ABRAN ASSOCIAÇÃO BRASILEIRA DE NUTROLOGIA
International Journal of Nutrology
(Official Journal of the ABRAN - Brazilian Association of Nutrology)

REVIEW ARTICLE

DOI: 10.54448/ijn26225

Role of herbal bioactive compounds in the prevention of dental caries and periodontal diseases: a narrative review

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DOI: https://doi.org/10.54448/ijn26225
Received: 03-21-2026; Revised: 05-24-2026; Accepted: 05-29-2026; Published: 06-25-2026; IJN-id: 26225

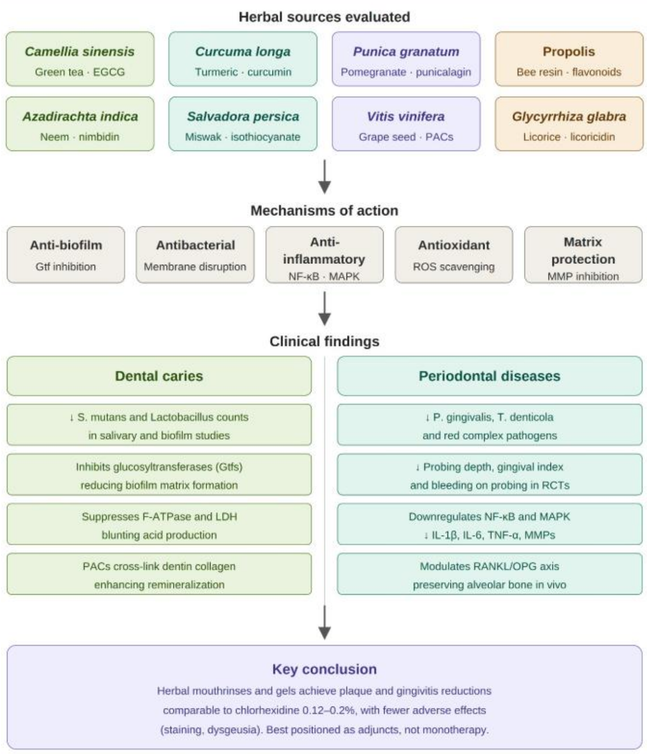
Editor: Dr. Idiberto José Zotarelli-Filho, MSc, Ph.D., Post-Doctoral.

Abstract

Introduction: Dental caries and periodontal diseases remain two of the most prevalent chronic non-communicable conditions worldwide, with substantial impact on systemic health and public health expenditure. Although fluoride, mechanical biofilm control, and chlorhexidine remain cornerstones of prevention, concerns regarding antimicrobial resistance, dysbiosis, staining, and altered taste have stimulated interest in herbal bioactive compounds as complementary agents. **Objective:** To critically synthesize current evidence on the role of herbal bioactive compounds, including polyphenols, flavonoids, terpenoids, alkaloids, and essential oils — in the prevention of dental caries and periodontal diseases, with attention to mechanisms of action, clinical efficacy, safety, and translational nutrological perspectives. **Methods:** A structured narrative review was conducted using PubMed/MEDLINE, Scopus, Web of Science, and the Cochrane Library covering literature published between January 2000 and December 2025. In vitro studies, animal experiments, randomized controlled trials, systematic reviews, and meta-analyses published in English were eligible. **Results:** Multiple herbal bioactives demonstrate antibacterial, antibiofilm, anti-inflammatory, antioxidant, and matrix-stabilizing properties relevant to oral disease prevention. *Camellia sinensis* catechins (especially EGCG), curcumin, propolis flavonoids, pomegranate ellagitannins, grape-seed proanthocyanidins, *Salvadora persica* derivatives, *Azadirachta indica* extracts, aloe vera polysaccharides, and *Glycyrrhiza glabra* isoflavans show consistent activity against key cariogenic and periodontal pathogens. Clinical trials suggest that herbal mouthrinses, gels, and dentifrices achieve plaque and gingivitis reductions comparable to chlorhexidine, with fewer adverse effects. **Conclusion:** Herbal bioactive compounds represent a scientifically promising adjunct to conventional oral preventive strategies. However, methodological heterogeneity, lack of standardized formulations, and limited long-term safety data preclude their unqualified recommendation as monotherapies. Future research should prioritize adequately powered randomized controlled trials with standardized phytochemical preparations and integration with nutrological frameworks.

