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## **Propolis Hard Candy as A Sustainable Oral Functional Confectionery for Prolonged Intraoral Antimicrobial Delivery in Dental Caries Prevention: A Literature Review**

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### **ABSTRACT**

Background: Dental caries is a prevalent biofilm-mediated disease in which *Streptococcus mutans* plays an important role. Propolis has demonstrated antimicrobial and antibiofilm activities, but conventional oral formulations may provide limited intraoral exposure. Objectives: This review explores propolis hard candy as a potential prolonged intraoral delivery platform and considers its sustainability-oriented application in preventive oral healthcare. Methods: This narrative literature review synthesized relevant scientific literature, primarily published within the last 10 years, on the antimicrobial and antibiofilm properties of propolis, oral propolis formulations, controlled delivery systems, functional confectionery, and sustainable oral healthcare. Evidence was thematically analyzed to identify the potential rationale, research gaps, and future directions for propolis hard-candy development. Results: Available evidence supports the antimicrobial and antibiofilm potential of propolis against cariogenic microorganisms, particularly *S. mutans*. Propolis has also been incorporated into various oral and controlled delivery systems. A slowly dissolving hard-candy matrix may potentially prolong intraoral exposure and provide a convenient functional confectionery format. The proposed concept integrates natural propolis bioactivity, prolonged intraoral delivery, and sustainability-oriented preventive oral healthcare. Sustainability considerations include responsible sourcing, efficient use of bioactive ingredients, formulation and manufacturing efficiency, packaging, and waste reduction. Conclusion: Propolis hard candy represents a promising research and formulation concept for prolonged intraoral antimicrobial delivery and sustainability-oriented caries prevention. However, its preventive efficacy and sustainability remain to be established through formulation, release-kinetic, safety, sensory, environmental, and clinical studies.

**Keywords:** propolis, hard candy, antimicrobial delivery, dental caries, sustainable



### **INTRODUCTION**

Dental caries remains one of the most common oral diseases and is strongly associated with the development and persistence of cariogenic dental biofilms. *Streptococcus mutans* is an important cariogenic microorganism because of its ability to adhere to tooth surfaces, produce extracellular polysaccharides, and contribute to the development of an acidic biofilm environment. Therefore, effective caries prevention requires not only mechanical plaque control but also strategies capable of suppressing cariogenic microorganisms and biofilm activity (Banas & Drake, 2018; Mazurel *et al.*, 2025).

Natural bioactive compounds have increasingly attracted attention as complementary approaches to conventional oral healthcare. Among these, propolis, a resinous bee product containing flavonoids, phenolic acids, and other phenolic compounds, has demonstrated antimicrobial, antibiofilm, antioxidant, and anti-inflammatory activities relevant to oral health (Alghutaimel *et al.*, 2024; Hoshino *et al.*, 2021; Kasote *et al.*, 2022; Sforcin & Bankova, 2021). Recent evidence indicates that propolis can inhibit oral microorganisms and interfere with bacterial adhesion and biofilm formation (Bouchelaghem *et al.*, 2021; Gao & Chen, 2024; Hoshino *et al.*, 2021). Studies investigating propolis-containing dentifrices have also demonstrated inhibitory effects on *S. mutans* and other oral biofilms (Djais *et al.*, 2020; Furtado Júnior *et al.*, 2020). Furthermore, randomized clinical trials have reported reductions in *S. mutans*, plaque, and gingival inflammation following the use of propolis-based oral preparations (Bapat *et al.*, 2021; Gunjal & Pateel, 2024; Kiani *et al.*, 2022; Santiago *et al.*, 2018). These findings support the potential of propolis as a naturally derived bioactive agent for preventive dentistry.

Despite these promising findings, most research has focused on propolis extracts incorporated into mouthwashes, dentifrices, gels, sprays, or other conventional formulations (Alghutaimel *et al.*, 2024; Halboub *et al.*, 2020; Parolia *et al.*, 2022). A recent systematic review of controlled delivery systems demonstrated that propolis has been investigated in several localized and controlled-release formulations for dental and oral applications (Barboza *et al.*, 2023). However, substantial methodological heterogeneity remains, particularly regarding propolis composition, extraction methods, concentrations, formulation characteristics, and clinical outcomes (Alghutaimel *et al.*, 2024; Kasote *et al.*, 2022). Importantly, the existing literature has primarily emphasized whether propolis possesses antimicrobial activity rather than how its intraoral residence and release can be optimized to maintain antimicrobial exposure against cariogenic biofilms (Alghanem *et al.*, 2023; Barboza *et al.*, 2023; Parolia *et al.*, 2022).

This issue is particularly relevant to mouthwash-based delivery. Although propolis-containing mouthwashes have demonstrated beneficial effects on oral microorganisms, plaque, and gingival parameters, liquid formulations are subject to rapid clearance through expectoration, salivary secretion, swallowing, tongue movement, and dilution (Bapat *et al.*, 2021; Gunjal & Pateel, 2024; Halboub *et al.*, 2020; Kiani *et al.*, 2022). Consequently, antimicrobial potency alone may not determine the preventive effectiveness of an oral formulation; the duration and site of exposure may also influence

its biological activity. Intraoral delivery systems designed for sustained or localized drug release have therefore attracted increasing interest as a means of extending the availability of active compounds within the oral cavity (Alghanem *et al.*, 2023; Macartney *et al.*, 2025).

