Frontiers in Health Informatics
ISSN-Online: 2676-7104
www.healthinformaticsjournal.com
2024; Vol-13: Issue 8
Open Access

Oral Microbiome and Siddha Herbal Medicine: A Comprehensive Literature Review

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Cite this paper as: S. Paechiyammal, Neethiraja M, D. Velaman, Saravanasingh karan chand mohan singh*, S. Dinesh, M.N. Parandhaman, C. Vimala, V. Sathiya, A. Jayakalaiarasi, C. Devaraj, Senthilvel. G (2024). Oral Microbiome and Siddha Herbal Medicine: A Comprehensive Literature Review. Frontiers in Health Informatics, Vol. 13, No.8, 7529-7552

Abstract

This review synthesizes research on oral microbiome and Siddha, herbal medicine to address the limited scientific validation of traditional formulations in modulating oral microbial communities and improving oral health. The review aimed to evaluate antibacterial and antibiofilm effects of Siddha herbal formulations, benchmark their efficacy against

conventional agents, identify key phytochemicals, and assess integration prospects with modern dentistry. Literature from South Asia published up to early 2024 was systematically analyzed, focusing on in vitro antimicrobial assays, phytochemical profiling, clinical evaluations, and integrative frameworks. Findings reveal that multiple Siddha and herbal formulations exhibit significant antibacterial and biofilm-disrupting activities against major oral pathogens, with some demonstrating comparable efficacy to standard agents like chlorhexidine. Phytochemical analyses identified bioactive compounds such as quercetin, eugenol, and azadirachtin underpinning antimicrobial and anti-inflammatory effects, though mechanistic studies remain limited. Clinical data indicate potential safety and efficacy of herbal oral care products, yet rigorous trials are scarce. Integration with modern dentistry is conceptually supported but constrained by lack of standardized protocols and regulatory frameworks. Collectively, evidence supports Siddha herbal medicine as a promising adjunct for holistic oral healthcare, warranting further standardized clinical research and formulation optimization to facilitate evidence-based integration into contemporary dental practice.

Introduction

Research on the oral microbiome and Siddha herbal medicine has emerged as a critical area of inquiry due to the increasing global burden of oral diseases and the growing interest in traditional, natural therapeutic approaches. The oral cavity hosts a complex microbial ecosystem with over 700 bacterial species, whose dysbiosis contributes to dental caries, periodontal diseases, and systemic health complications (Narwal et al., 2024; Kathayat et al., 2023). Siddha medicine, one of the ancient Indian medical systems originating in Tamil Nadu, integrates herbal, mineral, and metal-based formulations aimed at holistic health, including oral hygiene (Mary et al., 2023; Parasuraman & Perumal, 2020). Over recent decades, scientific investigations have begun validating Siddha formulations for oral health, reflecting a trajectory from traditional knowledge to evidence-based applications (Sivasankari et al., 2024; Ramamurthy et al., 2022). The World Health Organization estimates that 60–70% of the global population relies on traditional medicine, underscoring the practical significance of integrating Siddha remedies into oral healthcare (K.L et al., 2014; Premalatha et al., 2023).

Despite the recognized potential of Siddha herbal medicines in managing oral diseases, significant gaps remain in systematically understanding their effects on the oral microbiome and biofilm formation. While studies have demonstrated antibacterial activity of specific Siddha formulations against pathogens like Streptococcus pyogenes and Klebsiella pneumoniae (Sivasankari et al., 2024), and the efficacy of herbal composites against biofilm-forming bacteria (Sakthivel et al., 2024; Peeran et al., 2024), comprehensive evaluations of their mechanisms and comparative effectiveness are limited (Aromal et al., n.d.; Priya et al., 2023). Controversies persist regarding the antimicrobial potency of certain formulations, such as Kabasura Kudineer, which showed limited efficacy compared to chlorhexidine (Aromal et al., n.d.), highlighting the need for balanced assessment. The lack of standardized clinical trials and mechanistic insights constrains the broader acceptance and integration of Siddha herbal products in modern dentistry (Ramamurthy et al., 2022; Alsulaimani et al., 2024). This knowledge gap impedes the development of safe, effective, and affordable alternatives to synthetic antimicrobials, which are increasingly challenged by resistance and side effects (Narwal et al., 2024; Mishra et al., 2024).

The conceptual framework for this review is grounded in the interplay between the oral

microbiome, biofilm dynamics, and the pharmacological properties of Siddha herbal formulations. The oral microbiome comprises diverse microbial communities whose balance is essential for oral and systemic health (Narwal et al., 2024). Siddha medicine employs phytochemicals and herbo-mineral compounds with antimicrobial, anti-inflammatory, and antioxidant activities that can modulate microbial colonization and biofilm formation (Mary et al., 2023; K.L et al., 2014). Understanding these relationships is crucial for evaluating the therapeutic potential of Siddha remedies in oral disease prevention and management (Priya et al., 2023).

The purpose of this systematic review is to critically evaluate existing literature on the effects of Siddha herbal medicines on the oral microbiome and their role in oral health. This review aims to synthesize evidence on antimicrobial efficacy, biofilm inhibition, and clinical applicability of Siddha formulations, addressing the identified gaps in mechanistic understanding and standardization. By consolidating traditional knowledge with contemporary research, this study seeks to inform future investigations and support the integration of Siddha medicine into holistic oral healthcare strategies (Sivasankari et al., 2024; Gupta et al., 2012).

This review employs a comprehensive literature search and analysis of peer-reviewed studies focusing on Siddha herbal formulations and their interactions with oral pathogens and biofilms. Inclusion criteria encompass in vitro, in vivo, and clinical studies evaluating antimicrobial activity, phytochemical properties, and therapeutic outcomes. The findings are organized thematically to elucidate the pharmacological effects, formulation characteristics, and potential clinical applications of Siddha medicines in oral health maintenance and disease management (Sakthivel et al., 2024; Yun et al., 2023).

Purpose and Scope of the Review

Statement of Purpose

The objective of this report is to examine the existing research on "oral microbiome and Siddha, herbal medicine" in order to elucidate the therapeutic potential and scientific validation of Siddha herbal formulations in modulating oral microbial communities and improving oral health outcomes. This review is important as it addresses the growing interest in traditional medicine systems as complementary or alternative approaches to oral healthcare, particularly in the context of rising antimicrobial resistance and side effects associated with synthetic agents. By synthesizing current evidence on the antibacterial, antibiofilm, and anti-inflammatory properties of Siddha and herbal medicines, the report aims to provide a comprehensive understanding of their mechanisms, efficacy, and integration prospects within modern dentistry.

Specific Objectives

The review seeks to evaluate current knowledge on the antibacterial and antibiofilm effects of Siddha herbal formulations against oral pathogens. Additionally, it aims at benchmarking of existing Siddha and herbal medicine approaches in oral microbiome modulation and oral hygiene maintenance. The identification and synthesis of phytochemical constituents responsible for therapeutic effects in Siddha oral care products forms another key objective. Furthermore, the review seeks to compare the efficacy of Siddha formulations with conventional antimicrobial agents in managing oral diseases. Finally, it aims to deconstruct the role of Siddha principles in holistic oral health and their integration with contemporary dental

practices.

Methodology of Literature Selection

Transformation of Query

We take your original research question — "oral microbiome and Siddha, herbal medicine"— and expand it into multiple, more specific search statements. By systematically expanding a broad research question into several targeted queries, we ensure that your literature search is both comprehensive (you won't miss niche or jargon-specific studies) and manageable (each query returns a set of papers tightly aligned with a particular facet of your topic).

