth surface. It is made up of microbial populations embedded in an extracellular polymeric matrix made up of proteins, nucleic acids, and polysaccharides. This biofilm's metabolic cooperation and structural intricacy allow microorganisms to withstand severe oral environments and withstand antimicrobial treatments. Plaque's pathogenicity is determined by its location, composition, and maturity as well as host variables such immunological response, nutrition, and saliva

composition¹⁴ The most common oral illnesses in the world, gingivitis, periodontitis, and dental caries, can be avoided with effective plaque control.¹⁵

Types of Dental Plaque

Each type of plaque has unique microbiological and clinical implications and is categorised according to its location, composition, and level of maturation.¹⁶

Supragingival Plaque:

Actinomyces viscosus, *Streptococcus mutans*, and *Streptococcus sanguinis* are among the Gram-positive cocci and rods that make up supragingival plaque, which forms above the gingival edge. Dental caries begins when these bacteria break down dietary carbohydrates into lactic acid, which demineralises enamel. Furthermore, these microbes' metabolic byproducts cause minor gingival irritation.¹⁷

Subgingival Plaque:

This type of plaque, which is found in the sulcus or periodontal pockets beneath the gingival margin, is primarily made up of Gram-negative anaerobes such as *Porphyromonas gingivalis*, *Prevotella intermedia*, and *Fusobacterium nucleatum*. These species generate volatile sulphur compounds, endotoxins, and proteolytic enzymes that weaken immune systems, degrade connective tissue, and encourage chronic periodontitis.¹⁸

Adherent (Tooth-Associated) Plaque:

This kind is rich in filamentous germs and sticks firmly to the surface of the tooth or calculus. It is essential for the development of calculus and root caries. This layer's high bacterial population avoids being disturbed by brushing or rinsing.¹⁹

Non-Adherent (Loosely Attached) Plaque:

This group includes spirochetes and motile bacteria that are found close to the epithelial surface. Although it increases gingival bleeding and inflammation, mechanical cleaning makes it easier to get rid of.²⁰

Mature Plaque:

Microbial succession eventually results in a tiered, intricate biofilm structure. Late colonisers like *Fusobacterium* and *Porphyromonas* are made easier to attach by early colonisers like *Streptococcus* spp. Antimicrobial agent resistance and increased pathogenicity are characteristics of mature plaque.²¹

Plaque Control: Mechanisms and Strategies

Reducing microbial load, preventing biofilm development, and preserving oral homeostasis are all necessary for effective plaque control. The methods fall into three categories: chemical, mechanical, and herbal or biological.²²

MECHANICAL PLAQUE CONTROL

Mechanical removal of plaque remains the cornerstone of oral hygiene.

- **Toothbrushing:** Supragingival plaque can be efficiently removed and its maturation stopped with

regular brushing using the proper technique (e.g., the Modified Bass method). Bacterial colonies are more mechanically disrupted when toothbrushes are used with herbal or fluoride dentifrices.

- **Flossing and Interdental Cleaning:** By focusing on proximal surfaces that toothbrush bristles are unable to reach, floss and interdental brushes stop the buildup of interproximal plaque.
- **Professional Scaling:** To reduce bacterial reservoirs, calculus and subgingival biofilm are removed with routine dental scaling and root planning. Adjunctive chemical or herbal procedures are advised for optimal control because mechanical approaches are efficient but require consistent technique and motivation.

Chemical Plaque Control

Chemical agents are used to inhibit microbial proliferation and biofilm development.

- **Fluoride:** Promotes remineralisation, decreases enamel solubility, and suppresses bacterial metabolism.
- **Chlorhexidine:** Because of its broad-spectrum antibacterial action, it is regarded as the gold standard for chemical plaque control; however, chronic use may result in tooth discoloration, altered taste, and irritation of the mucosa.
- **Zinc and triclosan salts:** They have antibacterial properties, but prolonged exposure raises safety issues.