A slowly dissolving hard-candy matrix may provide a potentially useful approach for prolonged intraoral delivery because gradual dissolution could allow incorporated bioactive compounds to remain in contact with saliva, tooth surfaces, and dental biofilms for a longer period than rapidly cleared liquid preparations. Propolis has already been investigated in controlled-delivery systems for oral therapeutics, supporting the general pharmaceutical rationale for incorporating propolis into delivery matrices rather than using it solely as a free extract (Barboza *et al.*, 2023). Moreover, the use of propolis in confectionery formulations has been explored, including studies demonstrating the potential of green propolis to contribute antioxidant and sensory properties to jelly candies (Cedeño-Pinos *et al.*, 2021). A randomized crossover clinical trial also investigated xylitol tablets with and without red propolis, demonstrating the feasibility of combining propolis with an oral confectionery-type delivery format (Martins *et al.*, 2020).

However, the concept of propolis hard candy specifically designed as a prolonged intraoral antimicrobial delivery system for dental caries prevention remains insufficiently investigated. Existing studies have generally evaluated propolis as an antimicrobial ingredient, as a component of mouthwash or dentifrice, or within other controlled-release systems rather than as a slowly dissolving functional confectionery specifically designed to prolong intraoral exposure to cariogenic biofilms (Alghutaimel *et al.*, 2024; Barboza *et al.*, 2023; Martins *et al.*, 2020). Thus, the potential value of hard candy lies not merely in providing another formulation of propolis but in integrating bioactivity, residence time, patient acceptability, and functional-food characteristics within a preventive oral-health platform.

The sustainability dimension is also increasingly relevant to contemporary oral healthcare. Responsible consumption and production, efficient use of resources, appropriate formulation and packaging, and reduction of unnecessary material waste are recognized as important components of environmentally sustainable oral healthcare (Martin & Mulligan, 2022; Mulligan, 2023). In addition, the use of non-cariogenic sugar substitutes may be relevant when developing confectionery-based oral-health products because dietary fermentable sugars are an established risk factor for dental caries (Liang *et al.*, 2024; World Health Organization, 2025). Therefore, a propolis hard-candy formulation should not be considered sustainable merely because propolis is a naturally derived material; sustainability should also encompass responsible sourcing, formulation efficiency, use of appropriate excipients, packaging, product stability, and waste reduction (Martin *et al.*, 2022; Martin & Mulligan, 2022).

Accordingly, the novelty of this literature review lies in integrating four previously fragmented concepts: (1) the antimicrobial and antibiofilm properties of propolis; (2) prolonged intraoral residence through a slowly dissolving hard-candy delivery matrix; (3) functional confectionery as a patient-oriented preventive oral-health

platform; and (4) sustainability-oriented oral healthcare (Alghutaimel *et al.*, 2024; Barboza *et al.*, 2023; Cedeño-Pinos *et al.*, 2021; Martin & Mulligan, 2022; Martins *et al.*, 2020). Rather than proposing hard candy simply as another propolis formulation, this review positions propolis hard candy as a potential prolonged intraoral antimicrobial delivery system for preventive dentistry. Nevertheless, this proposition remains a formulation hypothesis and requires experimental validation through dissolution studies, release kinetics, antimicrobial and antibiofilm assays, safety assessment, sensory evaluation, and clinical research.

Therefore, this literature review aims to critically synthesize recent evidence regarding the antimicrobial and antibiofilm potential of propolis, evaluate the formulation rationale for hard-candy-based prolonged intraoral delivery, and identify its potential role as a sustainable oral functional confectionery for dental caries prevention. The review also identifies key research priorities, including propolis standardization, formulation stability, dissolution and release kinetics, intraoral residence time, safety, sensory acceptability, environmental considerations, and clinical efficacy.

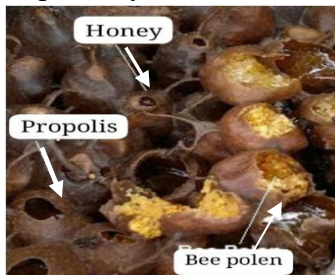


Figure 1. Propolis



Figure 2. Raw propolis



Figure 3. Hard candy propolis.

## LITERATURE REVIEW

### Dental Caries and Cariogenic Biofilm

Dental caries is a biofilm-mediated, multifactorial disease in which the interaction between cariogenic microorganisms, dietary fermentable carbohydrates, susceptible tooth surfaces, and time contributes to demineralization of dental hard tissues. *Streptococcus mutans* is an important microorganism associated with cariogenesis because of its capacity to adhere to tooth surfaces, produce extracellular polysaccharides, form structured biofilms, and survive under acidic environmental conditions. Therefore, suppression of cariogenic bacterial growth and biofilm formation represents an important component of preventive strategies against dental caries (Banas & Drake, 2018; Gao & Chen, 2024; Mazurel *et al.*, 2025; Zhou *et al.*, 2021).

The cariogenic potential of *S. mutans* is closely related to its ability to produce extracellular glucans through glucosyltransferase activity. These extracellular polysaccharides facilitate bacterial adhesion, accumulation, and biofilm maturation on dental surfaces. Consequently, antimicrobial strategies that interfere with bacterial adhesion, growth, and biofilm formation may provide an important approach to reducing cariogenic activity (Gao & Chen, 2024; Zhou *et al.*, 2021).

### Propolis as a Natural Bioactive Agent in Oral Health

Propolis is a resinous substance collected by honeybees from plant exudates and subsequently modified with bee enzymes, wax, and other components. Its chemical composition is complex and varies according to geographical origin, botanical source, season, bee species, and extraction method. Major bioactive components include flavonoids, phenolic acids, aromatic acids, terpenoids, and other polyphenolic compounds (Kasote et al., 2022; Parolia et al., 2022; Sarapa et al., 2025).