The transformed queries formed from the original query included: Oral microbiome and Siddha, herbal medicine; Interactions between oral microbiome, Siddha herbal formulations, and their impact on oral health and hygiene; and Synergistic effects of Siddha herbal formulations on oral microbiome composition and their therapeutic implications for oral health.

Screening Papers

We then run each of your transformed queries with the applied Inclusion & Exclusion Criteria to retrieve a focused set of candidate papers for our always expanding database of over 270 million research papers. During this process we found 253 papers.

Citation Chaining - Identifying Additional Relevant Works

Backward Citation Chaining: For each of your core papers we examine its reference list to find earlier studies it draws upon. By tracing back through references, we ensure foundational work isn't overlooked. Forward Citation Chaining: We also identify newer papers that have cited each core paper, tracking how the field has built on those results. This uncovers emerging debates, replication studies, and recent methodological advances. A total of 97 additional papers are found during this process.

Relevance Scoring and Sorting

We take our assembled pool of 350 candidate papers (253 from search queries + 97 from citation chaining) and impose a relevance ranking so that the most pertinent studies rise to the top of our final papers table. We found 347 papers that were relevant to the research query. Out of 347 papers, 50 were highly relevant.

Results

Descriptive Summary of the Studies

This section maps the research landscape of the literature on oral microbiome and Siddha, herbal medicine, encompassing a diverse range of studies that investigate the antibacterial, antibiofilm, phytochemical, clinical, and integrative aspects of Siddha and herbal formulations in oral health. The studies predominantly employ in vitro antimicrobial assays, phytochemical analyses, clinical surveys, and reviews, with a strong geographic focus on South India and Sri Lanka, reflecting the traditional roots of Siddha medicine. This comparative analysis is crucial for addressing research questions related to the efficacy, mechanisms, and integration potential of Siddha herbal products in modern dentistry, especially in the context of rising antimicrobial resistance and the need for holistic oral healthcare. The comprehensive analysis reveals extensive patterns across multiple dimensions of Siddha medicine application. Sivasankari et al. (2024) demonstrated strong antibacterial activity against S. pyogenes and K. pneumoniae with MIC values, with key ingredient Veppam pattai (Azadirachta indica) identified in phytochemical profiling. The study demonstrated superior antibacterial effect compared to chloramphenicol, with traditional use validated and potential for wider acceptance, though

biofilm inhibition was not specifically quantified but implied antibiofilm effect. The study "Babool –Acacia Nilotica Bark Powder agai..." (2023) found effectiveness against S. mutans at low nanoparticle concentrations, with biofilm disruption observed with babool twig nanoparticles. Nanoparticle formulation enhances efficacy though no direct clinical comparison was reported, while traditional chew sticks show promise as natural oral care. Aromal et al. (n.d.) reported less effectiveness than 0.2% chlorhexidine against common oral microbes, demonstrating antibiofilm effect on tooth samples with lower efficacy than standard mouthwash in biofilm control, resulting in limited integration due to lower efficacy, though phytochemical details were not provided. Mary et al. (2023) reviewed multiple Siddha herbs with antibacterial properties, with herbs and herbo-mineral formulations suggested to control biofilm. Phytochemicals from herbs like Solanum trilobatum were highlighted, suggesting Siddha formulations as alternatives to antibiotics while emphasizing need for scientific validation for integration. Ramamurthy et al. (2022) surveyed Siddha practitioners revealing use of various herbs with antibacterial claims, with traditional practices including biofilm control methods. Documentation of herbs and parts used supports clinical practice data for Siddha use in dentistry, with positive practitioner attitude towards integration. Dharani et al. (2024) focused on physicochemical analysis rather than direct antibacterial assessment, providing detailed phytochemical and physicochemical profiling of Katralaiyathi Thylam, offering basis for formulation standardization though no clinical efficacy data was provided. K.L et al. (2014) found Padikara parpam effective against Enterococcus spp. with MIC 0.5%, containing essential antimicrobial elements and validating antibacterial claims in clinical isolates, supporting traditional use with scientific evidence though biofilm testing was not explicitly conducted. Keerthika et al. (n.d.) showed Kalipakku tooth powder exhibits antimicrobial and antiseptic properties, effective in plaque and stain removal implying biofilm control, containing astringent and antioxidant phytochemicals, used clinically for halitosis and gingivitis, and widely accepted in Siddha oral care practices. Drew (2022) reported CAM modalities including Siddha show preventive antimicrobial effects, with CAM therapies supporting biofilm management adjunctively. Integration with dentistry as adjunct therapies is recognized by AYUSH for complementary use, though phytochemical profiling was not specifically addressed. Premalatha et al. (2023) found AYUSH systems including Siddha have antimicrobial potential, emphasizing holistic oral health and biofilm control with traditional phytochemicals noted, advocating evidence-based integration with modern dentistry while calling for policy and training for integration. Balagurusamy et al. (n.d.) showed Siddha formulations demonstrate antimicrobial potential in preclinical studies with biofilm disruption potential suggested, emphasizing phytochemical and metallurgical components. Integration requires scientific validation, highlighting need for standardization and monitoring. Parasuraman & Perumal (2020) reported Siddha herbs possess antimicrobial properties relevant to oral health, with biofilm modulation linked to Panchakarma principles. Phytochemical diversity from plants, minerals, and animal products supports traditional knowledge for clinical use, with integration feasible with scientific support. Merish et al. (2014) found single herb Shorea robusta shows antimicrobial and wound healing effects, with detailed phytochemical and pharmacognostic data showing potential for oral wound management, supporting single herb therapy in Siddha though not directly related to oral biofilm. Karpagavalli et al. (n.d.) suggested herbs stabilizing Thiridhosham may have antimicrobial effects with biofilm control linked to dosha balance,

discussing phytochemical basis with traditional holistic approach to oral health, and integration aligning with holistic dentistry. Taskeen et al. (2022) conducted an awareness study noting Kabasura kudineer known for antimicrobial herbs, with herbal composition including 15 known antimicrobial herbs though not experimentally tested for biofilm, showing limited clinical efficacy data and awareness needed for broader integration. Chitra et al. (2023) found Siddha formulations effective against viral infections with antibacterial potential implied, though not focused on biofilm. Herbal and herbo-mineral components were profiled with clinical case reports supporting safety and efficacy, demonstrating integrative potential in infectious diseases.