Although these substances successfully inhibit microbial development, growing worries about resistance and adverse effects have prompted research into herbal substitutes.²³

Herbal or Phytochemical Plaque Control

Medicinal plant phytoconstituents provide a comprehensive, biocompatible strategy for managing plaque. These substances have a variety of uses, including as antibacterial, anti-inflammatory, antioxidant, and astringent qualities.²⁴

- **Antimicrobial Effects:** Tulsi (*Ocimum sanctum*), clove (*Syzygium aromaticum*), and neem (*Azadirachta indica*) interfere with quorum sensing, disrupt bacterial cell membranes, and block glucosyltransferase enzymes to impede microbial adherence and EPS generation.
- **Anti-Inflammatory Activity:** By suppressing prostaglandins and cytokines, phytochemicals including nimbidin, eugenol, and glycyrrhizin lessen gingival inflammation.
- **Antioxidant Effects:** By neutralising reactive oxygen species, flavonoids, catechins, and polyphenols shield periodontal tissues from oxidative damage.
- **Astringent and Wound-Healing Properties:** Anthraquinones and tannins tighten gingival tissue and aid in the healing of mucosal ulcers.

Clinical research show that herbal formulations with these bioactives are just as effective as traditional toothpaste without the negative effects of chemicals.

Stages of Plaque Control and Maintenance

Three ongoing phases are necessary for effective plaque control:

Prevention:

To prevent early bacterial colonisation, develop good oral hygiene practices include flossing, brushing twice a day with a herbal dentifrice, and using antimicrobial mouthwash.

Disruption:

Biofilm integrity is disrupted and bacterial communication networks are inhibited when mechanical cleaning is paired with phytochemical agents (such as neem, clove, and miswak).

Maintenance:

Long-term gingival health is maintained through the use of natural formulations, regular follow-up treatment, and reinforcement of oral hygiene education.²⁵

Importance for Periodontal and Gingival Health

Unchecked plaque buildup results in gingivitis, which is characterised by redness, bleeding, and irritation. Bacterial invasion of periodontal tissues is facilitated by persistent plaque biofilm, resulting in permanent periodontitis. By lowering bacterial load, regulating inflammation, scavenging free radicals, and promoting gingival tissue repair, phytoconstituents offer complete protection. Herbal-based dental care is a long-term, efficient, and patient-friendly method of preserving oral health when combined with mechanical plaque management.

Table 1: Common Phytoconstituents Used in Herbal Toothpastes and Their Oral Health Benefits^{26,27}

Phytoconstituent	Herbal Source	Pharmacological Role	Oral Health Benefits
Allicin	Garlic (<i>Allium sativum</i>)	Antimicrobial, antifungal	Reduces oral pathogens, prevents halitosis
Catechins	Green tea (<i>Camellia sinensis</i>)	Antioxidant, antibacterial	Inhibits <i>S. mutans</i> , reduces gingivitis and plaque
Curcumin	Turmeric (<i>Curcuma longa</i>)	Anti-inflammatory, antioxidant	Reduces gingival bleeding, controls inflammation
Tannins	Neem (<i>Azadirachta indica</i>)	Astringent, antimicrobial	Plaque reduction, strengthens gums
Glycyrrhizin	Liquorice (<i>Glycyrrhiza glabra</i>)	Anti-inflammatory, antiviral, sweetening agent	Soothes oral mucosa, prevents caries
Eugenol	Clove (<i>Syzygium aromaticum</i>)	Analgesic, antiseptic	Relieves toothache, inhibits bacterial growth
Aloin	Aloe vera (<i>Aloe barbadensis</i>)	Anti-inflammatory, wound-healing	Promotes gingival healing, reduces irritation

ACTIVE PHYTOCONSTITUENTS IN HERBAL TOOTHPASTES

Herbal toothpastes include a wide range of bioactive substances produced from plants. Alkaloids, flavonoids, tannins, terpenoids, saponins, and essential oils are the groups of these phytoconstituents. By focusing on microbial development, reducing inflammation, or fortifying tooth tissues, each makes a distinct contribution to oral health.²⁸