Keywords: Dental Caries. Periodontal Diseases. Phytotherapy. Plant Extracts. Biofilms. Oral Health.

Graphical Abstract



Source: Own authorship.

Introduction

Dental caries and periodontal diseases are among the most widespread chronic conditions affecting humans across all age groups and socioeconomic strata **[1]**. The Global Burden of Disease Study estimates that untreated caries in permanent teeth and severe periodontitis collectively affect more than 3.5 billion people, making oral diseases the most prevalent non-communicable health problem worldwide **[2]**. Beyond their local consequences - pain, tooth loss, masticatory dysfunction, and aesthetic impairment these conditions are increasingly recognized as contributors to systemic disorders, including cardiovascular disease, diabetes mellitus, adverse pregnancy outcomes, rheumatoid arthritis, and Alzheimer's-type dementia, primarily through chronic low-grade inflammation and translocation of oral pathogens or their virulence factors **[3]**.

The pathogenesis of both diseases is fundamentally microbial and biofilm-mediated, modulated by host immunity, salivary factors, dietary habits, and lifestyle **[4,5]**. Dental caries results from a dysbiotic shift of the dental biofilm toward acidogenic and aciduric species — most notably *Streptococcus mutans*, *Lactobacillus* spp., and *Bifidobacterium dentium* — leading to repeated demineralization of dental hard tissues. Periodontal diseases, conversely, involve a polymicrobial dysbiotic community in which keystone pathogens such as *Porphyromonas gingivalis*, *Tannerella forsythia*, *Treponema denticola* ("red complex"), and *Aggregatibacter actinomycetemcomitans* subvert host immunity and trigger destructive inflammation of the supporting tissues **[6,7]**.

Conventional preventive strategies center on mechanical plaque control, topical and systemic fluoride, dietary counseling, and antimicrobial mouthrinses, of which chlorhexidine digluconate is considered the gold standard **[8,9]**. While these interventions are effective, prolonged use of chlorhexidine is associated with tooth staining, calculus formation, taste alteration, mucosal desquamation, and possible disruption of the broader oral microbiome **[10,11]**. The widespread, sometimes injudicious, use of synthetic antimicrobials in dentistry has also fueled concerns about antimicrobial resistance and ecological impact on the oral biofilm **[12,13]**. These limitations, combined with rising consumer interest in "natural" and plant-based health products, have driven a vigorous resurgence of research into herbal bioactive compounds for oral disease prevention **[14]**.

From a nutrological perspective, the oral cavity is the gateway through which dietary patterns and bioactive food constituents exert their first effects on the human microbiome. Many of the herbal compounds discussed in this review are also present in common foods and beverages — green tea, pomegranate, turmeric, grapes, berries, and culinary spices — making them attractive candidates for integrated preventive strategies that bridge nutrition, oral health, and chronic disease prevention. Furthermore, several phytochemicals have demonstrated remineralizing, matrix-stabilizing, and host-modulatory properties that go beyond simple antimicrobial action, offering a more holistic intervention paradigm consistent with modern concepts of the oral–systemic axis **[15,16]**.

Despite this momentum, the translational evidence base is heterogeneous. Many studies remain in vitro, use non-standardized extracts, and lack adequate clinical correlates **[17]**. The present narrative review aims to provide a critical, mechanism-oriented synthesis of the current evidence on herbal bioactive compounds in the prevention of dental caries and periodontal diseases. It also seeks to position these agents within a broader nutrological framework, highlighting opportunities, limitations, and priorities for future research.

Materials and Methods

Study design

This is a structured narrative review with elements of a scoping synthesis, designed to map and critically appraise the current evidence on the use of herbal bioactive compounds in the prevention of dental caries and periodontal diseases. The review was conducted following the general principles of the SANRA (Scale for the Assessment of Narrative Review Articles) framework and incorporated key recommendations from the PRISMA 2020 statement regarding transparency of search strategy and study selection, although a formal systematic review protocol was not registered.

