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REVIEW

Natural Strategies for Dental Hard-Tissue Remineralization: A Scoping Review of Galla Chinensis and Its Dual Anticaries Action

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Abstract: Dental caries remains a global public health challenge, traditionally managed through fluoride-based strategies that enhance enamel remineralization and inhibit demineralization. However, concerns regarding fluoride resistance, fluorosis, and the growing demand for minimally invasive alternatives have stimulated interest in bioactive, plant-derived compounds. Galla chinensis extract (GCE), rich in polyphenols and tannins, has emerged as a promising candidate with dual effects on hard tissue repair and microbial control. This scoping review aimed to assess the evidence on Galla chinensis extract (GCE) as a non-fluoride agent for enhancing enamel and dental hard tissue remineralization and preventing dental caries. A structured search of available literature was conducted, focusing on experimental, in vitro, in vivo, and clinical studies evaluating GCE's biological properties, mechanisms of action, and translational potential in dentistry. Our findings indicate that GCE consistently promotes mineral deposition and enhances enamel surface microhardness, effectively inhibiting demineralization processes. In addition, GCE exhibits strong antimicrobial activity against cariogenic biofilms, particularly *Streptococcus mutans*, highlighting its potential to reduce caries risk by modulating the oral microbiome. Preliminary clinical studies show favorable outcomes, although the available evidence is limited in scale and duration. Collectively, these results demonstrate a dual action of GCE: supporting enamel repair while concurrently suppressing cariogenic activity. This suggests that GCE may serve as a promising adjunct or alternative to conventional fluoride-based strategies within minimally invasive dentistry. However, further well-designed clinical trials are necessary to confirm its efficacy, safety, and long-term benefits in caries management.

Keywords: galla chinensis, remineralization, dental caries, enamel, non-fluoride agent, anti-cariogenic

Introduction

Enamel is a tough, protective tissue that encases the teeth, made primarily of inorganic materials like hydroxyapatite, along with organic substances such as proteins, lipids, and water.[1–3] Healthy teeth contribute to clear speech and a radiant smile. The oral cavity is a complex biological system, with interactions and processes that can affect enamel quality, leading to issues like enamel erosion, tooth decay, and other oral diseases. Oral health is meant to last a lifetime, but certain external and internal factors, as shown in Figure 1, can weaken the enamel structure, making regular dental visits essential.[4,5] The flow of ions from ingested food (both liquid and solid) contributes to changes in opacity and colour. Also, masticatory force, thermal stress, gastrointestinal issues, poor dental structure quality, harmful habits and teeth grinding promote the formation of cracks in tooth enamel, leading to increased dental wear and cavities.[6–10]

Dental caries represents a dynamic process involving alternating cycles of demineralization and remineralization of dental hard tissues. However, under pathological conditions, demineralization predominates over remineralization, and the natural repair mechanisms are insufficient to restore mineral balance. Preventing enamel demineralization has been

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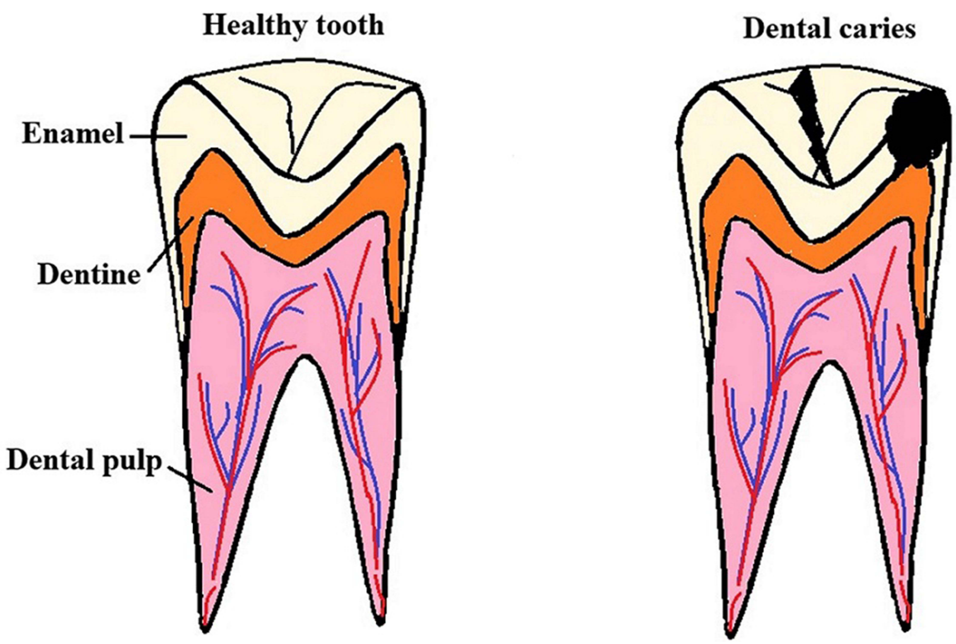