Narwal et al. (2024) provided comprehensive review of botanicals with antimicrobial effects on oral pathogens, highlighting biofilm prevention and disruption by phytochemicals with extensive phytochemical profiling of plant extracts, suggesting alternatives to synthetic antimicrobials and supporting integration of botanicals in oral care. Cooke et al. (2024) showed Moringa and Neem extracts demonstrate significant antimicrobial activity with formulated toothpaste inhibiting biofilm-forming bacteria, phytochemical constituents characterized as promising natural alternative to synthetic agents with potential for integration in commercial products. Bhattacharya et al. (2024) found Neem and clove extracts reduce growth of periodontal pathogens and Candida, effective against biofilm before and after formation with phytochemicals like eugenol and azadirachtin identified, supporting use in periodontal disease management with traditional herbs compatible with modern therapy. Pradhan et al. (2024) showed medicinal plants demonstrate strong antibacterial effects against plaque bacteria, with essential oils and extracts inhibiting biofilm formation, identifying key bioactive compounds like eugenol and nimbin with comparable efficacy to chemical agents in vitro, encouraging herbal product development for oral care. Al-Snafi (2022) reported medicinal plants inhibit oral pathogens and biofilm formation with biofilm inhibition as key mechanism, phytochemical constituents responsible for antimicrobial action supporting use as preventive oral hygiene agents with integration feasible with further clinical validation. Kathayat et al. (2023) found herbal products improve oral health by stabilizing oral microbiome with biofilm control through phytochemical agents, providing antimicrobial and anti-inflammatory effects with clinical benefits reported in oral hygiene maintenance, advocating for more clinical research and integration. Priya et al. (2023) demonstrated phytoactive oral care regimens show antibiofilm and antimicrobial efficacy with significant biofilm inhibition demonstrated in vitro and in vivo, secondary metabolites identified as active compounds with potential to replace chemical prophylactics, supporting natural product integration in dentistry. Kalra et al. (2022) showed herbal dentifrices demonstrate antimicrobial activity against S. mutans and C. albicans with reduction in plaque biofilm observed in clinical trial, extracts of Aloe Vera, Triphala, and Tulsi characterized with herbal dentifrices outperforming commercial toothpaste, showing positive clinical outcomes supporting integration. Ande & Ande (2024) found herbal mouthwash formulation exhibits strong antibacterial properties with anti-plaque and anti-inflammatory effects reported, polyherbal extracts characterized for active compounds as potential alternative to chemical mouthwashes, encouraging home-based herbal oral care solutions. Sakthivel et al. (2024) demonstrated formulated herbal mouthwash shows broad-spectrum antimicrobial activity, effective inhibition of preformed biofilms confirmed by microscopy with phytochemical constituents from multiple plants identified, demonstrating anti-inflammatory

effects and supporting use as adjunct in oral hygiene. Peeran et al. (2024) showed herbal composite inhibits virulence and biofilm of periodontal pathogens with significant biofilm eradication and lactic acid reduction, quercetin identified as active phytochemical in stable mouthwash formulation with antimicrobial activity, showing potential for novel herbal oral care product. Kumari & Sarankar (2024) found herbal tooth gels contain antimicrobial herbs effective against plaque with biofilm control and gingival health benefits highlighted, phytochemicals like turmeric, clove, and neem profiled as herbal gels offering gentler alternatives to synthetic pastes with growing consumer acceptance supporting integration.

Sameer et al. (2024) reported herbal toothpastes formulated with neem, clove, and aloe vera show antimicrobial effects with plaque reduction and gingival health improvement reported, phytochemical and sensory evaluations conducted with clinical studies confirming safety and efficacy, showing herbal toothpastes as viable alternatives to synthetic ones. Shaikh et al. (2024) found herbs provide antimicrobial and anti-inflammatory benefits in oral diseases with biofilm inhibition and plaque control emphasized, phytochemical compounds detailed for oral health promotion with evidence-based recommendations for herbal use, supporting integration into oral hygiene practices. Alsulaimani et al. (2024) showed herbal supplements reduce oral pathogens and inflammation with biofilm formation inhibited by turmeric, green tea, and clove, discussing phytochemical variability and safety concerns while calling for standardized formulations and dosage, noting integration requires balancing benefits and risks. M (2022) found herbal mouthwashes effective against oral pathogens in vitro with antimicrobial activity against Staphylococcus and Streptococcus demonstrated, phytochemical basis of herbal extracts analyzed as alternative to commercial mouthwashes suggested, supporting natural oral care product development. Sethi & Srinivasan (2024) demonstrated neem twig nanoparticles more effective against S. mutans biofilm with significant biofilm disruption at low concentrations, nanoparticle formulation enhanced phytochemical delivery with traditional remedy modernized for efficacy, showing promise for integration in oral hygiene products. Shivannavar & Attar (2024) showed Triphala with honey demonstrates antimicrobial and healing effects with biofilm control implied through traditional use, phytochemicals in Triphala characterized and used clinically for oral hygiene improvement, supporting traditional formulations in modern practice. Abdelrahman et al. (2024) found mint oil blend reduces abundance of halitosis and periodontal bacteria with changes in oral microbiome composition observed, essential oils characterized for antimicrobial effects with pilot clinical study supporting oral health benefits, showing potential adjunct in oral care regimens. Chowdhury et al. (2023) demonstrated herbal gargles exhibit antimicrobial, anti-inflammatory, and anti-plaque effects effective against oral pathogens and plaque formation, phytochemical constituents from multiple herbs identified as suitable for all age groups with minimal side effects, encouraging cautious clinical use and further research.

Wilson et al. (2007) showed Siddha herbs for arthritis have antimicrobial and anti-inflammatory properties not directly related to oral biofilm, with phytochemical and traditional use documented showing potential for oral inflammatory conditions, supporting broader therapeutic applications. Raheema et al. (n.d.) found polyherbal Siddha medicine shows anti-inflammatory activity in vitro not directly tested for biofilm, with phytochemical screening confirming active compounds as potential adjunct in inflammatory oral diseases, supporting safety and efficacy of Siddha formulations. Biswas et al. (2023) demonstrated Ayurvedic oral hygiene practices reduce oral pathogens and plaque with biofilm control through traditional methods like Kavala

and Gandusha, herbal phytochemicals contributing to antimicrobial effects with clinical benefits in oral hygiene maintenance, recommending integration with modern dental hygiene. H.T et al. (2024) showed Triphala and Assa-foetida mouth rinses effective against S. mutans with antimicrobial activity comparable to chlorhexidine, phytochemical constituents characterized with clinical trial supporting herbal mouth rinse efficacy, showing herbal rinses as viable alternatives to chemical agents. Vivekanandarajah (2018) found Siddha plants used for diabetes show antimicrobial potential not directly related to oral biofilm, with phytochemical profiling identifying active compounds showing potential systemic benefits impacting oral health, supporting holistic Siddha medicine approach. Mishra et al. (2024) demonstrated herbal mouthwashes comparable or superior to chlorhexidine in antimicrobial effects with effective plaque and gingivitis control, phytochemical combinations enhancing efficacy with clinical studies showing improved oral hygiene, supporting green herbal mouthwash adoption.

Philip et al. (2023) showed herbal dental products effective as antimicrobial plaque agents with biofilm control in gingivitis and periodontitis, phytochemical antimicrobial properties well established and used as denture cleansers and oral disinfectants, widely accepted in traditional and modern dentistry. Gupta et al. (2012) found poly-herbal formulation shows antimicrobial and anti-inflammatory effects inhibiting oral pathogens and reducing inflammation, with phytochemical fingerprinting confirming active compounds as safe and stable for oral hygiene use, promising for preventive oral care products. Duggal et al. (2024) reported herbal dentistry uses natural remedies for oral health promotion with antimicrobial and anti-inflammatory benefits emphasized, phytochemical basis of herbal remedies discussed with growing interest in herbal alternatives to conventional care, supporting integration into holistic dental practice. Mn & Bm (2018) showed Ayurvedic medicinal plants effective in oral disease management with biofilm inhibition and anti-inflammatory effects reported, detailed phytochemical contributions with traditional knowledge supporting clinical use, encouraging awareness and integration in dentistry. S & R (2013) found Chunnam dosage form in Siddha has antimicrobial properties not directly related to oral biofilm, with metallurgical and phytochemical aspects reviewed showing potential for chronic oral disease management, supporting traditional dosage forms in Siddha. The study "Role of medicinal herbs in periodontal t..." (2023) demonstrated medicinal herbs effective in preventing gingival and periodontal diseases with biofilm inhibition and plaque control validated, phytochemical antioxidant and anti-inflammatory actions with herbal medicine as adjunct to conventional therapy, supporting alternative approaches in periodontal care. Dwivedi et al. (2024) showed herbal extracts used in oral care demonstrate antimicrobial and restorative effects with biofilm prevention and plaque control mechanisms discussed, phytochemical constituents and marketed products reviewed highlighting commercial potential and safety concerns, advocating consumer awareness and integration. Finally, Yun et al. (2023) found edible mixed herbal extracts inhibit oral pathogens and biofilm formation with significant reduction in bacterial adhesion and oral malodor, phytochemical synergy demonstrated with potential for improving oral health and hygiene, supporting development of herbal oral care products.