The biological properties of propolis include antimicrobial, antibiofilm, antioxidant, anti-inflammatory, and immunomodulatory activities. These properties have stimulated considerable interest in dentistry, particularly for the prevention and management of dental caries, periodontal disease, oral infections, and other oral conditions (Alghutaimel et al., 2024; Hoshino et al., 2021; Kasote et al., 2022; Parolia et al., 2022). A recent narrative review identified 104 studies evaluating propolis in dentistry, comprising laboratory, animal, and human clinical studies. The review reported antimicrobial effects against several oral pathogens and potential benefits for plaque control, reduction of pathogenic microorganisms, and periodontal inflammation. However, the authors also emphasized substantial methodological limitations and variability in propolis extraction methods, concentrations, safety profiles, and study designs (Alghutaimel et al., 2024).

The variability of propolis composition is particularly important when considering its application as a functional oral product. Different botanical sources may produce substantially different concentrations of bioactive compounds and consequently different antimicrobial activities. Therefore, standardization of propolis extracts and characterization of their chemical profiles are essential for reproducible formulation and clinical evaluation (Kasote et al., 2022; Pastor et al., 2025).

### **Antimicrobial and Antibiofilm Activity of Propolis**

The antimicrobial activity of propolis is relevant to cariogenic biofilm control. Polyphenolic constituents of propolis may interfere with bacterial cell integrity, inhibit bacterial adhesion, and affect biofilm development. Recent reviews have described antibacterial effects of propolis against several oral microorganisms, including cariogenic bacteria, although the magnitude of the effect varies according to propolis type, extraction method, concentration, and experimental conditions (Alghutaimel et al., 2024; Hoshino et al., 2021; Kasote et al., 2022; Sforcin & Bankova, 2021).

Experimental evidence supports the antibiofilm potential of propolis-containing oral formulations. Djais et al. (2020) evaluated propolis dentifrice against *S. mutans*, *Streptococcus sanguinis*, and *Candida albicans* biofilms and demonstrated the feasibility of using propolis-containing dentifrice to influence oral microbial biofilms. Similarly, Furtado Júnior et al. (2020) conducted a randomized double-blind clinical trial involving 92 orthodontic patients and reported a significant reduction in *S. mutans* in the group using fluoride dentifrice containing Brazilian red propolis compared with the control dentifrice.

These findings indicate that the antimicrobial activity of propolis can be maintained after incorporation into an oral-care formulation. Nevertheless, most studies have primarily investigated whether propolis exhibits antimicrobial activity, whereas considerably less attention has been directed toward how the delivery system can optimize the duration of antimicrobial exposure within the oral cavity (Alghanem *et al.*, 2023; Barboza *et al.*, 2023; Parolia *et al.*, 2022).

### **Evidence from Propolis Mouthwash and Other Oral Formulations**

Mouthwash is one of the most frequently investigated dosage forms for propolis. A systematic review of propolis-based mouthwashes reported evidence of beneficial effects on dental plaque and gingival inflammation, although substantial heterogeneity existed among the included studies regarding formulations, concentrations, comparators, and outcome measures (Halboub *et al.*, 2020).

Bapat *et al.* (2021) conducted a randomized controlled trial evaluating propolis mouth rinse against oral microorganisms. The study provided clinical evidence that propolis-containing mouth rinse can influence oral microbial parameters, supporting its potential as an adjunctive oral-health intervention [32]. However, mouthwash is inherently a relatively short-contact formulation because the preparation is rinsed and expectorated after administration.

A broader scoping review also reported that propolis-containing toothpaste, dentifrice, and mouthwash formulations may improve oral-health indices and inhibit specific oral microorganisms. However, the available studies showed varying degrees of effectiveness, reinforcing the need for standardized formulations and better-designed clinical investigations (Saeed *et al.*, 2021).

A recent comprehensive narrative review further demonstrated that propolis has been incorporated into numerous oral preparations, including toothpastes, mouthwashes, chewable tablets, mucoadhesive gels, and sprays. Despite promising results, the review concluded that the evidence remains heterogeneous and that optimal concentrations, extraction methods, safety, and standardized preparations require further investigation (Alghutaimel *et al.*, 2024).

### **Intraoral Residence Time and Controlled Delivery**

The effectiveness of an antimicrobial oral formulation depends not only on the intrinsic activity of the active compound but also on the duration and extent of its interaction with the target microorganism. Salivary flow, swallowing, tongue movement, mastication, and other oral clearance mechanisms can reduce the concentration of an active compound in the oral cavity. Consequently, a formulation capable of prolonging intraoral residence may provide an opportunity to maintain antimicrobial exposure for a longer period (Alghanem *et al.*, 2023; Barboza *et al.*, 2023; Parolia *et al.*, 2022).

This principle has particular relevance to propolis because a systematic review evaluating controlled delivery systems of propolis for oral and dental applications identified 21 eligible studies, including *in vitro*, *in vivo*, animal, and clinical investigations

(Barboza et al., 2023). The review demonstrated that propolis has been incorporated into a variety of controlled and localized delivery systems developed for different dental applications. However, the reviewed systems were heterogeneous in terms of their formulations, delivery platforms, and intended therapeutic purposes, and the evidence did not specifically establish a hard-candy formulation for prolonged intraoral antimicrobial delivery. Therefore, these findings provide a formulation rationale for further investigation of controlled propolis delivery, rather than direct evidence that propolis hard candy can achieve sustained intraoral antimicrobial exposure (Barboza et al., 2023).