Information sources and search strategy

Electronic searches were conducted in PubMed/MEDLINE, Scopus, Web of Science, the Cochrane Central Register of Controlled Trials, and Google Scholar for studies published between January 2000 and December 2025. The search strategy combined Medical Subject Headings (MeSH) and free-text terms grouped into three blocks: (i) intervention — "herbal," "phytochemical," "plant extract," "polyphenol," "flavonoid," "essential oil," "propolis," "green tea," "curcumin," "pomegranate," "neem," "miswak," "aloe vera," "licorice," "grape seed," "proanthocyanidins"; (ii) disease/condition — "dental caries," "tooth demineralization," "periodontitis," "gingivitis," "plaque," "oral biofilm," "halitosis"; and (iii) target organisms — "*Streptococcus mutans*," "*Porphyromonas gingivalis*," "*Aggregatibacter actinomycetemcomitans*," "*Fusobacterium nucleatum*," "*Lactobacillus*." Boolean operators "AND" and "OR" were used to combine blocks.

Eligibility criteria

Original research articles, including *in vitro* microbiological studies, *in situ* studies, animal experiments, randomized controlled trials, controlled clinical trials, and high-quality systematic reviews and meta-analyses were considered eligible. Review articles, narrative syntheses, and authoritative book chapters were used selectively to contextualize mechanisms and historical perspectives. Studies were included if they (i) evaluated a defined herbal extract or isolated phytochemical, (ii) reported outcomes relevant to dental caries (e.g., bacterial counts, enamel demineralization, biofilm formation) or periodontal disease (e.g., gingival or plaque indices, probing depth, clinical attachment level, inflammatory biomarkers), and (iii) were published in English. Studies focused exclusively on oral cancer, candidiasis without bacterial co-targets, or non-oral applications were excluded.

Study selection and data extraction

Titles and abstracts retrieved from each database were screened for relevance. Full texts of potentially eligible articles were retrieved and assessed against the eligibility criteria. Data extracted from included studies covered: type of botanical source and bioactive compound, formulation (extract, isolated molecule, mouthrinse, gel, varnish, dentifrice), study design and population (for clinical studies), comparator, primary and secondary outcomes, follow-up duration, and adverse events. Particular emphasis was placed on mechanistic insights linking molecular structure to anticariogenic or anti-periodontal effects.

Synthesis of evidence

Given the heterogeneity of study designs, outcome measures, and intervention formulations, evidence was synthesized narratively, organized by botanical source and mechanism of action. Where multiple randomized trials addressed the same intervention–comparator pair, qualitative summaries of effect direction and magnitude were provided.

Results

Overview of herbal bioactive compounds with oral health relevance

The herbal bioactive compounds with documented activity against cariogenic and periodontopathic bacteria can be broadly classified into five major chemical families: (i) polyphenols (flavonoids, tannins, phenolic acids, stilbenes), (ii) terpenoids and essential oils (mono-, sesqui-, and triterpenes), (iii) alkaloids, (iv) saponins, and (v) sulfur-containing compounds **[14-16]**. Polyphenols dominate the literature, both because of their abundance in dietary plants and their well-characterized antimicrobial, antioxidant, and matrix-stabilizing properties. Table 1 summarizes the principal herbal sources, their major bioactives, dominant mechanism(s) of action, and oral microbial or tissue targets.

Table 1. Major herbal bioactive compounds with documented activity against dental caries and periodontal diseases.

Herbal source	Major bioactive compound(s)	Principal mechanism	Oral targets
Camellia sinensis (green tea)	Epigallocatechin-3-gallate (EGCG), catechins	Inhibition of glucosyltransferases; antioxidant; antibacterial	*Streptococcus mutans*, *Porphyromonas gingivalis*, dental biofilm
Punica granatum (pomegranate)	Punicalagin, ellagic acid, anthocyanins	Antibiofilm; anti-inflammatory; collagenase inhibition	*S. mutans*, gingival inflammation, MMPs
Curcuma longa (turmeric)	Curcumin	NF-κB inhibition; antioxidant; antibacterial	Gingival inflammation, *P. gingivalis*, oxidative stress
Vitis vinifera (grape seed)	Proanthocyanidins (PACs), resveratrol	Collagen crosslinking; antioxidant; antibacterial	Dentin remineralization, MMPs, periodontal ligament