Figure 1 Factors that lead to the degradation of tooth quality.

widely acknowledged as a key strategy in caries control. This process involves the dissolution of hydroxyapatite crystals and the diffusion of mineral ions through the enamel structure. Emerging evidence indicates that these diffusion pathways are influenced by the enamel organic matrix, which occupies both inter-prismatic and intra-prismatic spaces. As a result, any modifications to this matrix can significantly affect mineral ion transport, thereby modulating the degree of enamel demineralization. Fluoride has long been established as a powerful anticariogenic agent, extensively studied and utilized for its ability to enhance remineralization and reduce demineralization. Its effectiveness has been consistently demonstrated in both clinical and laboratory settings. However, fluoride's cariostatic effect is not absolute, and discussions continue regarding its long-term safety and ideal modes of delivery. In response, current research is increasingly focused on discovering alternative or adjunctive agents with enhanced or synergistic anticaries potential.[11–19]

Among natural bioactive compounds, *Galla chinensis* extract (GCE), a traditional and non-toxic herbal medicine used in Chinese pharmacology, has garnered increasing scientific interest. Recent studies have revealed that Galla Chinensis extract, a brown powder, seen in Figure 2, contains Gallo tannins, gallic acid, methyl gallate, and various traces of

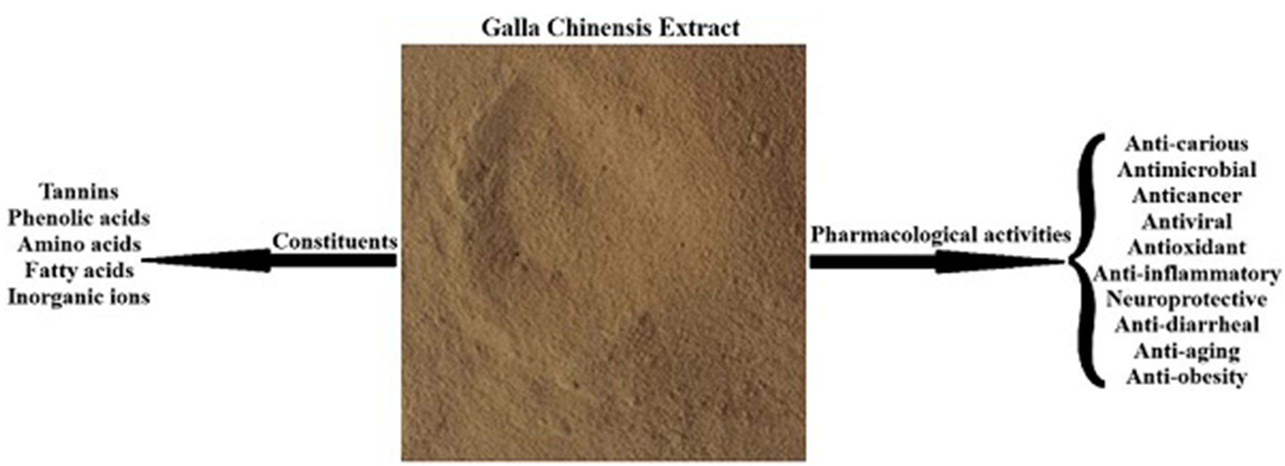

Figure 2 Chemical compounds and pharmacological activities of Galla Chinensis extract.