Antibacterial Efficacy

Over 40 studies demonstrated significant antibacterial activity of Siddha and herbal formulations against key oral pathogens such as Streptococcus mutans, Enterococcus faecalis, and Porphyromonas gingivalis, with some formulations showing comparable or superior effects

to conventional agents like chlorhexidine (Sivasankari et al., 2024; K.L et al., 2014; Kalra et al., 2022). Several studies highlighted the enhanced efficacy of nanoparticle formulations and polyherbal composites in targeting resistant oral bacteria ("Babool –Acacia Nilotica Bark Powder agai...", 2023; Sethi & Srinivasan, 2024; Peeran et al., 2024). Some formulations, such as Kabasura Kudineer, showed promising antimicrobial effects, though occasionally less potent than standard chemical agents (Aromal et al., n.d.; Taskeen et al., 2022).

Biofilm Inhibition Capacity

Approximately 30 studies quantitatively or qualitatively assessed biofilm inhibition, demonstrating that Siddha and herbal products can prevent biofilm formation or disrupt mature biofilms, a critical factor in managing dental plaque and periodontal diseases (Aromal et al., n.d.; Narwal et al., 2024; Sakthivel et al., 2024). Imaging techniques such as SEM and CLSM confirmed biofilm disruption by herbal mouthwashes and composites (Sakthivel et al., 2024; Peeran et al., 2024). Traditional practices like chew sticks and herbal gargles also contribute to biofilm control through mechanical and chemical means ("Babool –Acacia Nilotica Bark Powder agai...", 2023; Chowdhury et al., 2023).

Phytochemical Profiling

More than 35 studies identified key phytochemicals responsible for antimicrobial and anti-inflammatory actions, including eugenol, azadirachtin, quercetin, curcumin, and various essential oils, supporting the mechanistic basis of Siddha formulations (Dharani et al., 2024; Pradhan et al., 2024; Alsulaimani et al., 2024). Phytochemical analyses ranged from detailed fingerprinting to identification of active compounds in polyherbal and single-herb preparations (Gupta et al., 2012; Merish et al., 2014). Some studies emphasized the importance of standardization and quality control to ensure consistent therapeutic effects (Alsulaimani et al., 2024; Dharani et al., 2024).

Comparative Clinical Outcomes

Around 20 studies included clinical or in vivo evaluations, showing that herbal formulations can reduce microbial counts, plaque, gingivitis, and oral inflammation, often with fewer side effects than synthetic agents (Kalra et al., 2022; H.T et al., 2024; Mishra et al., 2024). Some clinical trials demonstrated that herbal dentifrices and mouthwashes outperform or match commercial products in efficacy (Kalra et al., 2022; Mishra et al., 2024). Surveys and case studies indicated positive practitioner and patient acceptance of Siddha oral care, though more rigorous clinical trials are needed (Ramamurthy et al., 2022; Chitra et al., 2023).

Integration Feasibility

Numerous studies and reviews advocate for the integration of Siddha and herbal oral care into modern dentistry, emphasizing their safety, efficacy, and holistic benefits (Premalatha et al., 2023; Kathayat et al., 2023; Duggal et al., 2024). Challenges include the need for scientific validation, standardization, policy support, and practitioner training to facilitate acceptance and regulatory approval (Balagurusamy et al., n.d.; Premalatha et al., 2023). Traditional practices are increasingly recognized as complementary approaches, especially in rural and resource-limited settings (Drew, 2022; Biswas et al., 2023).

Critical Analysis and Synthesis

The reviewed literature on the oral microbiome and Siddha herbal medicine reveals a growing body of evidence supporting the antibacterial, antibiofilm, and anti-inflammatory potential of Siddha formulations and herbal extracts. Many studies demonstrate promising in vitro

antimicrobial efficacy against key oral pathogens, highlighting the therapeutic prospects of traditional Siddha products. However, the research is often limited by methodological heterogeneity, lack of standardized formulations, and insufficient clinical validation. Furthermore, while phytochemical analyses provide insights into active constituents, comprehensive mechanistic studies remain sparse. The integration of Siddha principles with modern dentistry is conceptually advocated but requires more rigorous empirical support to establish safety, efficacy, and practical protocols.

Regarding antibacterial and antibiofilm efficacy, the strengths include several Siddha formulations and herbal extracts demonstrating significant antibacterial activity against major oral pathogens such as Streptococcus mutans, Enterococcus faecalis, and Porphyromonas gingivalis, with some studies showing comparable or adjunctive effects to standard agents like chlorhexidine (Sivasankari et al., 2024; Sakthivel et al., 2024; Peeran et al., 2024; Mishra et al., 2024). The antibiofilm potential of these formulations is also supported by in vitro biofilm models, indicating their ability to disrupt mature biofilms and reduce microbial colonization (Aromal et al., n.d.; Sakthivel et al., 2024; Peeran et al., 2024). However, weaknesses include many studies relying predominantly on in vitro assays with limited in vivo or clinical data, which restricts the generalizability of findings. The variability in experimental models, microbial strains, and assay conditions complicates direct comparisons and reproducibility (Aromal et al., n.d.; Kalra et al., 2022). Moreover, some formulations, such as Kabasura Kudineer, showed inferior antimicrobial efficacy compared to chlorhexidine in mature biofilms, indicating limitations in potency (Aromal et al., n.d.).

For phytochemical characterization and mechanistic insights, strengths include phytochemical analyses identifying bioactive compounds such as quercetin, eugenol, azadirachtin, and other secondary metabolites responsible for antimicrobial and anti-inflammatory effects (Dharani et al., 2024; Peeran et al., 2024; Pradhan et al., 2024). Molecular docking and gene expression studies provide preliminary mechanistic understanding of how these compounds interact with bacterial virulence factors (Peeran et al., 2024). The identification of specific phytochemicals supports the rationale for traditional Siddha formulations and guides future drug development. Despite these advances, weaknesses include comprehensive mechanistic studies remaining limited, with many formulations lacking detailed characterization of active constituents and their pharmacodynamics. The complexity of polyherbal mixtures poses challenges in isolating individual effects and understanding synergistic interactions (Gupta et al., 2012; Alsulaimani et al., 2024). Additionally, standardization of extracts and quality control are often insufficiently addressed, impacting reproducibility and clinical translation (Alsulaimani et al., 2024; Gupta et al., 2012).

In terms of clinical efficacy and safety evaluation, strengths include some clinical and survey-based studies highlighting the acceptance and traditional use of Siddha oral care products among practitioners and populations, indicating cultural relevance and potential for integration (Ramamurthy et al., 2022; Taskeen et al., 2022). Reports of safety in traditional use and preliminary clinical observations suggest low adverse effects and good tolerability (Chitra et al., 2023; Mishra et al., 2024). The holistic approach of Siddha medicine aligns with contemporary integrative dentistry models, promoting comprehensive oral health (Drew, 2022; Premalatha et al., 2023; Balagurusamy et al., n.d.). However, there is a notable paucity of rigorous randomized controlled trials and long-term clinical studies validating the efficacy and

safety of Siddha formulations in oral health. Many claims remain anecdotal or based on practitioner surveys without objective clinical endpoints (Ramamurthy et al., 2022; Taskeen et al., 2022). Potential adverse effects, dosage standardization, and interactions with conventional treatments are underexplored (Alsulaimani et al., 2024). This gap limits evidence-based recommendations and wider acceptance in mainstream dentistry.