1. Neem (*Azadirachta indica*)

In Ayurvedic medicine, neem is highly valued as a natural treatment for oral diseases. Nimbodin, azadirachtin, quercetin, and limonoids with broad-spectrum antibacterial qualities are found in its bark and leaves. These substances prevent *S. mutans* and *P. gingivalis* from growing, interfere with the formation of biofilms, and lower acid production.²⁹



Figure 2: Neem (*Azadirachta indica*)

Additionally, neem reduces gingival oedema and bleeding by scavenging free radicals and inhibiting prostaglandin formation.

2. Clove (*Syzygium aromaticum*)

Eugenol-rich clove oil has analgesic, antibacterial, and anti-inflammatory qualities. By rupturing cell membranes and blocking bacterial enzymes, eugenol has bactericidal effects. Its local anaesthetic action also relieves gingival pain and toothaches. Additionally, the antioxidant activity of clove phytoconstituents reduces oxidative stress in gingival tissues.³⁰



Figure 3: Clove (*Syzygium aromaticum*)

3. Miswak (*Salvadora persica*)

Traditionally, miswak has been used as a natural toothbrush. Silica, tannins, flavonoids, and essential oils are among its phytoconstituents. Tannins have astringent properties that fortify gingival tissues, while silica offers mechanical abrasion to help remove plaque.³¹



Figure 4: Miswak (*Salvadora persica*)

4. Licorice (*Glycyrrhiza glabra*)

Glycyrrhizin, glabridin, and liquiritin—all of which have strong antibacterial and anti-inflammatory properties—are extracted from liquorice roots. While glabridin prevents *Actinomyces* and *S. mutans* from growing, glycyrrhizin controls immunological responses. Additionally, liquorice phytochemicals support periodontal health by guarding against oxidative stress.³²



Figure 5: Licorice (*Glycyrrhiza glabra*)³³

5. Aloe vera (*Aloe barbadensis miller*)

Polysaccharides, anthraquinones, vitamins, and flavonoids are all present in aloe vera gel. These substances lessen gingival inflammation, speed up wound healing, and have antibacterial properties against mouth infections. Additionally, aloe vera has antioxidant properties that counteract reactive oxygen species linked to periodontal tissue destruction.³⁴



Figure 6: Aloe vera (*Aloe barbadensis miller*)

6. Tulsi (*Ocimum sanctum*)

Rosmarinic acid, ursolic acid, and eugenol are abundant in tulsi. These phytoconstituents exhibit anti-

inflammatory, antifungal, and antibacterial properties. Tulsi extracts enhance wound healing, reduce gingival inflammation, and prevent *S. mutans* biofilm formation.³⁵



Figure 7: Tulsi (*Ocimum sanctum*)

7. Tea Tree Oil (*Melaleuca alternifolia*)

Terpinen-4-ol and cineole, which have broad-spectrum antibacterial activity, are found in tea tree oil. These substances lessen plaque buildup, damage bacterial cell membranes, and minimise gingival irritation. Additionally, tea tree oil has antifungal properties that make it useful against *Candida albicans*.³⁶



Figure 8: Tea Tree Oil (*Melaleuca alternifolia*)³⁷

The pharmacological foundation of herbal toothpastes is made up of various phytoconstituents, which work in concert to preserve gingival health and dental cleanliness.

MECHANISMS OF ACTION OF PHYTOCONSTITUENTS

Phytoconstituents have a variety of effects on oral health, frequently working in concert to offer comprehensive defence.