Propolis (resinous bee product)	Flavonoids (pinocembrin, galangin), CAPE	Antibacterial; anti-inflammatory; immunomodulatory	Cariogenic bacteria, gingivitis, wound healing
Azadirachta indica (neem)	Nimbidin, azadirachtin, gedunin	Antibacterial; antifungal; antiplaque	Plaque biofilm, *S. mutans*, periodontal pathogens
Salvadora persica (miswak)	Benzyl isothiocyanate, salvadorine, silica	Antibacterial; mechanical cleansing; salivary stimulation	Plaque, gingivitis, halitosis
Ocimum sanctum (tulsi/holy basil)	Eugenol, ursolic acid, rosmarinic acid	Antibacterial; anti-inflammatory	*S. mutans*, periodontal pathogens
Aloe barbadensis (aloe vera)	Anthraquinones, acemannan, polysaccharides	Wound healing; anti-inflammatory; antibacterial	Gingival tissues, oral ulcers, periodontitis
Glycyrrhiza glabra (licorice)	Glycyrrhizin, licoricidin, licorisoflavan A	Antibacterial; anti-inflammatory	*S. mutans*, *P. gingivalis*, *A. actinomycetemcomitans*

Note: MMPs, matrix metalloproteinases; CAPE, caffeic acid phenethyl ester; EGCG, epigallocatechin3-gallate. Source: Own authorship.

Mechanisms of action against cariogenic biofilms

Inhibition of bacterial adhesion and biofilm assembly

The earliest event in caries pathogenesis is the adhesion of *S. mutans* to the salivary pellicle on tooth surfaces, followed by glucan-mediated accretion and biofilm maturation. Glucosyltransferases (Gtfs B, C, and D) of *S. mutans* synthesize water-insoluble glucans from dietary sucrose, providing the structural matrix of the cariogenic biofilm **[17,18]**. Several polyphenols notably EGCG from green tea, theaflavins from black tea, and proanthocyanidins from cranberry and grape seed — bind to and inactivate Gtfs, reducing glucan formation and weakening biofilm cohesion **[18,19]**. Propolis flavonoids (apigenin, tt-farnesol, pinocembrin) similarly inhibit Gtfs and disrupt acidogenic glycolysis in *S. mutans*, even at sub-inhibitory concentrations that minimize selection pressure for resistance **[20]**.

Inhibition of acidogenesis and aciduricity

Cariogenicity depends not only on bacterial colonization but also on the ability of biofilm bacteria to produce and tolerate acid. Several phytochemicals, including curcumin, eugenol, and licoricidin, suppress the F-ATPase and lactate dehydrogenase activities of *S. mutans*, thereby blunting its acid production and its capacity to maintain intracellular pH homeostasis in an acidic environment **[21]**. This shifts the ecological balance of the biofilm away from cariogenic species and partially restores microbial homeostasis **[22]**.

Quorum sensing interference

Bacterial communities coordinate biofilm-related behavior through quorum-sensing (QS) systems. In *S. mutans*, the competence-stimulating peptide (CSP)–ComDE system regulates biofilm formation, bacteriocin production, and stress responses. Compounds such as carvacrol, eugenol, curcumin, and certain catechins act as quorum-quenching agents by interfering with QS signaling, leading to reduced virulence without necessarily killing the bacteria a strategy thought to exert lower selection pressure for resistance than bactericidal antibiotics **[23]**.

Effects on demineralization and remineralization

Beyond their antimicrobial actions, several polyphenols influence the dental hard tissue itself. Proanthocyanidins from grape seed extract cross-link collagen in the dentin organic matrix, increasing its biomechanical resistance to enzymatic degradation by matrix metalloproteinases (MMPs) and cysteine cathepsins activated in caries lesions **[24]**. EGCG and tannic acid similarly inhibit dentin MMPs. Some phytochemicals (e.g., from *Galla chinensis*) have also been shown to enhance fluoride uptake and promote subsurface remineralization, suggesting a synergistic role with fluoride-based preventive strategies **[25]**.

Mechanisms of action in periodontal diseases

Antimicrobial action against periodontopathogens

Periodontal disease is driven by Gram-negative anaerobic bacteria, particularly *P. gingivalis*, *T. forsythia*, *T. denticola*, and *A. actinomycetemcomitans*, organized within subgingival biofilms. Curcumin, EGCG, punicalagin, licoricidin, and propolis flavonoids exhibit minimal inhibitory concentrations against these pathogens that are clinically achievable through topical formulations **[26]**. Many of these compounds disrupt outer membrane integrity, inhibit key virulence enzymes such as gingipains (cysteine proteinases of *P. gingivalis*), and impair iron acquisition pathways.