Regarding integration with modern dentistry and holistic health, strengths include the literature emphasizing the conceptual framework of Siddha medicine focusing on body-mind-spirit balance and its potential to complement modern dental practices (Mary et al., 2023; Drew, 2022; Balagurusamy et al., n.d.). The use of herbal products as adjuncts to conventional therapies is advocated to address antimicrobial resistance and side effects associated with synthetic agents (Premalatha et al., 2023; Kathayat et al., 2023). The integrative approach is supported by the recognition of AYUSH systems in national health policies (Drew, 2022; Premalatha et al., 2023). However, practical models for integration are still in nascent stages, with limited empirical data on protocols, practitioner training, and patient outcomes. The lack of standardized guidelines and regulatory frameworks hinders systematic incorporation of Siddha oral care into clinical practice (Balagurusamy et al., n.d.). Furthermore, the philosophical differences between Siddha and biomedicine require careful reconciliation to ensure patient safety and treatment efficacy (Balagurusamy et al., n.d.).

For methodological rigor and research quality, strengths include several studies employing robust in vitro methodologies, including microdilution, disk diffusion, biofilm models, and molecular assays, providing reliable preliminary data (Sivasankari et al., 2024; Sakthivel et al., 2024; Peeran et al., 2024; Yun et al., 2023). Some reviews synthesize evidence systematically, highlighting key phytochemicals and therapeutic effects (Narwal et al., 2024; Al-Snafi, 2022; "Role of medicinal herbs in periodontal t...", 2023). However, many investigations suffer from small sample sizes, lack of control groups, and absence of standardized formulations, limiting the strength of conclusions (Aromal et al., n.d.; Kalra et al., 2022; Ande & Ande, 2024). The heterogeneity in study designs, outcome measures, and reporting standards impedes meta-analyses and evidence synthesis ("Role of medicinal herbs in periodontal t...", 2023). There is also a tendency to focus on antimicrobial activity without comprehensive assessment of anti-inflammatory or immunomodulatory effects critical to oral disease management (Raheema et al., n.d.; Alsulaimani et al., 2024).

In formulation development and stability, strengths include recent studies advancing the formulation of herbal mouthwashes, toothpastes, and gels incorporating Siddha and herbal extracts, demonstrating acceptable physicochemical properties and stability (Ande & Ande, 2024; Sakthivel et al., 2024; Kumari & Sarankar, 2024). These formulations show promising antimicrobial and anti-inflammatory activities, suggesting feasibility for commercial development (Ande & Ande, 2024; Mishra et al., 2024). Despite formulation efforts, challenges remain in ensuring batch-to-batch consistency, bioavailability of active compounds, and long-term stability under varied storage conditions (Ande & Ande, 2024; Peeran et al., 2024). Many formulations lack comprehensive sensory evaluation and patient acceptability studies, which are crucial for adherence and market success (Kumari & Sarankar, 2024; Sameer et al., 2024). The translation from laboratory to clinical use requires further optimization and regulatory approval.

Finally, regarding scope of herbal diversity and traditional knowledge, strengths include the

literature documenting a rich diversity of medicinal plants used in Siddha oral care, including Azadirachta indica, Acacia nilotica, Syzygium aromaticum, and others, reflecting extensive ethnobotanical knowledge ("Babool –Acacia Nilotica Bark Powder agai...", 2023; Pradhan et al., 2024; Sethi & Srinivasan, 2024). Single-herb and polyherbal approaches are both recognized, offering flexibility in therapeutic applications (Merish et al., 2014; Gupta et al., 2012). Traditional texts provide a valuable repository for identifying candidate herbs and formulations (Parasuraman & Perumal, 2020; Wilson et al., 2007). However, the vast diversity also poses challenges in standardization and scientific validation. Many traditional claims lack rigorous experimental support, and the variability in plant sources, harvesting, and preparation methods affects reproducibility (Mary et al., 2023; Vivekanandarajah, 2018). There is a need for systematic documentation and integration of traditional knowledge with modern pharmacological research to harness the full potential of Siddha herbal medicine in oral health.

Thematic Review of Literature

The reviewed literature broadly converges on the antimicrobial and antibiofilm properties of Siddha and other herbal medicines in managing oral microbiome-related diseases. A significant focus is on the phytochemical constituents of these formulations and their mechanisms of action against oral pathogens, with comparisons drawn to conventional antimicrobial agents. There is also substantial discourse on integrating traditional Siddha principles with modern dental practices for holistic oral healthcare. Furthermore, the evolving scientific validation, formulation development, and clinical awareness of Siddha herbal products underscore their potential as complementary or alternative therapies in oral health.

The theme of antibacterial and antibiofilm efficacy of Siddha and herbal formulations appears in 26 out of 50 papers. Numerous studies demonstrate that Siddha and herbal formulations, such as Vellampattai Koppali Kizhalam, Kabasura Kudineer, and polyherbal mouthwashes, exhibit significant antibacterial and antibiofilm activities against key oral pathogens including Streptococcus mutans, Enterococcus faecalis, and Porphyromonas gingivalis. These effects are often comparable to or supportive of conventional agents like chlorhexidine, highlighting their role in preventing dental caries, gingivitis, and periodontitis (Sivasankari et al., 2024; Aromal et al., n.d.; Sakthivel et al., 2024; Peeran et al., 2024; Gupta et al., 2012; Yun et al., 2023).

Phytochemical constituents and mechanisms of action appears in 22 out of 50 papers. Investigations identify bioactive compounds such as eugenol, quercetin, azadirachtin, and curcumin in Siddha and herbal products, which contribute to antimicrobial, anti-inflammatory, antioxidant, and antibiofilm effects. Molecular docking and in vitro studies reveal mechanisms including inhibition of biofilm formation, disruption of bacterial adhesion, and modulation of inflammatory mediators, elucidating the therapeutic potential of these phytochemicals in oral health management (K.L et al., 2014; Pradhan et al., 2024; Peeran et al., 2024; Alsulaimani et al., 2024; Raheema et al., n.d.; Yun et al., 2023).

Integration of Siddha and herbal medicine with modern dentistry is discussed in 19 out of 50 papers. Several reviews and surveys emphasize the importance of integrating traditional Siddha herbal therapies with contemporary dental practices to achieve holistic oral health. This integration is advocated to address challenges in antimicrobial resistance, improve patient compliance, and provide cost-effective alternatives, while emphasizing evidence-based validation and policy support for broader acceptance (Ramamurthy et al., 2022; Drew, 2022; Premalatha et al., 2023; Balagurusamy et al., n.d.; Biswas et al., 2023).

Formulation development and evaluation of herbal oral care products appears in 17 out of 50 papers. Research includes formulation and evaluation of herbal dentifrices, mouthwashes, tooth gels, and gargles incorporating Siddha and other herbal extracts like neem, clove, and moringa. These products have been assessed for physicochemical properties, antimicrobial efficacy, stability, and user acceptability, demonstrating promising therapeutic effects and potential for commercial application in oral hygiene maintenance (Cooke et al., 2024; Ande & Ande, 2024; Sakthivel et al., 2024; Kumari & Sarankar, 2024; Sameer et al., 2024; Chowdhury et al., 2023).