However, the available controlled-delivery literature has mainly addressed localized or therapeutic dental applications, including dental materials, periodontal systems, endodontic applications, and other specialized delivery platforms (Alghanem et al., 2023; Barboza et al., 2023; Parolia et al., 2022). These approaches differ substantially from a patient-oriented, slowly dissolving confectionery designed to provide prolonged intraoral exposure to antimicrobial compounds. Accordingly, the available evidence supports the feasibility of exploring controlled propolis delivery, but does not yet provide direct evidence for the effectiveness of a propolis hard-candy formulation as a prolonged intraoral antimicrobial system for dental caries prevention (Alghanem et al., 2023; Barboza et al., 2023; Parolia et al., 2022).

### **Hard Candy as a Potential Prolonged Intraoral Delivery Platform**

Hard candy is a slowly dissolving oral matrix that can remain in the oral cavity during gradual dissolution. From a formulation perspective, this characteristic provides a potential opportunity for incorporation and gradual release of bioactive compounds. Unlike a liquid mouthwash, which is removed after rinsing, a slowly dissolving matrix can theoretically maintain interaction between the active compound, saliva, oral tissues, and dental biofilm during the dissolution period (Alghanem et al., 2023; Barboza et al., 2023; Martins et al., 2020; Parolia et al., 2022).

The proposed use of hard candy for propolis delivery therefore differs from simply adding propolis to another confectionery product. The formulation concept is based on the possibility that gradual dissolution may provide prolonged intraoral exposure to propolis-derived antimicrobial compounds. This could potentially increase the cumulative duration of interaction between the bioactive compounds and cariogenic biofilm compared with rapidly cleared formulations (Alghanem et al., 2023; Barboza et al., 2023; Martins et al., 2020; Parolia et al., 2022).

Nevertheless, this proposition remains a formulation hypothesis rather than an established clinical outcome. The actual benefit would depend on dissolution characteristics, propolis concentration, release kinetics, chemical stability, salivary dilution, antimicrobial concentration at the tooth–biofilm interface, and the biological activity of the released compounds. Therefore, experimental evaluation of dissolution and release kinetics is essential before claims regarding sustained antimicrobial activity can be made (Alghanem et al., 2023; Barboza et al., 2023; Parolia et al., 2022).

### **Propolis as Functional Food and Oral Functional Confectionery**

The concept of functional food has increasingly expanded toward products that provide physiological benefits beyond basic nutrition. Propolis has been proposed as a functional food ingredient because of its antibacterial, antifungal, antioxidant, and anti-inflammatory properties. A 2024 review identified 22 eligible studies concerning propolis as a functional food and reported potential benefits for oral health, including effects against microorganisms associated with dental caries and periodontal disease (Etebarian *et al.*, 2024).

This evidence provides a conceptual basis for developing propolis as an oral functional confectionery. However, the development of a dental functional confectionery should not be based solely on the presence of a bioactive ingredient. The formulation should also consider dose uniformity, chemical stability, sensory acceptability, safety, dissolution behavior, and the intended duration of oral exposure (Barboza *et al.*, 2023; Cedeño-Pinos *et al.*, 2021; Etebarian *et al.*, 2024; Martins *et al.*, 2020).

Thus, propolis hard candy can potentially bridge the fields of functional food and preventive dentistry, transforming a conventional confectionery matrix into a vehicle for oral-health-oriented bioactive delivery. Such an approach may also improve patient acceptability and convenience compared with some conventional oral preparations (Barboza *et al.*, 2023; Cedeño-Pinos *et al.*, 2021; Etebarian *et al.*, 2024; Martins *et al.*, 2020).

### **Sustainability Perspective**

The use of naturally derived bioactive compounds has generated increasing interest in the development of sustainable health products. Propolis is a naturally renewable bee-derived material and may serve as a source of biologically active compounds for functional oral products. However, describing a propolis-based product as “sustainable” requires consideration beyond the natural origin of the active ingredient (Etebarian *et al.*, 2024; Martin *et al.*, 2022; Martin & Mulligan, 2022; Mulligan, 2023).

Sustainability should encompass responsible propolis sourcing, standardized production, efficient formulation, appropriate packaging, product stability, consumer safety, and potential reduction in resource-intensive or repeatedly administered oral preparations. Therefore, sustainability in the proposed propolis hard-candy concept should be interpreted as a multidimensional formulation objective, rather than as a claim that the product is inherently environmentally sustainable solely because propolis is a natural substance (Martin *et al.*, 2022; Martin & Mulligan, 2022; Mulligan, 2023; Pastor *et al.*, 2025).

### **Research Gap**

The existing literature provides substantial evidence supporting the antimicrobial and antibiofilm potential of propolis in dentistry. Nevertheless, several important gaps remain (Alghutaimel *et al.*, 2024; Barboza *et al.*, 2023; Halboub *et al.*, 2020; Saeed *et al.*, 2021). First, considerable heterogeneity exists among propolis preparations because of

differences in botanical origin, extraction method, chemical composition, and concentration. This limits direct comparison among studies and emphasizes the importance of standardized extracts and formulation protocols (Alghutaimel *et al.*, 2024; Kasote *et al.*, 2022; Pastor *et al.*, 2025).

Second, most clinical investigations have focused on the antimicrobial efficacy of propolis-containing products, particularly mouthwash and dentifrice, rather than the relationship between antimicrobial efficacy and intraoral residence time (Bapat *et al.*, 2021; Furtado Júnior *et al.*, 2020; Gunjal & Pateel, 2024; Halboub *et al.*, 2020; Kiani *et al.*, 2022; Santiago *et al.*, 2018).

Third, although a systematic review has demonstrated the potential of propolis in controlled delivery systems, the existing evidence has mainly concerned therapeutic dental materials and localized drug-delivery systems rather than a slowly dissolving functional confectionery designed for prolonged exposure to cariogenic biofilms (Alghanem *et al.*, 2023; Barboza *et al.*, 2023; Parolia *et al.*, 2022).