Host modulation: anti-inflammatory and antioxidant effects

Periodontal tissue destruction is largely host-mediated, driven by dysregulated production of pro-inflammatory cytokines (IL-1β, IL-6, TNF-α, IL-17), prostaglandin E2, and MMPs in response to bacterial challenge. Curcumin, resveratrol, EGCG, and quercetin downregulate NF-κB and MAPK signaling in gingival fibroblasts, periodontal ligament cells, and macrophages, attenuating pro-inflammatory cytokine release **[27]**. Concurrently, their antioxidant capacity neutralizes reactive oxygen species (ROS) generated during the neutrophilic respiratory burst, protecting periodontal tissues from collateral oxidative damage **[28]**.

Inhibition of bone resorption and support of regeneration

Several phytochemicals modulate the RANKL/RANK/OPG axis governing osteoclastogenesis. Curcumin, EGCG, resveratrol, and genistein inhibit RANKL-induced osteoclast differentiation and activity, supporting alveolar bone preservation in animal models of experimental periodontitis **[29]**. Aloe vera polysaccharides and propolis flavonoids further enhance fibroblast proliferation, collagen synthesis, and angiogenesis, contributing to soft tissue healing after periodontal interventions **[30,31]**.

Clinical evidence by botanical source

Camellia sinensis (green tea)

Green tea catechins, dominated by EGCG, are among the most extensively studied phytochemicals in oral health. Randomized clinical trials show that green tea mouthrinses (0.5–2%) significantly reduce plaque index, gingival index, and bleeding on probing compared with placebo, with several studies reporting non-inferiority to chlorhexidine 0.12–0.2% over short-term follow-up **[32]**. Green tea dentifrices and chewing gums have similarly demonstrated reductions in salivary *S. mutans* counts. Epidemiological data from East Asian populations have linked habitual green tea consumption to lower prevalence of periodontitis and tooth loss **[33]**, supporting a dietary–oral health continuum.

Curcuma longa (turmeric / curcumin)

Curcumin, the principal curcuminoid of turmeric, has been evaluated as a local-drug-delivery agent, gel, and mouthrinse adjunctive to scaling and root planing in chronic periodontitis. Meta-analyses of randomized trials suggest that adjunctive curcumin produces statistically significant additional reductions in probing depth, gingival index, and bleeding on probing compared with mechanical therapy alone, with effect sizes broadly comparable to chlorhexidine gel but with fewer reports of staining and dysgeusia **[34]**. Limitations include curcumin's intrinsically low aqueous solubility and bioavailability, partially mitigated by novel delivery systems (nanoparticles, liposomes, phytosomes) **[35]**.

Punica granatum (pomegranate)

Pomegranate fruit, peel, and seed extracts are rich in ellagitannins (notably punicalagin), ellagic acid, and anthocyanins **[36]**. Clinical studies of pomegranate mouthrinses and gels demonstrate reductions in dental plaque scores, *S. mutans* counts, and clinical signs of gingivitis **[37]**. In vitro evidence further supports inhibition of *P. gingivalis*-derived gingipains and MMP activity, suggesting a dual antibacterial and host-modulatory effect that may be particularly useful in periodontal maintenance.

Propolis

Propolis is a resinous substance collected by honeybees from plant exudates; its composition varies geographically, with Brazilian green propolis, poplar-type European propolis, and Mediterranean propolis representing major chemotypes **[38]**. Despite this variability, randomized trials of propolis-containing mouthrinses, gels, and dentifrices have consistently shown reductions in plaque indices, gingival bleeding, and salivary cariogenic bacteria **[39]**. Pulpotomy and direct pulp-capping studies in primary teeth have also explored propolis as an alternative to formocresol, with promising biocompatibility outcomes.

Azadirachta indica (neem)

Neem has been used for centuries in South Asian oral hygiene practices. Modern clinical trials of neem-based mouthrinses and dentifrices report plaque-reducing and anti-gingivitis effects comparable to chlorhexidine in short-term studies, with the additional benefit of not staining teeth **[40]**. Active constituents — nimbidin, azadirachtin, gedunin, and quercetin — exhibit antibacterial activity against *S. mutans*, *Lactobacillus* spp., and periodontopathogens, alongside immunomodulatory effects **[41,42]**.