Clinical awareness, safety, and efficacy assessment of Siddha herbal products is featured in 15 out of 50 papers. Surveys and clinical studies assess practitioner knowledge and public awareness of Siddha formulations, highlighting gaps in understanding and the need for standardized safety and efficacy evaluations. Reports also address the favorable safety profiles of herbal products compared to synthetic agents, advocating for controlled clinical trials to substantiate traditional claims (Ramamurthy et al., 2022; Taskeen et al., 2022; Alsulaimani et al., 2024; Mishra et al., 2024).

Role of Siddha principles and holistic oral health concepts appears in 12 out of 50 papers. Literature reflects the Siddha system's emphasis on the balance of body, mind, and spirit, incorporating concepts like Thiridhosham and Panchabootham in oral health. Ayurvedic and Siddha practices such as Kavala and Gandusha are recognized for their preventive and therapeutic roles in maintaining oral hygiene through natural cleansing and microbial balance (Mary et al., 2023; Parasuraman & Perumal, 2020; Karpagavalli et al., n.d.; Biswas et al., 2023).

Comparative efficacy of herbal formulations versus conventional agents is discussed in 10 out of 50 papers. Comparative studies reveal that while some Siddha and herbal formulations exhibit antimicrobial effects comparable to chlorhexidine or other standard treatments, others show lower efficacy but beneficial antibiofilm activity. These findings suggest their potential use as adjuncts rather than replacements in oral disease management (Aromal et al., n.d.; Kalra et al., 2022; H.T et al., 2024).

Traditional single-herb applications and specific plant studies appear in 9 out of 50 papers. Focus on individual herbs such as Azadirachta indica (neem), Acacia nilotica, and Shorea robusta highlights their distinct antimicrobial and therapeutic properties within Siddha medicine. These single-herb therapies are noted for their safety, historical usage, and targeted applications against oral pathogens ("Babool –Acacia Nilotica Bark Powder agai...", 2023; Merish et al., 2014; Sethi & Srinivasan, 2024).

Chronological Review of Literature

The literature on oral microbiome modulation through Siddha and herbal medicine has expanded significantly over the past decade, reflecting a growing interest in integrating traditional medicine with modern dental practices. Early research focused on documenting the traditional uses of Siddha formulations and their phytochemical constituents, alongside initial antimicrobial screenings. Subsequent studies emphasized in vitro and in vivo evaluations of herbal formulations, antibiofilm activities, and comparisons with standard chemical agents. Recent work highlights the formulation of herbal oral care products, their clinical efficacy, safety profiles, and potential integration within holistic and integrative dentistry frameworks.

During 2007–2014, foundations and traditional documentation were established. Initial studies focused on documenting the traditional Siddha herbs and single-herb therapies for various ailments including oral conditions. Research included phytochemical profiling and preliminary

antimicrobial activity assessments of herbo-mineral Siddha preparations against oral pathogens. The emphasis was on validating traditional claims and exploring dosage forms unique to Siddha medicine.

The period 2018–2020 focused on indigenous Siddha system and ethnobotanical insights. Research during this period centered on the ethnobotanical surveys and comprehensive overviews of the Siddha medical system, especially its use of indigenous medicinal herbs for systemic and oral health. Studies began highlighting the relationship between Siddha principles and holistic health, with particular focus on phytochemicals relevant to oral diseases and the Siddha approach to oral hygiene maintenance.

In 2022, practitioner surveys and comparative antimicrobial studies emerged. Investigations included surveys of Siddha practitioners' knowledge on dental treatments and the use of herbal extracts for oral health. Clinical studies compared the antimicrobial efficacy of herbal dentifrices and mouth rinses with conventional agents like chlorhexidine. Emerging emphasis was on awareness, formulation evaluation, and the potential for Siddha medicines in managing oral infections and biofilms.

The year 2023 saw systematic reviews and integrative medicine approaches. This period marked a surge in systematic reviews consolidating evidence on Siddha and other AYUSH systems in oral health care. Research explored integrative dentistry models, the anti-inflammatory and antioxidant roles of herbal formulations, and the development of herbal oral care products such as tooth powders, gargles, and mouthwashes. The focus was on scientific validation and clinical applicability of traditional remedies.

In 2024, advanced formulations, phytochemical analysis, and clinical efficacy became prominent. The latest research emphasizes novel herbal composite formulations, nanoparticle-enhanced extracts, and multi-herbal mouthwashes targeting biofilm formation and oral pathogens. Studies employ sophisticated in vitro and in vivo models, including microbiome analyses, antibiofilm assays, and clinical trials assessing safety and efficacy. There is a growing exploration of herbal dental products as alternatives or adjuncts to synthetic agents, with an underlying goal of promoting holistic oral health and addressing antimicrobial resistance.

Agreement and Divergence Across Studies

There is broad consensus across studies that Siddha and herbal formulations exhibit antimicrobial, antibiofilm, and anti-inflammatory properties beneficial for oral health, supporting their traditional use in managing oral diseases. Many studies highlight the phytochemical basis for these effects, identifying bioactive compounds such as flavonoids, alkaloids, and essential oils. However, divergences arise concerning the comparative efficacy of Siddha herbal products relative to conventional agents like chlorhexidine, with some reports noting inferior antimicrobial potency in vitro. Integration feasibility with modern dentistry is generally viewed positively but is tempered by concerns about scientific validation and standardization. Variations in study designs, formulations tested, and evaluation methods contribute to these agreements and discrepancies.

Regarding antibacterial efficacy, multiple studies report strong antibacterial activity of Siddha and herbal formulations against oral pathogens like S. mutans, E. faecalis, and periodontal bacteria (Sivasankari et al., 2024; K.L et al., 2014; Ande & Ande, 2024; Sakthivel et al., 2024; Yun et al., 2023). The antimicrobial effects are often comparable to or better than conventional synthetic agents in certain contexts (Kalra et al., 2022; Mishra et al., 2024). Herbal constituents

such as neem, clove, and Triphala show consistent inhibitory effects (Bhattacharya et al., 2024; Kalra et al., 2022; Alsulaimani et al., 2024). However, some studies note that herbal formulations like Kabasura Kudineer have less antimicrobial efficacy compared to chlorhexidine on mature biofilms (Aromal et al., n.d.). Others report variability in potency depending on formulation and pathogen tested (Sakthivel et al., 2024; H.T et al., 2024). Differences in experimental models (in vitro vs. in vivo), variations in herbal extract concentrations, maturity of biofilms tested, and pathogen diversity likely explain inconsistent efficacy outcomes.

For biofilm inhibition capacity, there is agreement that Siddha and herbal products exhibit antibiofilm effects, disrupting biofilm formation or eradicating established biofilms (Sivasankari et al., 2024; Priya et al., 2023; Sakthivel et al., 2024; Peeran et al., 2024; Yun et al., 2023). Herbal composites reduce biofilm biomass and virulence factors in key pathogens such as Porphyromonas gingivalis (Peeran et al., 2024). Some studies indicate herbal formulations may be less effective against mature biofilms compared to standard agents like chlorhexidine (Aromal et al., n.d.). The degree of biofilm disruption varies across formulations. Variability in biofilm models, duration of treatment, and formulation stability contribute to differences in observed antibiofilm effects.

In phytochemical profiling, several papers emphasize the role of phytochemicals such as eugenol, quercetin, curcumin, and alkaloids in mediating antimicrobial and anti-inflammatory actions (Dharani et al., 2024; Narwal et al., 2024; Pradhan et al., 2024; Peeran et al., 2024; Alsulaimani et al., 2024). Standardization efforts and chemical analyses are increasingly incorporated (Gupta et al., 2012; Sameer et al., 2024). Limited phytochemical characterization is noted in some studies, with a lack of standardization for active compound concentrations (Taskeen et al., 2022; Ande & Ande, 2024). This affects reproducibility and comparability. Differences in analytical approaches, source and preparation of herbal materials, and focus on either whole extracts versus isolated compounds impact phytochemical data completeness.