Fourth, the concept of propolis as a functional food has been reviewed, but the integration of functional confectionery, prolonged intraoral delivery, antimicrobial biofilm control, and sustainability remains insufficiently developed (Cedeño-Pinos *et al.*, 2021; Etebarian *et al.*, 2024; Martin *et al.*, 2022; Martin & Mulligan, 2022; Mulligan, 2023).

### **Novelty of the Proposed Concept**

Based on the identified research gaps, the novelty of this literature review does not lie in the antimicrobial activity of propolis itself, which has been extensively investigated. Rather, the novelty lies in the integration of propolis bioactivity, prolonged intraoral delivery, functional confectionery, and sustainable oral healthcare within a single preventive-dentistry framework (Alghutaimel *et al.*, 2024; Barboza *et al.*, 2023; Cedeño-Pinos *et al.*, 2021; Etebarian *et al.*, 2024; Martin *et al.*, 2022; Martin & Mulligan, 2022; Martins *et al.*, 2020; Mulligan, 2023; Parolia *et al.*, 2022).

The proposed concept differs from previous studies that have predominantly evaluated propolis as a crude extract or as an active ingredient in conventional oral-care formulations. In this review, the hard-candy matrix is considered not merely as a different dosage form, but as a potential patient-oriented delivery platform that may prolong intraoral residence and facilitate gradual exposure of propolis-derived bioactive compounds. However, this proposed delivery advantage remains a formulation hypothesis that requires experimental validation through dissolution, release-kinetic, antimicrobial, safety, and clinical studies (Alghanem *et al.*, 2023; Barboza *et al.*, 2023; Parolia *et al.*, 2022).

Importantly, sustainability is incorporated as an integral dimension of the proposed novelty rather than as an attribute derived solely from the natural origin of propolis. A potentially sustainable oral functional confectionery should consider responsible sourcing of propolis, efficient use and standardization of bioactive ingredients, selection of non-cariogenic excipients, formulation and manufacturing

efficiency, appropriate packaging, storage stability, and reduction of material and product waste (Cedeño-Pinos *et al.*, 2021; Martin *et al.*, 2022; Martin & Mulligan, 2022; Mulligan, 2023). If prolonged intraoral residence can be demonstrated experimentally, the formulation may also offer an opportunity to explore whether an extended exposure profile could reduce the need for repeated administration compared with rapidly cleared oral preparations. Nevertheless, such a potential sustainability benefit cannot be assumed and should be evaluated using measurable environmental, functional, and health-related outcomes.

Accordingly, the proposed conceptual pathway is:

Standardized propolis extract → incorporation into a slowly dissolving hard-candy matrix → gradual dissolution and controlled release → prolonged intraoral exposure → interaction with saliva and cariogenic biofilm → potential antimicrobial and antibiofilm effects → potential contribution to dental caries prevention → evaluation of environmental and healthcare sustainability.

This integrated framework connects four domains that have largely been investigated separately: (1) natural-product antimicrobial activity, (2) oral controlled-delivery principles, (3) functional confectionery, and (4) sustainable preventive oral healthcare (Alghutaimel *et al.*, 2024; Barboza *et al.*, 2023; Cedeño-Pinos *et al.*, 2021; Etebarian *et al.*, 2024; Martin *et al.*, 2022; Martin & Mulligan, 2022; Martins *et al.*, 2020; Mulligan, 2023; Parolia *et al.*, 2022). The novelty is therefore primarily conceptual and translational, rather than a claim that the clinical efficacy or environmental sustainability of propolis hard candy has already been established.

Future research should determine whether this proposed platform can achieve reproducible release kinetics, adequate antimicrobial activity, acceptable safety and sensory properties, and meaningful preventive effects. In parallel, sustainability should be assessed through measurable parameters such as responsible raw-material sourcing, resource utilization, packaging impact, waste generation, product stability, and, where feasible, life-cycle assessment. Such evidence would be necessary to establish whether propolis hard candy can ultimately be considered a genuinely sustainable oral-health intervention rather than simply a natural-product formulation (Martin *et al.*, 2022; Martin & Mulligan, 2022; Mulligan, 2023).

## DISCUSSION

The present literature review indicates that propolis has considerable potential as a natural antimicrobial and antibiofilm agent for preventive oral healthcare. Evidence from laboratory investigations, clinical studies, and recent reviews consistently demonstrates that propolis and propolis-containing oral formulations can inhibit oral microorganisms and influence dental biofilm formation (Alghutaimel *et al.*, 2024; Hoshino *et al.*, 2021; Kasote *et al.*, 2022; Sforcin & Bankova, 2021; Djais *et al.*, 2020; Kiani *et al.*, 2022; Gunjal & Pateel, 2024). However, the major issue identified from the reviewed literature is that the antimicrobial potential of propolis has been investigated

more extensively than the optimization of its intraoral delivery and residence time. This distinction is important because the effectiveness of an antimicrobial compound in the oral cavity is determined not only by its intrinsic biological activity but also by the duration and site of exposure (Alghanem *et al.*, 2023; Barboza *et al.*, 2023; Parolia *et al.*, 2022).

### **Propolis as an Antimicrobial and Antibiofilm Agent**

The antimicrobial activity of propolis can be attributed primarily to its diverse polyphenolic constituents, including flavonoids and phenolic acids. These compounds may affect bacterial cell integrity, interfere with bacterial adhesion, inhibit biofilm formation, and influence bacterial metabolic processes (Alghutaimel *et al.*, 2024; Hoshino *et al.*, 2021; Kasote *et al.*, 2022; Sforcin & Bankova, 2021). Such multimodal activity is particularly relevant to dental caries because cariogenicity is strongly associated with the ability of microorganisms to adhere to dental surfaces and establish a structured biofilm (Banas & Drake, 2018; Gao & Chen, 2024; Mazurel *et al.*, 2025; Zhou *et al.*, 2021).