inorganic ions, including calcium (Ca), iron (Fe), manganese (Mn), phosphorus (P), and zinc (Zn).[20–22] According to specialized literature, Galla Chinensis demonstrates a range of pharmacological activities, including anti-caries, anti-bacterial, antiviral, anticancer, antioxidant, anti-inflammatory, neuroprotective, and anti-diarrheal properties.[23–26]

Recent investigations have highlighted its dual functionality, exhibiting both antimicrobial activity and modulatory effects on the enamel demineralization–remineralization dynamic (Figure 3). Demineralization of dental enamel involves the alteration of its structure by the removal of the main ions of Ca, phosphorus and carbonate. This process leads to the formation of biofilm and the deepening of cavities, leaving room for streptococci and other bacteria to manifest their activity until the tooth is lost.[27] In vitro studies have demonstrated that GCE facilitates the redeposition of mineral ions onto demineralized enamel surfaces, thereby enhancing the remineralization process. Additionally, GCE has been shown to suppress the growth and acidogenicity of cariogenic microorganisms, suggesting a multifaceted protective role in the prevention of dental caries.[13,20,28–31] In light of these promising findings, further research is warranted to elucidate the underlying mechanisms through which *Galla chinensis* extract modulates enamel remineralization and to evaluate its potential as an effective non-fluoride anticaries agent.

Enamel and dentin remineralization represent essential strategies in the prevention and management of early carious lesions. Although a range of agents has been developed to promote this process, their comparative efficacy, mechanisms of action, and long-term outcomes remain subjects of ongoing investigation. In recent years, there has been growing interest in biologically active, fluoride-free alternatives that combine remineralizing capacity with antibacterial activity. Among these, *Galla chinensis* extract has gained attention for its potential as a dual-action agent capable of both enhancing mineral redeposition and inhibiting cariogenic biofilms. However, current evidence on GCE remains scattered across in vitro, in situ, and limited in vivo studies, with substantial heterogeneity in methodologies, formulations, and reported outcomes.

Recent evidence shows that microRNA regulation, oxidative stress modulation, and biomimetic remineralization strategies, play key roles in dental tissue regeneration, reinforcing the relevance of investigating natural agents such as *Galla chinensis* extract for their potential remineralizing benefits and their value as adjuncts in contemporary caries management.[32–34]

To address this knowledge gap, we conducted a scoping review to systematically map existing research, assess the range of investigated outcomes, and identify methodological strengths and limitations. The rationale for this study stems from the need to better understand the potential of GCE in promoting dental hard tissue remineralization and antibacterial

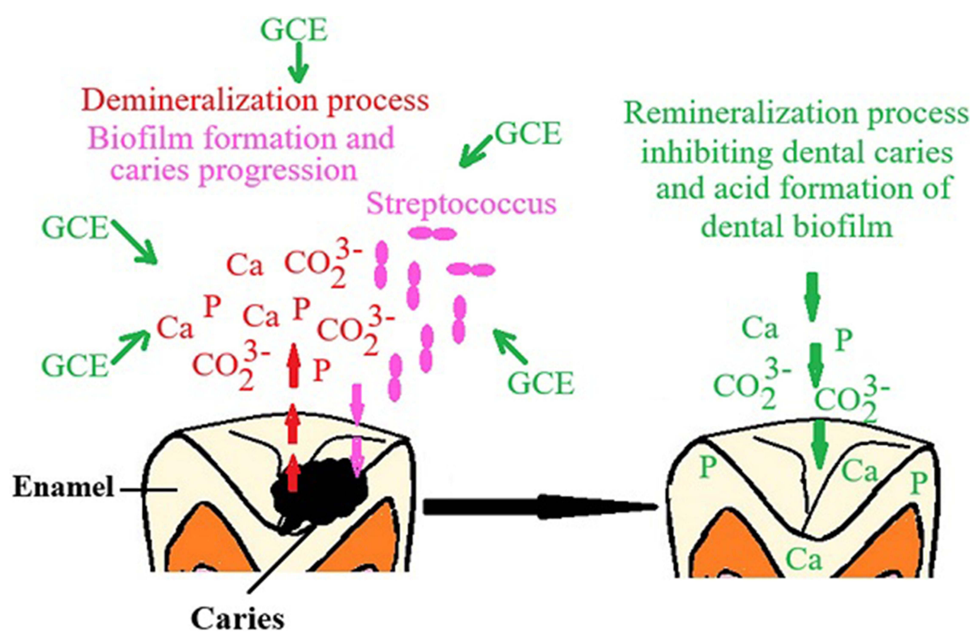

Figure 3 Demineralization/remineralization process of enamel using Galla chinensis extract.