Salvadora persica (miswak)

Miswak chewing sticks deliver a combination of mechanical cleansing and pharmacologically active compounds, including benzyl isothiocyanate, salvadorine, trimethylamine, silica, and tannins **[43]**. Systematic reviews indicate that, when used correctly and frequently, miswak achieves plaque control and gingival health outcomes comparable to toothbrushing, supporting WHO recommendations regarding its role in oral hygiene, particularly in low-resource settings **[44]**.

Vitis vinifera (grape seed) and proanthocyanidins

Grape-seed proanthocyanidins (PACs) have attracted growing interest as biomimetic agents for dentin remineralization and stabilization **[45]**. In situ and in vitro studies show that PAC treatment increases the modulus of elasticity of demineralized dentin, inhibits MMP-mediated degradation, and enhances resin–dentin bond strength when used as a pre-treatment. While direct clinical caries-prevention data are still emerging, PACs hold promise as adjuncts in non-restorative caries control and as components of remineralizing varnishes **[46]**.

Aloe barbadensis miller (aloe vera)

Aloe vera mouthrinses and gels have been studied in patients with plaque-induced gingivitis, denture stomatitis, and recurrent aphthous ulcers **[47]**. Meta-analyses indicate that aloe vera-based formulations achieve plaque- and gingivitis-reducing effects comparable to chlorhexidine over short to medium terms, with the added advantages of palatability, lack of staining, and soft-tissue healing properties attributed to acemannan and other polysaccharides.

Glycyrrhiza glabra (licorice)

Licorice root contains licoricidin and licorisoflavan A, which show selective antimicrobial activity against major caries and periodontal pathogens while sparing many commensal species **[48]**. Clinical studies of licorice-containing lozenges have demonstrated reductions in salivary *S. mutans* counts and in gingival inflammation, supporting its inclusion in modern functional foods aimed at oral health.

Other botanicals of interest

Several additional botanicals merit brief mention: *Ocimum sanctum* (tulsi) mouthrinses are non-inferior to chlorhexidine in some short-term trials; *Cinnamomum* spp. and *Syzygium aromaticum* (clove) essential oils, rich in cinnamaldehyde and eugenol respectively, show strong antibacterial activity against oral biofilms; *Mentha piperita* (peppermint) and *Melaleuca alternifolia* (tea tree) essential oils are common components of natural mouthwashes **[49]**; and *Hibiscus sabdariffa* anthocyanins exhibit antiglucosyltransferase activity **[50]**. More recently, marine-derived nutraceuticals such as fucoidan have emerged as adjuncts in periodontal disease, particularly through their antibacterial and anti-inflammatory effects on periodontopathogens **[51]**.

Comparative clinical evidence

Table 2 summarizes representative randomized and controlled clinical studies comparing herbal bioactive formulations with conventional preventive agents. Across the evidence base, the most consistent finding is that herbal formulations achieve plaque- and gingivitis-related outcomes comparable to chlorhexidine 0.12–0.2% over short follow-up periods, while displaying superior tolerability and lower rates of staining and dysgeusia **[9,10,20,22,25,29,33,39]**. Strong evidence supports adjunctive use in caries-active patients and as maintenance interventions in periodontal patients, particularly when chronic chlorhexidine use is undesirable.

Table 2. Summary of representative clinical evidence on herbal bioactive formulations for dental caries and periodontal disease prevention.

Bioactive / formulation	Study design	Comparator	Outcome	Direction of effect
Green tea mouthrinse	RCT	Chlorhexidine 0.2%	Plaque & gingival index	Comparable reduction; fewer side effects
Curcumin gel (1%)	RCT (chronic periodontitis adjunct)	Chlorhexidine gel	Probing depth, CAL, BOP	Non-inferior; better tolerability
Propolis mouthwash	RCT	Placebo / chlorhexidine	*S. mutans* counts, plaque index	Significant reduction vs placebo
Aloe vera mouthwash	RCT (gingivitis)	Chlorhexidine	Gingival index, plaque index	Comparable; less staining
Miswak (*Salvadora persica*) chewing sticks	Cross-over / cohort	Toothbrush + paste	Plaque, gingival bleeding	Equivalent when properly used
Pomegranate extract gel/rinse	RCT	Placebo	Plaque, *S. mutans*, gingivitis	Significant improvement
Neem mouthrinse	RCT	Chlorhexidine	Plaque index, gingival index	Non-inferior
Grape seed PAC varnish	In vitro / in situ	Fluoride varnish / control	Dentin remineralization, MMP inhibition	Synergistic with fluoride

Note: RCT, randomized controlled trial; CAL, clinical attachment level; BOP, bleeding on probing; MMP, matrix metalloproteinase; PAC, proanthocyanidin. Source: Own authorship.