Evidence from propolis-containing dentifrices supports this biological rationale. Djais *et al.* (2020) demonstrated that propolis dentifrice could influence biofilms involving *Streptococcus mutans*, *Streptococcus sanguinis*, and *Candida albicans*. In a randomized clinical trial, Furtado Júnior *et al.* (2020) reported a reduction in *S. mutans* among orthodontic patients using a dentifrice containing Brazilian red propolis [14]. These findings suggest that the antimicrobial activity observed in experimental studies may remain biologically relevant following incorporation into an oral formulation.

However, propolis should not be considered a single chemically standardized substance. Its composition varies according to botanical origin, geographical location, season, bee species, and extraction method (Kasote *et al.*, 2022; Pastor *et al.*, 2025; Sarapa *et al.*, 2025). This variability represents an important challenge for translating laboratory evidence into a reproducible functional product. Consequently, any future propolis hard-candy formulation should include chemical characterization and standardization of the propolis extract to ensure consistency between batches (Kasote *et al.*, 2022; Pastor *et al.*, 2025).

This consideration is particularly important for a prolonged-release oral formulation because variations in the chemical composition of propolis may affect not only antimicrobial potency but also the reproducibility of the formulation, release characteristics, sensory properties, and ultimately its biological performance. Therefore, future formulation studies should characterize the botanical and chemical profile of the propolis source, establish an appropriate marker or group of bioactive compounds, and evaluate batch-to-batch consistency before antimicrobial and clinical outcomes are interpreted (Kasote *et al.*, 2022; Pastor *et al.*, 2025).

### **Importance of Intraoral Residence Time**

One important finding of this review is the distinction between antimicrobial potency and antimicrobial exposure time. Although propolis mouthwashes have

demonstrated beneficial effects on oral microorganisms and plaque-related parameters, their antimicrobial exposure is limited by expectoration, salivary flow, swallowing, and other oral clearance mechanisms (Bapat *et al.*, 2021; Gunjal & Pateel, 2024; Halboub *et al.*, 2020; Kiani *et al.*, 2022; Santiago *et al.*, 2018). Thus, efficacy of a mouthwash does not necessarily imply prolonged intraoral antimicrobial exposure.

Controlled-delivery research has demonstrated that propolis can be incorporated into localized oral and dental delivery systems; however, these approaches have primarily involved dental materials, periodontal or endodontic applications, rather than a slowly dissolving functional confectionery (Barboza *et al.*, 2023; Parolia *et al.*, 2022; Sipos *et al.*, 2023). A propolis hard-candy matrix may therefore provide a potential means of extending intraoral exposure, although the actual exposure profile would depend on dissolution rate, release kinetics, salivary dilution, chemical stability, and the concentration maintained at the tooth–biofilm interface.

From a preventive-dentistry perspective, prolonged availability of antimicrobial compounds may theoretically increase their opportunity to interact with cariogenic biofilms (Banas & Drake, 2018; Gao & Chen, 2024; Zhou *et al.*, 2021). However, prolonged intraoral residence should not be equated with sustained antimicrobial or caries-preventive efficacy. Therefore, future studies should compare propolis hard candy with conventional formulations using standardized measures of dissolution, release, antimicrobial and antibiofilm activity, safety, and clinical outcomes (Barboza *et al.*, 2023; Sipos *et al.*, 2023).

### **Rationale for Hard Candy as a Prolonged Intraoral Delivery System**

The proposed use of hard candy represents a shift from considering propolis simply as an antimicrobial ingredient toward considering it as a potential oral delivery platform. A slowly dissolving hard-candy matrix may theoretically allow progressive release of propolis-derived bioactive compounds and prolong their interaction with saliva, tooth surfaces, and dental biofilms compared with rapidly cleared formulations (Barboza *et al.*, 2023; Alghanem *et al.*, 2023; Sipos *et al.*, 2023). From a pharmaceutical perspective, the potential advantage is therefore not necessarily a higher antimicrobial concentration, but a longer period of intraoral availability.

Nevertheless, prolonged dissolution should not be equated with sustained antimicrobial efficacy. The proposed delivery mechanism remains a formulation hypothesis that requires experimental validation. Future studies should evaluate dissolution behavior, release kinetics, chemical stability, and the concentration of relevant propolis compounds under simulated oral conditions, followed by assessment of antimicrobial and antibiofilm activity against cariogenic biofilms (Barboza *et al.*, 2023; Macartney *et al.*, 2025; Sipos *et al.*, 2023).

Accordingly, the value of propolis hard candy should be determined through a stepwise chain of evidence from physicochemical characterization and controlled release to antimicrobial and antibiofilm activity, safety, sensory acceptability, and ultimately clinical outcomes. Thus, prolonged dissolution should be regarded as a formulation

characteristic rather than an efficacy endpoint, and further research is required to determine whether this delivery approach can provide meaningful and reproducible benefits for preventive oral healthcare (Barboza *et al.*, 2023; Sipos *et al.*, 2023).

### **Integration of Propolis and Functional Confectionery**

The concept of using propolis in functional confectionery is supported by the growing interest in natural bioactive ingredients as functional food components. A recent review identified propolis as a promising functional food ingredient with antimicrobial, antioxidant, and anti-inflammatory properties and highlighted its potential relevance to oral health (Etebarian *et al.*, 2024). The incorporation of propolis into confectionery matrices has also been investigated, providing preliminary evidence that propolis-containing food products can be developed while maintaining functional and sensory characteristics (Cedeño-Pinos *et al.*, 2021; Martins *et al.*, 2020).