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activity, which could inform preventive strategies in dentistry. The specific objectives of this scoping review are to: (1) examine the current evidence on the remineralizing and antibacterial effects of GCE on dental hard tissues, (2) summarize study designs, interventions, and outcome measures, (3) highlight gaps in the literature, and (4) provide evidence-based perspectives to guide future research and clinical applications.

Materials and Methods

This literature review was conducted following the PRISMA-ScR guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews).[35] Eligibility criteria were established using the PCC (Population, Concept, Context) framework, which include extracted human or animal teeth or patients in clinical settings (Population), the use of *Galla chinensis* extract (GCE) or its formulations for dental hard tissue remineralization and/or antibacterial activity (Concept), and in vitro, in situ, or clinical studies published in peer-reviewed journals (Context).

Research Question

This review addresses the research question: How has *Galla chinensis* extract been investigated for its remineralizing and antibacterial effects on dental hard tissues, and what implications does this evidence hold for caries prevention?

Objectives

- To examine the experimental and clinical evidence regarding the remineralizing and antibacterial effects of GCE on dental hard tissues.
- To summarize the different formulations, mechanisms of action, and outcomes assessed across studies.
- To identify methodological limitations and gaps in the evidence base.
- To provide insights to guide future research and inform the potential preventive applications of GCE in contemporary dentistry.

Eligibility Criteria

The eligibility criteria for study inclusion comprised in vitro, in situ, or clinical investigations assessing *Galla chinensis* formulations applied to dental hard tissues (enamel and/or dentin). Studies were eligible if they evaluated outcomes such as microhardness, mineral content, lesion depth, or surface morphology, and were published in English.

The exclusion criteria included studies involving combination interventions where the specific effect of *Galla chinensis* could not be isolated, as well as reviews, commentaries, letters, abstracts without full data, conference proceedings, and non-English publications.

All studies were screened by title and abstract, and those meeting the eligibility criteria underwent full-text review to confirm inclusion.

Data Sources and Search Strategy

A comprehensive search was conducted across four electronic databases: PubMed, ScienceDirect, Embase, and Scopus. The strategy combined both controlled vocabulary (MeSH terms) and free-text keywords using Boolean operators (AND/OR). Search terms included variations and synonyms of the main concepts: "Galla chinensis" OR "Chinese gall" OR "Gallae chinensis" (intervention); "dental caries"[MeSH] OR "caries prevention" (outcome); "remineralization" OR "tooth remineralization"[MeSH] OR "demineralization inhibition" (mechanism); "enamel"[MeSH] OR "dentin" OR "dental hard tissue" (structure); and "antibacterial" OR "anti-bacterial agents"[MeSH] OR "biofilm" OR "Streptococcus mutans" (microbial activity).

Data Extraction and Analysis

The titles and abstracts were screened for relevance, followed by full-text analysis of selected articles. To ensure consistency and minimize bias, data extraction was performed independently by two reviewers (L.M.R. and M.M.). Any discrepancies were resolved through discussion, and when consensus could not be reached, a third reviewer was consulted (A.M).

A standardized data charting form was developed to extract the following information:

- Study characteristics (authors, year, design).
- Sample characteristics (tooth type, human/animal, clinical population).
- Intervention details (type of GCE formulation, concentration, application method).
- Outcomes assessed (microhardness, lesion depth, mineral content, antibacterial effect).
- Key findings and conclusions.

Extracted data were summarized descriptively in tables and figures. Findings were grouped thematically according to remineralization outcomes, antibacterial properties, and methodological characteristics.