- **Antibacterial Action:** Numerous phytochemicals reduce the formation of plaque biofilms by disrupting bacterial cell membranes, inhibiting enzymes like glucosyltransferase, and interfering with quorum sensing.
- **Anti-inflammatory Effects:** Gingival inflammation is reduced by compounds such as nimbodin, eugenol, and glycyrrhizin that control cytokine production, suppress prostaglandins, and decrease neutrophil infiltration.
- **Antioxidant Activity:** By neutralising reactive oxygen species, flavonoids, tannins, and polyphenols reduce oxidative tissue damage and promote healing.
- **Anti-plaque and Remineralisation:** Liquorice and miswak offer ions and minerals that fortify enamel and prevent demineralisation.
- **Analgesic Effects:** Toothache and gingival pain are relieved by the local anaesthetic activity of eugenol and other phytoconstituents.³⁸

COMPARISONS WITH CONVENTIONAL ACTIVES

Traditional toothpastes use artificial active ingredients such chlorhexidine, triclosan, and fluoride. Despite their effectiveness, some agents have drawbacks.

- **Fluoride** strengthens enamel, but if consumed in excess, it can lead to dental fluorosis.
- **Triclosan** is an antibacterial agent, however its use is restricted due to endocrine disruption and resistance.
- Although **chlorhexidine** is quite efficient against plaque, it can cause mucosal irritation, taste changes, and tooth discolouration.

Herbal phytoconstituents, on the other hand, offer a variety of advantages with less adverse effects. However, because to variations in plant sources, extraction techniques, and formulation stability, their effectiveness may vary.³⁹

Table 2: Comparison of Conventional and Herbal Actives in Toothpaste^{40,41}

Parameter	Herbal Actives (Neem, Clove, Tulsi, Green Tea, etc.)	Conventional Actives (Fluoride, Triclosan, Chlorhexidine)
Mechanism of Action	Multifactorial: antimicrobial, antioxidant, anti-inflammatory, astringent	Primarily single-target: anticaries (fluoride), antibacterial (triclosan, chlorhexidine)
Safety Profile	Generally safe; rare cases of mild irritation or allergies	Possible side effects: staining, taste alteration, fluorosis (long-term)
Cost-effectiveness	Usually affordable and widely available	Moderate to high, depending on formulation and brand
Long-term Efficacy	Promising but limited large-scale clinical evidence	Well-documented effectiveness in plaque control and caries prevention
Patient Acceptance	Increasing due to preference for natural products	Established, but sometimes avoided due to chemical concerns

SAFETY PROFILE AND SIDE EFFECTS

Herbal toothpastes are generally regarded as safe and have little side effects. There have been a few documented instances of allergic responses to essential oils like tea tree or clove. In contrast, conventional chemicals are more frequently linked to mucosal irritation, discolouration, and changed taste. For long-term use, herbal formulations are therefore better, especially for sensitive people and children.⁴²

CURRENT EVIDENCE: IN VITRO STUDIES, CLINICAL TRIALS, AND SYSTEMATIC REVIEWS

Neem, clove, miswak, and tulsi extracts have been shown in vitro to have antibacterial activity against cariogenic and periodontopathic bacteria. Herbal toothpastes are just as effective at lowering plaque indices and gingival scores as fluoride-based formulations, according to clinical trials. Promising results are highlighted by systematic reviews, but they also stress the necessity for long-term follow-up, larger sample numbers, and standardised techniques.⁴³

RESEARCH GAPS AND FUTURE PROSPECTS

Despite positive data, there are still a lot of unanswered questions. There is a lack of standardisation in herbal formulations, which causes variations in the phytochemical content and clinical results. To confirm long-term safety and efficacy, rigorous randomised controlled trials are required. Next-generation herbal toothpastes may be made possible by developments in nanotechnology and medication delivery that improve the stability and bioavailability of phytoconstituents.^{44,45}

CONCLUSION

Because they target several pathways involved in plaque formation and gingival disease, phytoconstituents in herbal toothpastes present a possible substitute for traditional oral care products. With few adverse effects, their antibacterial, anti-inflammatory, and antioxidant qualities support all-encompassing dental health care. Even if there is evidence to support their effectiveness, more research is necessary to create standardised formulations and maximise therapeutic results. Herbal toothpastes have the potential to be a major part of contemporary oral healthcare due to consumers' increasing desire for natural goods.

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