Formulation, bioavailability, and delivery considerations

The therapeutic potential of herbal bioactives in oral care depends not only on their intrinsic pharmacological activity but also on formulation parameters that govern local bioavailability and substantivity. Many polyphenols are chemically unstable in aqueous solution, sensitive to oxidation, light, and pH, and poorly retained on oral surfaces **[52]**. Modern formulation strategies including chitosan-based mucoadhesive films, lipid nanoparticles, phytosomes, cyclodextrin complexes, and bioactive glasses loaded with phytochemicals are being developed to improve retention, controlled release, and bioactive delivery to specific oral niches such as periodontal pockets and dentinal tubules **[53]**.

Standardization remains a central challenge. Herbal extracts are inherently complex mixtures whose composition varies with plant cultivar, harvest conditions, extraction method, and storage. Without rigorous standardization (e.g., to a defined content of marker compounds), batch-to-batch variability undermines reproducibility and complicates regulatory approval. Increasingly, the field is moving toward standardized extracts, isolated phytochemicals, or synergistic combinations with defined ratios, which are more amenable to pharmaceutical development **[54]**.

Safety, adverse events, and interactions

Overall, the herbal bioactives discussed have demonstrated favorable short-term safety profiles in oral applications. Reported adverse events are generally mild and self-limited - including transient taste alteration, mild mucosal irritation, and occasional allergic reactions, particularly with propolis and tea tree oil **[55]**. Nevertheless, several considerations warrant attention. High-dose oral or systemic intake of some polyphenols (e.g., EGCG) has been linked to hepatic effects in rare cases; cinnamon-derived coumarin may pose hepatotoxic risk at high systemic exposure; and licorice glycyrrhizin can induce pseudohyperaldosteronism with prolonged use **[56]**. Potential interactions with anticoagulants, antiplatelet agents, and cytochrome P450 substrates should be considered, particularly in older adults and patients with polypharmacy.

Discussion

Translating mechanisms into prevention strategies

The accumulated mechanistic and clinical evidence supports the view that herbal bioactive compounds can play a meaningful adjunctive role in the prevention of dental caries and periodontal diseases. The pleiotropic action of polyphenols, in particular combining antimicrobial, antibiofilm, anti-inflammatory, antioxidant, and matrix-stabilizing effects aligns conceptually with modern "ecological" approaches to oral disease prevention that emphasize biofilm modulation rather than indiscriminate killing. Such strategies seek to restore microbial homeostasis rather than impose dysbiosis through broad-spectrum antimicrobials.

From a clinical standpoint, herbal mouthrinses and gels are best positioned as alternatives or complements to chlorhexidine in patients who cannot tolerate long-term chlorhexidine use, as part of personalized caries-risk management, and as maintenance adjuncts after non-surgical periodontal therapy

[57]. The combination of phytochemicals with fluoride for instance, theaflavin–fluoride dentifrices, or PAC-modified glass-ionomer cements represent a particularly promising direction, leveraging complementary mechanisms of remineralization and biofilm modulation **[58]**.

The nutrological and oral–systemic perspective

From a nutrological standpoint, the herbal bioactives reviewed here are not merely topical agents but also dietary constituents whose habitual intake may influence both oral and systemic health **[4,5,53–55]**. The oral cavity is the proximal interface where diet meets the host microbiome, and oral dysbiosis is increasingly implicated in systemic conditions including cardiovascular disease, type 2 diabetes, metabolic syndrome, and cognitive decline **[59]**. Dietary patterns rich in polyphenols Mediterranean, traditional Japanese, and certain plant-based diets are associated with lower periodontitis prevalence and improved metabolic profiles, suggesting that the oral-health benefits of herbal bioactives form part of a broader systemic anti-inflammatory effect **[60]**.