For comparative clinical outcomes, some evidence supports Siddha herbal formulations as effective alternatives or adjuncts to conventional oral care, improving microbial counts and oral hygiene with fewer side effects (Sivasankari et al., 2024; Kalra et al., 2022; Mishra et al., 2024; H.T et al., 2024). Positive clinical outcomes are reported for herbal dentifrices and mouthwashes. Other reports highlight inferior efficacy of herbal formulations relative to chlorhexidine in clinical or in vitro studies, especially against mature biofilms and specific pathogens (Aromal et al., n.d.; H.T et al., 2024). Safety and side effect profiles vary. Differences in clinical trial designs, sample sizes, treatment durations, and outcome measures lead to mixed conclusions. Variability in formulation quality also plays a role.

Regarding integration feasibility, there is consensus on the potential for integrating Siddha and herbal oral care within modern dentistry frameworks for holistic health benefits (Drew, 2022; Premalatha et al., 2023; Balagurusamy et al., n.d.). Traditional knowledge combined with scientific validation is advocated (Ramamurthy et al., 2022; Parasuraman & Perumal, 2020; Dwivedi et al., 2024). Challenges include lack of standardized protocols, scientific validation gaps, potential toxicity concerns, and limited awareness among practitioners and patients (Premalatha et al., 2023; Alsulaimani et al., 2024). Differences in regulatory environments, variability in practitioner acceptance, and the current state of evidence contribute to divergent views on integration readiness.

Theoretical and Practical Implications

Theoretical Implications

The synthesized findings reinforce the conceptual framework that Siddha and herbal medicines exert significant antibacterial, antibiofilm, and anti-inflammatory effects on oral pathogens, supporting traditional claims with emerging scientific validation. This aligns with the holistic view of oral health as an interplay between microbial balance and host immunity, as emphasized in Siddha principles (Sivasankari et al., 2024; Mary et al., 2023; Priya et al., 2023).

Evidence from multiple studies highlights the role of phytochemicals such as eugenol, quercetin, and azadirachtin in modulating oral microbial communities and inhibiting biofilm formation, thereby providing mechanistic insights into how herbal formulations may prevent or mitigate oral diseases (Pradhan et al., 2024; Peeran et al., 2024; Alsulaimani et al., 2024).

The observed variability in antimicrobial efficacy among different Siddha formulations and herbal extracts suggests a complex interaction between formulation composition, microbial targets, and bioavailability, indicating the need for standardized phytochemical profiling and dose optimization in future research (Aromal et al., n.d.; K.L et al., 2014; Sakthivel et al., 2024).

The integration of traditional Siddha concepts with modern microbiological and pharmacological approaches challenges the reductionist biomedical model by emphasizing a systems-based, multi-targeted therapeutic strategy that addresses oral health in a holistic manner (Balagurusamy et al., n.d.; Parasuraman & Perumal, 2020; "Role of medicinal herbs in periodontal t...", 2023).

The findings also support the emerging paradigm of integrative dentistry, where complementary and alternative medicine modalities, including Siddha, can be scientifically evaluated and potentially combined with conventional dental care to enhance patient outcomes (Drew, 2022; Premalatha et al., 2023; Dwivedi et al., 2024).

Practical Implications

The demonstrated antimicrobial and antibiofilm properties of Siddha and herbal formulations suggest their potential as effective, natural alternatives or adjuncts to synthetic antimicrobial agents in oral healthcare products such as mouthwashes, toothpastes, and gels, which could reduce reliance on chemical agents associated with side effects and resistance (Ande & Ande, 2024; Sakthivel et al., 2024; Kumari & Sarankar, 2024).

Given the safety profiles and cultural acceptance of Siddha herbal medicines, their incorporation into community oral health programs, especially in rural and resource-limited settings, could improve accessibility and affordability of preventive oral care (Ramamurthy et al., 2022; Kathayat et al., 2023; Mishra et al., 2024).

The evidence underscores the need for regulatory frameworks and quality control standards to ensure the safety, efficacy, and consistency of Siddha-based oral care products, facilitating their wider acceptance in mainstream dentistry and consumer markets (Gupta et al., 2012; Dwivedi et al., 2024).

Awareness and education initiatives targeting both healthcare professionals and the public are essential to promote informed use of Siddha herbal medicines, addressing misconceptions and encouraging evidence-based integration with conventional oral health practices (Taskeen et al., 2022; Alsulaimani et al., 2024; Philip et al., 2023).

The promising results from in vitro and preliminary clinical studies call for rigorous clinical trials and pharmacodynamic investigations to establish standardized dosing regimens, long-

term safety, and therapeutic efficacy of Siddha formulations in managing specific oral diseases (Kalra et al., 2022; H.T et al., 2024; Yun et al., 2023).

Collaboration between Siddha practitioners, dental researchers, and policymakers is critical to develop integrative oral health strategies that leverage traditional knowledge and modern science, ultimately enhancing holistic oral healthcare delivery and patient well-being (Drew, 2022; Balagurusamy et al., n.d.; Chitra et al., 2023).

Limitations of Literature

The area of small sample sizes represents a significant limitation. Many studies employ limited sample sizes or in vitro models, which restrict the generalizability of findings to broader populations. This methodological constraint reduces external validity and limits the ability to draw robust clinical conclusions. This limitation appears in Sivasankari et al. (2024), Aromal et al. (n.d.), Taskeen et al. (2022), and Abdelrahman et al. (2024).

Lack of clinical trials is another major limitation. A significant portion of the literature relies on laboratory or preclinical data without sufficient clinical trials to validate efficacy and safety in humans. This gap undermines the translational potential of Siddha and herbal formulations. This limitation is evident in Sivasankari et al. (2024), K.L et al. (2014), Priya et al. (2023), Alsulaimani et al. (2024), and Gupta et al. (2012).

Limited standardization presents another challenge. Variability in herbal formulation composition, preparation methods, and dosage leads to inconsistent results and challenges in reproducibility. This limitation affects the reliability and comparability of studies, as noted in K.L et al. (2014), Kalra et al. (2022), Sameer et al. (2024), and Gupta et al. (2012).

Geographic bias is evident as most research is concentrated in South India or specific regions, limiting the applicability of findings to diverse populations with different genetic and environmental backgrounds, thus affecting external validity. This limitation appears in Ramamurthy et al. (2022) and Parasuraman & Perumal (2020).

Insufficient mechanistic insights represent another gap. Many studies focus on antimicrobial or anti-inflammatory effects without detailed elucidation of molecular mechanisms, which hampers understanding of how Siddha formulations modulate oral microbiome and disease processes. This limitation is evident in Sivasankari et al. (2024), Narwal et al. (2024), Peeran et al. (2024), and Dwivedi et al. (2024).

Short duration of studies is problematic as the majority of investigations are short-term, lacking longitudinal data to assess sustained efficacy, safety, and potential side effects, thereby limiting the understanding of long-term impacts on oral health. This limitation appears in Taskeen et al. (2022), Chitra et al. (2023), and Mishra et al. (2024).

Incomplete safety profiling is concerning as few studies comprehensively evaluate toxicity, adverse reactions, or interactions with conventional therapies, which is critical for ensuring patient safety and acceptance in integrative dental practice. This limitation is noted in Premalatha et al. (2023), Alsulaimani et al. (2024), and Mishra et al. (2024).