Results

A total of 494 records were identified through database searching (PubMed=109, ScienceDirect=28, Embase=150 and Scopus=207). After the applied filters were inserted, a total of 69 articles remained. Following the removal of duplicates, 52 unique records were screened based on title and abstract. All 52 full-text articles were assessed for eligibility. After content evaluation, 22 articles were excluded due to lack of relevance to the topic, insufficient experimental data or being written in a language other than English. Ultimately, 30 studies met the inclusion criteria and were included in the final qualitative synthesis.

The study selection process is summarized in the PRISMA 2020 flow diagram (Figure 4).

The literature reviewed provides substantial evidence supporting the potential of *Galla chinensis* extract (GCE) and its active compounds in promoting dental hard tissue remineralization, inhibiting demineralization, and exerting antimicrobial effects relevant to oral health.

A detailed synthesis of the experimental findings from both in vitro and in vivo studies examining the therapeutic potential of *Galla chinensis* and its active compounds in dental research is presented in the research (Table 1). These studies evaluated various outcomes, including enamel and dentin remineralization, reduction in dentinal hypersensitivity, antibacterial activity against cariogenic biofilms, and morphological changes such as dentinal tubule occlusion and reduction in lesion depth. The methodologies used across studies ranged from microhardness testing and scanning electron microscopy to clinical sensitivity scoring and multispecies biofilm modeling. Collectively, the results support the role of *Galla chinensis* as a promising natural agent for preventive and restorative dental applications.

Effects on Enamel Remineralization

Multiple in vitro and in vivo studies have demonstrated that GCE significantly enhances enamel surface hardness and facilitates mineral deposition within the lesion body rather than merely at the surface level. Forcin et al[36] reported that GCE-containing toothpaste exhibited the highest post-treatment surface hardness (336.8 KHN) and the greatest percentage of surface hardness recovery (147.2%), outperforming all other herbal formulations tested. Experimental studies using animal models[37] confirmed that GCE increases enamel volume and mineral density, with remineralization layers visibly forming on lesion surfaces. Additional studies[36,54] highlighted the role of GCE in regulating the demineralization–remineralization balance by influencing crystal morphology and promoting ion diffusion into the deeper layers of the enamel, distinguishing its mechanism from that of fluoride.

Synergistic Effect with Other Agents

Several studies emphasized the biological synergy between GCE and other agents. For instance, Huang et al[44] observed enhanced mineral deposition when GCE was combined with nano-hydroxyapatite. Similarly, combinations of GCE with fluoride led to improved remineralization outcomes (Cheng et al),[40] with GCE driving mineral uptake deeper into the enamel structure. The organic matrix of enamel has been identified as a critical factor modulating the action of GCE. Zhang et al[42] showed that the organic matrix facilitates ion transport and supports the formation of structured remineralization patterns. GCE-treated enamel exhibited significantly lower surface roughness and morphological changes indicative of remineralization, as confirmed by AFM and SEM analyses.