Hard candy may provide an attractive delivery format because administration is simple and does not require rinsing, expectoration, or specialized equipment. The confectionery format may also facilitate patient acceptance and potentially improve adherence to preventive interventions. However, acceptability cannot be assumed. Propolis may possess characteristic resinous, bitter, or pungent sensory properties, and the concentration required to provide biological activity may influence the sensory characteristics of the final formulation (Cedeño-Pinos *et al.*, 2021; Martins *et al.*, 2020). Therefore, sensory acceptability should be evaluated systematically rather than inferred from the convenience of the dosage form.

Formulation development should consequently balance antimicrobial activity with palatability, texture, dissolution behavior, chemical stability, and safety. Sweeteners should also be selected carefully. If the intended purpose is dental caries prevention, the use of fermentable sugars may conflict with the preventive rationale of the product. A sugar-free formulation using appropriate sugar substitutes may therefore be more consistent with the proposed concept, provided that the selected sweeteners are safe, non-cariogenic, and compatible with the desired sensory and formulation characteristics (Liang *et al.*, 2024; World Health Organization, 2025).

### **Potential Role in Dental Caries Prevention**

The potential preventive mechanism of propolis hard candy can be conceptualized through several interconnected pathways. First, gradual dissolution may increase the duration of exposure to propolis-derived antimicrobial compounds within the oral cavity. Second, the antimicrobial and antibiofilm properties of propolis may inhibit the growth and organization of cariogenic microorganisms. Third, interference with bacterial adhesion and extracellular polysaccharide formation may inhibit biofilm maturation. Collectively, these effects could theoretically reduce the cariogenic activity of dental biofilms (Alghutaimel *et al.*, 2024; Hoshino *et al.*, 2021; Gao & Chen, 2024; Zhou *et al.*, 2021; Kasote *et al.*, 2022; Sforcin & Bankova, 2021).

However, the available evidence does not yet demonstrate that propolis hard candy prevents dental caries clinically. Most available studies have evaluated microbial counts, plaque indices, biofilm formation, or periodontal parameters rather than incident caries as the primary clinical endpoint (Alghutaimel *et al.*, 2024; Kiani *et al.*, 2022; Gunjal & Pateel, 2024; Furtado Júnior *et al.*, 2020; Halboub *et al.*, 2020; Santiago *et al.*, 2018; Bapat *et al.*, 2021). Therefore, the proposed relationship between propolis hard candy and caries prevention should currently be regarded as a plausible preventive pathway rather than an established clinical effect (Barboza *et al.*, 2023; Alghanem *et al.*, 2023; Mazurel *et al.*, 2025).

This distinction is particularly important because a reduction in *Streptococcus mutans* does not necessarily translate directly into prevention of dental caries. Dental caries is a multifactorial and biofilm-mediated disease involving microbial ecology, dietary factors, salivary characteristics, host susceptibility, fluoride exposure, oral hygiene, and behavioral factors (Banas & Drake, 2018; Mazurel *et al.*, 2025). Consequently, future clinical trials should evaluate clinically meaningful outcomes in addition to microbiological endpoints, including plaque and biofilm characteristics, caries incidence or progression, and relevant patient-centered outcomes.

### **Sustainability, Translational Potential, and Sustainability Perspective**

The sustainability aspect represents an additional dimension of the proposed concept. Propolis is a naturally derived source of bioactive compounds and has been investigated as a functional food ingredient with potential relevance to oral health. However, natural origin alone does not establish environmental sustainability (Etebarian *et al.*, 2024; Martin *et al.*, 2022; Martin & Mulligan, 2022; Mulligan, 2023).

A potentially sustainable propolis hard-candy product should therefore consider the entire product lifecycle, including responsible propolis sourcing, standardized extraction and formulation, manufacturing efficiency, packaging materials, storage stability, and waste generation. Sustainability should consequently be evaluated using measurable environmental and production criteria rather than treated simply as a marketing attribute (Martin *et al.*, 2022; Martin & Mulligan, 2022; Mulligan, 2023; Pastor *et al.*, 2025).

The functional-confectionery format may nevertheless offer translational advantages by combining preventive oral healthcare with a familiar and potentially convenient dosage form. If scientifically validated, propolis hard candy could be considered as an adjunct to established preventive measures, rather than a replacement for fluoride toothpaste, professional preventive care, or appropriate dietary practices (Etebarian *et al.*, 2024; Liang *et al.*, 2024; World Health Organization, 2025). Ultimately, its sustainability value should be demonstrated through measurable environmental, functional, safety, and health-related outcomes rather than inferred from the natural origin of propolis alone.

### **Research Gap and Novel Contribution**

The synthesis of the current evidence identifies an important gap between propolis antimicrobial research and propolis delivery-system research. Existing studies have established the antimicrobial and antibiofilm potential of propolis in oral health, while controlled-delivery studies have demonstrated its incorporation into localized delivery systems (Alghutaimel *et al.*, 2024; Barboza *et al.*, 2023; Hoshino *et al.*, 2021; Parolia *et al.*, 2022). Functional-food research has also recognized propolis as a promising natural bioactive ingredient (Etebarian *et al.*, 2024). However, these research domains have largely developed independently.

The novelty proposed in this review is therefore the integration of propolis antimicrobial activity, a slowly dissolving hard-candy matrix, prolonged intraoral residence, functional confectionery, and sustainability into a single preventive oral-health framework. This concept differs from previous research that has primarily evaluated propolis as an antimicrobial extract or as an ingredient in conventional oral-care products (Barboza *et al.*, 2023; Etebarian *et al.*, 2024; Martin *et al.*, 2022; Martin & Mulligan, 2022).