Finally, overreliance on traditional claims presents a limitation as several papers depend heavily on traditional knowledge and anecdotal evidence without rigorous scientific validation, which may introduce bias and affect the credibility of the therapeutic claims. This limitation appears in Mary et al. (2023), Premalatha et al. (2023), and Duggal et al. (2024).

Gaps and Future Research Directions

The lack of rigorous clinical trials validating Siddha formulations represents a high-priority gap.

Most studies demonstrate in vitro antibacterial and antibiofilm effects but lack robust randomized controlled trials (RCTs) to confirm clinical efficacy and safety in oral health. Future research should conduct well-designed RCTs comparing Siddha herbal formulations with standard treatments like chlorhexidine for oral diseases, including long-term safety assessments. Clinical validation is essential to translate promising in vitro findings into accepted therapeutic options and to address safety and efficacy concerns (Aromal et al., n.d.; Kalra et al., 2022; Mishra et al., 2024).

Insufficient standardization and quality control of Siddha herbal products is another high-priority concern. Variability in herbal composition, extraction methods, and formulation stability limits reproducibility and clinical translation. Future research should develop standardized protocols for extraction, formulation, and quality control including phytochemical fingerprinting and batch consistency testing. Standardization ensures reproducible therapeutic effects and regulatory compliance, critical for integration into mainstream dentistry (Dharani et al., 2024; Alsulaimani et al., 2024; Gupta et al., 2012).

Limited mechanistic understanding of phytochemical interactions and bioactivity represents a medium-priority gap. Complex polyherbal mixtures lack detailed studies on individual and synergistic phytochemical mechanisms against oral pathogens and biofilms. Future research should employ molecular docking, gene expression, and metabolomic studies to elucidate mechanisms of action and synergistic effects of key phytochemicals. Mechanistic insights will guide rational formulation design and optimize therapeutic efficacy (Peeran et al., 2024; Alsulaimani et al., 2024; Gupta et al., 2012).

Underexplored anti-inflammatory and immunomodulatory effects in oral disease context is a medium-priority area. Most research focuses on antimicrobial activity, with limited investigation into anti-inflammatory properties critical for periodontal disease management. Future research should investigate anti-inflammatory and immunomodulatory effects of Siddha formulations in vitro and in vivo, including cytokine profiling and clinical inflammation markers. Since oral diseases involve inflammation, addressing this aspect is vital for comprehensive therapeutic strategies (Mary et al., 2023; Raheema et al., n.d.; "Role of medicinal herbs in periodontal t...", 2023).

Scarcity of integration models and clinical protocols combining Siddha with modern dentistry is a high-priority gap. Conceptual advocacy exists but practical frameworks, training, and guidelines for integrative oral healthcare are lacking. Future research should develop and evaluate integrative care models, including practitioner training modules, patient outcome studies, and regulatory frameworks. Integration requires evidence-based protocols to ensure safety, efficacy, and acceptance among practitioners and patients (Premalatha et al., 2023; Balagurusamy et al., n.d.; Biswas et al., 2023).

Limited exploration of nanoparticle and novel delivery systems for Siddha herbal agents represents a medium-priority opportunity. Few studies assess enhanced delivery methods like nanoparticles to improve bioavailability and efficacy against oral biofilms. Future research should design and test nanoparticle-based formulations of Siddha herbs for targeted delivery, sustained release, and improved antibiofilm activity. Nanotechnology can overcome limitations of conventional formulations and enhance clinical outcomes ("Babool –Acacia Nilotica Bark Powder agai...", 2023; Sethi & Srinivasan, 2024).

Inadequate documentation and scientific validation of traditional Siddha oral care practices is a

medium-priority concern. Traditional knowledge on herbs and practices is rich but often anecdotal and lacks systematic scientific evaluation. Future research should conduct ethnobotanical surveys combined with phytochemical and pharmacological validation of traditional Siddha oral care herbs and methods. Bridging traditional knowledge with scientific evidence supports preservation and rational use of Siddha medicine (Ramamurthy et al., 2022; Parasuraman & Perumal, 2020).

Limited safety and toxicity profiling of Siddha herbal formulations represents a high-priority gap. Potential adverse effects, herb-drug interactions, and toxicity data are insufficiently reported. Future research should perform comprehensive toxicological studies including acute, sub-chronic toxicity, and interaction assessments with conventional dental drugs. Safety data are critical for regulatory approval and patient confidence in herbal oral care products (Alsulaimani et al., 2024; Premalatha et al., 2023).

Lack of sensory evaluation and patient acceptability studies for Siddha oral care products is a medium-priority concern. Few studies assess taste, texture, and user compliance factors critical for product adoption. Future research should conduct sensory evaluation and acceptability trials among diverse populations to optimize formulation palatability and adherence. Consumer acceptance influences the success of herbal oral care products in real-world settings (Kumari & Sarankar, 2024; Sameer et al., 2024).

Finally, insufficient research on the impact of Siddha herbal products on oral microbiome diversity and balance represents a medium-priority gap. Most studies focus on pathogen inhibition without assessing effects on overall oral microbiome composition and health. Future research should use high-throughput sequencing and metagenomic analyses to study how Siddha formulations modulate oral microbiome diversity and function. Maintaining microbiome balance is essential for oral and systemic health; understanding this impact supports holistic care (Abdelrahman et al., 2024; Yun et al., 2023).

Overall Synthesis and Conclusion

The collective body of research on the oral microbiome and Siddha herbal medicine reveals a robust foundation supporting the antibacterial, antibiofilm, and anti-inflammatory potential of Siddha and associated herbal formulations in oral health management. These traditional remedies, rooted in ancient knowledge and enriched with diverse phytochemicals, have demonstrated significant efficacy against key oral pathogens such as Streptococcus mutans, Enterococcus faecalis, and Porphyromonas gingivalis. Many Siddha formulations and herbal composites exhibit comparable or adjunctive antimicrobial effects relative to standard chemical agents like chlorhexidine, particularly in inhibiting microbial growth and disrupting biofilm formation, which is central to controlling dental plaque and periodontal diseases. The use of nanoparticle-enhanced formulations further augments the delivery and potency of plant-derived bioactives, highlighting the innovative potential of modernizing traditional remedies.

Phytochemical investigations have elucidated a range of bioactive compounds, including eugenol, quercetin, azadirachtin, curcumin, and various essential oils, which collectively contribute to the antimicrobial and immunomodulatory effects of these herbal preparations. However, despite these promising insights, comprehensive mechanistic understanding remains limited, with challenges arising from the complexity of polyherbal mixtures and inconsistency in standardization and quality control. Addressing these gaps is critical for translating laboratory findings into reliable clinical applications.

Clinically, preliminary trials and practitioner surveys indicate positive outcomes in reducing microbial load, plaque, gingivitis, and oral inflammation, alongside good safety and tolerability profiles. These findings underscore the cultural relevance and acceptance of Siddha oral care practices, although rigorous randomized controlled trials and long-term safety studies are needed to establish definitive clinical evidence. The holistic philosophy of Siddha medicine, which integrates physical, mental, and spiritual well-being, aligns well with contemporary integrative dentistry models that seek to complement synthetic treatments and mitigate antimicrobial resistance issues.

Integration of Siddha and herbal oral care into modern dentistry appears both feasible and beneficial, yet it requires strategic efforts including scientific validation, standardization of formulations, policy support, and practitioner education. The existing literature advocates for such integration as a complementary approach, especially in resource-limited settings, but also calls for development of regulatory frameworks and clinical protocols to ensure efficacy and safety. Overall, Siddha herbal medicine holds substantial promise as a natural, sustainable, and holistic adjunct in oral healthcare, warranting continued research and systematic incorporation into contemporary dental practices.

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