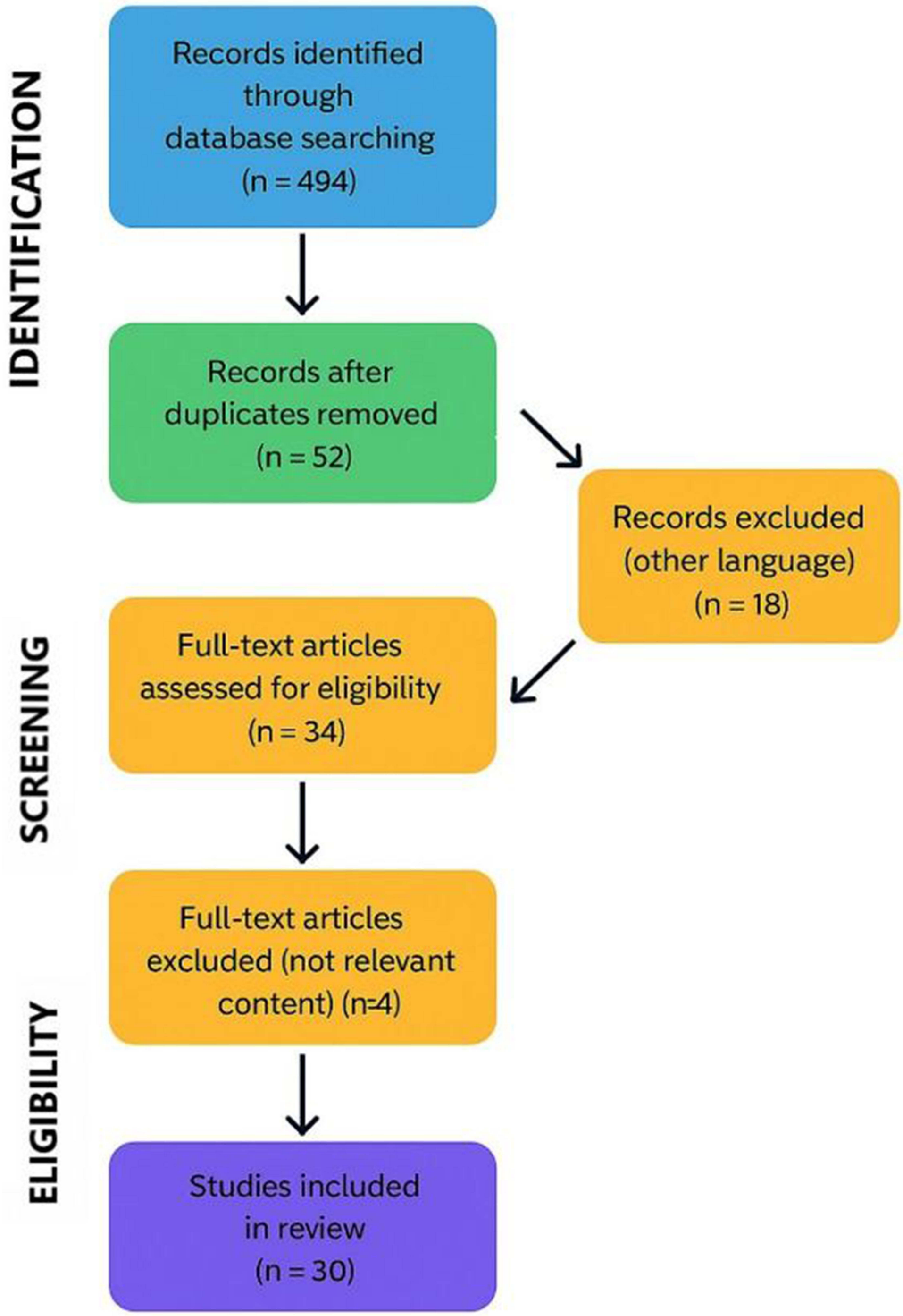

Figure 4 PRISMA flow diagram.

Antimicrobial Activity

Beyond remineralization, GCE has shown strong antimicrobial activity. Cheng et al[41] demonstrated that GCE inhibited both growth and acid production in polymicrobial biofilms, with observed reductions of up to 78% in CFU counts and lactic acid formation. These effects were dose-dependent and varied depending on the biofilm substrate.