Importantly, the novelty is conceptual and translational, rather than a claim that the clinical efficacy or environmental sustainability of propolis hard candy has already been established. The proposed framework therefore provides a rationale for future experimental studies investigating dissolution and release kinetics, antimicrobial and antibiofilm activity, safety, sensory acceptability, and clinical effectiveness. This distinction clearly separates established evidence from hypotheses requiring validation (Alghutaimel *et al.*, 2024; Barboza *et al.*, 2023; Parolia *et al.*, 2022).

### **Implications for Future Research**

Several research priorities emerge from this review. First, propolis extracts should be chemically characterized and standardized according to botanical origin and major bioactive compounds. Formulation studies should then determine the optimal propolis concentration within the hard-candy matrix while maintaining chemical stability and sensory acceptability (Barboza *et al.*, 2023; Cedeño-Pinos *et al.*, 2021; Martins *et al.*, 2020).

Second, dissolution and release kinetics should be systematically evaluated under simulated oral conditions, including dissolution time, cumulative release, marker-compound concentration, and storage stability. Antimicrobial evaluation should progress from planktonic *S. mutans* assays to multispecies oral-biofilm models that better reflect the complexity of the oral environment (Barboza *et al.*, 2023; Gao & Chen, 2024; Sipos *et al.*, 2023; Zhou *et al.*, 2021).

Finally, well-designed clinical trials are required to determine whether prolonged propolis exposure through hard candy produces meaningful effects on salivary and plaque microbiology, biofilm characteristics, and ultimately caries-related outcomes. Clinical studies should also assess safety, enamel effects, salivary parameters, adherence, sensory acceptability, and compatibility with established fluoride-based preventive strategies

(Alghutaimel *et al.*, 2024; Barboza *et al.*, 2023; Liang *et al.*, 2024; World Health Organization, 2025).

### Limitations

This literature review has several limitations. First, substantial heterogeneity exists in the botanical origin, extraction methods, chemical composition, and concentrations of propolis used across previous studies (Alghutaimel *et al.*, 2024; Kasote *et al.*, 2022; Sforcin & Bankova, 2021; Ballouk *et al.*, 2025; Pastor *et al.*, 2025). Second, many investigations have used *in vitro* models that may not fully reproduce the dynamic conditions of the oral cavity (Alghutaimel *et al.*, 2024; Barboza *et al.*, 2023). Third, clinical studies have frequently focused on surrogate outcomes such as microbial counts, plaque, or gingival indices rather than caries incidence (Alghutaimel *et al.*, 2024; Kiani *et al.*, 2022; Gunjal & Pateel, 2024; Furtado Júnior *et al.*, 2020; Halboub *et al.*, 2020; Santiago *et al.*, 2018; Bapat *et al.*, 2021).

Furthermore, direct evidence specifically evaluating propolis hard candy as a prolonged intraoral antimicrobial delivery system remains limited. Therefore, the proposed advantages of hard candy, including prolonged residence and gradual release, should be interpreted as a formulation hypothesis rather than established clinical efficacy (Barboza *et al.*, 2023; Alghanem *et al.*, 2023; Sipos *et al.*, 2023). These limitations highlight the need for standardized formulations, physiologically relevant experimental models, and well-designed clinical studies before the proposed concept can be translated into evidence-based preventive oral healthcare.

### Overall Interpretation

Overall, the available evidence supports the biological plausibility of propolis as a natural antimicrobial and antibiofilm agent in preventive dentistry. However, the major opportunity for innovation lies not simply in its antimicrobial activity, but in optimizing how, for how long, and through which delivery platform propolis-derived bioactive compounds are available within the oral cavity (Alghutaimel *et al.*, 2024; Barboza *et al.*, 2023; Parolia *et al.*, 2022; Sipos *et al.*, 2023).

A propolis hard-candy formulation may provide a potential bridge between natural-product dentistry, prolonged intraoral delivery, functional confectionery, and sustainable preventive healthcare. However, its sustainability should be evaluated beyond the natural origin of propolis, including responsible sourcing, formulation efficiency, safety, packaging, product stability, and waste reduction (Etebarian *et al.*, 2024; Martin *et al.*, 2022; Martin & Mulligan, 2022; Mulligan, 2023). If reproducible release kinetics, antimicrobial and antibiofilm activity, safety, sensory acceptability, clinical benefit, and relevant sustainability indicators are demonstrated, this approach could represent a promising adjunctive strategy for preventive oral healthcare.

At present, however, propolis hard candy should be regarded as a promising conceptual and formulation platform rather than an established clinical intervention. Further experimental and clinical validation is required before claims regarding sustained

antimicrobial efficacy, caries prevention, or environmental sustainability can be established (Barboza *et al.*, 2023; Sipos *et al.*, 2023).

## CONCLUSION

Propolis demonstrates promising antimicrobial and antibiofilm potential against cariogenic microorganisms, particularly *Streptococcus mutans*. Its incorporation into a slowly dissolving hard-candy matrix may provide prolonged intraoral exposure while offering a convenient functional confectionery format. The novelty of this concept lies in integrating natural propolis bioactivity, prolonged intraoral delivery, and sustainability-oriented preventive oral healthcare. Its sustainability potential is related to the responsible use of naturally derived bioactive resources and the development of a potentially resource-efficient, patient-friendly preventive product. However, propolis hard candy remains a promising research concept that requires validation through formulation, release kinetics, safety, sensory, environmental, and clinical studies before its preventive efficacy and sustainability can be established.

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