This perspective reframes oral disease prevention as an inherently nutritional problem. Counseling patients to adopt diets rich in vegetables, fruits, berries, tea, and minimally processed plant foods, while limiting free sugars and ultra-processed foods, supports not only systemic cardiometabolic health but also a more diverse, less acidogenic oral microbiome **[61]**. Functional foods, lozenges, and chewing gums enriched with standardized herbal bioactives can extend this approach into clinical practice, particularly for high-caries-risk populations and for older adults at risk of root caries and periodontitis-associated tooth loss **[62]**.

Methodological limitations of current evidence

Despite the breadth of the literature, several methodological limitations temper enthusiasm. First, many published clinical trials are small, short, single-center, and use surrogate endpoints (plaque and gingival indices, microbial counts) rather than disease incidence or progression. Second, the lack of standardization of herbal preparations limits cross-study comparability and reproducibility. Third, blinding is challenging in studies of distinctively colored or flavored herbal products, raising risks of performance and detection bias. Fourth, long-term safety and ecological effects on the oral microbiome remain understudied, particularly for chronic daily use. Fifth, publication bias favoring positive findings may inflate apparent efficacy.

Future research priorities therefore include (i) adequately powered, multicenter randomized controlled trials with clinically meaningful endpoints; (ii) systematic phytochemical characterization and standardization of test products; (iii) head-to-head comparisons with chlorhexidine and other active controls, rather than placebos alone; (iv) inclusion of metagenomic and metabolomic analyses to characterize ecological effects on the oral microbiome;

and (v) cost-effectiveness analyses for public health implementation.

Implications for nutrology and integrative practice

Integrating herbal bioactives into dental and nutrological practice requires interprofessional collaboration. Dentists, nutrologists, dietitians, and primary care physicians should share a common framework that conceptualizes the oral cavity as part of a continuous gastrointestinal and immune ecosystem. Within such a framework, dietary recommendations, oral hygiene practices, and supplementation strategies can be coordinated to maximize benefit and minimize redundant or contradictory advice **[63]**. Special populations including pregnant women, patients with diabetes **[64]**, the immunosuppressed, and older adults may benefit particularly from such integrated approaches, given their heightened susceptibility to oral and systemic complications of dysbiosis **[65]**.

Conclusion

Herbal bioactive compounds including polyphenols, flavonoids, terpenoids, and other secondary metabolites exert a wide spectrum of pharmacological effects relevant to the prevention of dental caries and periodontal diseases. Their actions span direct antibacterial and antibiofilm effects against key cariogenic and periodontopathic species, host-modulatory and anti-inflammatory properties, antioxidant activity, and stabilization of dental hard tissues. The available clinical evidence, while heterogeneous, consistently supports their use as adjuncts to mechanical oral hygiene and, in many scenarios, as well-tolerated alternatives to chlorhexidine-based interventions. Nevertheless, the field is constrained by methodological heterogeneity, formulation variability, and limited long-term data. Translating the considerable preclinical promise into routine clinical and public health practice will require rigorous, standardized clinical trials, regulatory frameworks tailored to complex botanical products, and integration with nutrological strategies emphasizing the diet–microbiome–oral health axis. In the meantime, herbal bioactives represent a scientifically credible, patient-acceptable, and ecologically sensible component of contemporary oral disease prevention, particularly within an integrative, nutrology-informed model of care.

CRediT

Author contributions: Conceptualization, methodology, investigation, writing – original draft preparation, writing – review and editing: All authors. All authors have read and agreed to the submitted version of the manuscript.

Acknowledgment

The authors thank the editorial team of the International Journal of Nutrology for their consideration of this manuscript, and acknowledge the broader community of researchers in oral microbiology, periodontology, cariology, and phytotherapy whose primary work forms the basis of this review.

Ethical Approval

Not applicable. This review article is based exclusively on previously published literature and did not involve any new studies with human participants or animals performed by any of the authors.

Informed Consent

It was applicable.

Funding

This review did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data Sharing Statement

The datasets created and analyzed during this study are available upon reasonable request from the responsible author.

Conflict of Interest

The authors declare no competing interests.

Similarity Check

It was applied by Ithenticate@.

Application of Artificial Intelligence (AI)

Not applicable.

Peer Review Process

It was performed.

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