Table 1 Key Findings From Selected Studies

No.	Author (Year)/Refs	Study Focus	Key Findings	Main Outcome
1	Forcin et al (2021)[36]	Enamel hardness, surface roughness	GCE showed the highest surface hardness recovery (147.2% SHR); reduced surface roughness	Effective enamel surface remineralization
2	Zhang et al (2016)[37]	Rat model of caries	GCE increased mineral density and enamel volume	In vivo enamel remineralization
3	Cheng et al (2009)[38]	Enamel crystal morphology	GCE regulates the de-/remineralization balance by modifying the enamel structure	Crystal-level regulation
4	Li J (2003)[39]	Cariostatic effect	Inhibited biofilm formation; Lower enamel demineralization	Cariostatic effects by reducing both biofilm acidogenicity and enamel mineral loss
5	Huang et al (2017)[13]	pH stability, biofilm control	eGCE and tannic acid showed better inhibition of acid and biofilm formation than GCE	Antimicrobial and remineralizing synergy
6	Cheng et al (2010)[30]	Lesion morphology	GCE promotes ion penetration into the lesion body	Improved Ca/Pi transport into enamel
7	Cheng et al (2008)[40]	Fluoride synergy	GCE + gallic acid + fluoride enhanced remineralization	Synergistic effect with fluoride
8	Cheng et al (2011)[41]	Microcosm biofilm	GCE inhibited biofilm growth and lactic acid formation	Biofilm modulation
9	Zhang et al (2009)[42]	Organic matrix role	Enamel organic matrix is critical for GCE-mediated remineralization	Organic matrix involvement
10	Zhang et al (2009b)[43]	Surface morphology (AFM)	GCE reduced roughness; visible crystal structure changes	Surface smoothness + microstructure
11	Huang et al (2010)[44]	GCE + nano-HA	Synergistic enhancement of surface and lesion-body mineralization	Combined remineralization therapy
12	Zhang et al (2011)[45]	pH effect on GCE	Neutral GCE ≈ original GCE in remineralization	pH has a limited influence
13	Tang et al (2015)[46]	Hydroxyapatite morphology	Gallic acid altered crystal formation	Gallic acid altered crystal formation
14	Deng et al (2013)[29]	Dentin matrix	GCE improved biomechanical resistance and matrix integrity	Potential for dentin preservation
15	Xiang et al (2015)[31]	Toxicology	GCE is safe up to 3× clinical topical dose	Demonstrated safety
16	Zhang et al (2009)[47]	Surface roughness (AFM)	Significant decrease in surface roughness after GCE treatment; associated with morphological changes	GCE promotes enamel surface remineralization
17	Zhang et al (2010)[48]	Microhardness & organic matrix	Increased microhardness; irregular deposits suggest organic matrix involvement	Organic matrix plays a role in remineralization
18	Chu et al (2007)[49]	Rehardening of carious enamel	Surface layer thickness increased; lesion depth reduced	GCE is effective in rehardening early enamel lesions

(*Continued*)

Table 1 (Continued).

No.	Author (Year)/Refs	Study Focus	Key Findings	Main Outcome
19	Chu et al (2006)[50]	Surface hardness (cyclic pH)	GCE formulations improved enamel surface hardness	GCE is effective under dynamic oral-like conditions
20	Al-Banaa et al (2025)[51]	Surface hardness (cyclic pH)	Nano-chitosan + gallic acid + CaP enhances physical and chemical adhesive properties	Promising as antimicrobial-remineralizing adhesive
21	Huang et al (2012)[52]	pH effect on activity	GCE inhibited demineralization and acid production at low pH, not at alkaline pH	GCE is most effective around pH 5.5
22	Zhang et al (2009)[53]	Demineralization inhibition	GCE is less effective than NaF but shows matrix-related remineralization	Organic matrix is crucial for GCE efficacy
23	Tang et al (2015)[54]	Gallic acid on HA crystals	GA alters HA crystal morphology and enhances formation	Gallic acid contributes to the remineralization mechanism
24	Zou et al (2008)[55]	GCE & chemical fractions	GCE inhibits demineralization more effectively than its fractions	GCE has synergistic antibacterial + anti-caries potential
25	Cheng & ten Cate (2010)[56]	Advanced enamel lesions	GCE slows surface remineralization but enhances subsurface ion transport	Mechanism distinct from fluoride; deeper lesion effect
26	Deng et al (2012)[57]	Dentin caries and bonding	GCE with mTGase preserves dentin structure and interface	Potential for use in root canal therapy and adhesives
27	Kim & Jin (2018)[58]	Enamel remineralization, biofilm inhibition	Treatment increased enamel surface microhardness and reduced CFU counts	The combination of GCE and calcium shows synergistic effects on enamel remineralization and antibacterial action
28	Xia et al (2020)[59]	Dentin hypersensitivity	Significant reduction in sensitivity scores	Effective relief from dentin hypersensitivity and promotes tubule sealing
29	Abdel-Azem et al (2020)[12]	Remineralization potential	Improved dentin surface hardness and crystal deposition within dentinal tubules	Promising remineralizing effects on demineralized dentin
30	Xie et al (2008)[28]	Anticaries effects	GC significantly reduced enamel demineralization, decreased lesion depth, and inhibited biofilm formation	Strong anticariogenic activity in complex microbial environments

Safety and Toxicological Considerations

Toxicological studies conducted by Xiang et al[31] confirmed that topical application of GCE is safe at clinical doses, with no significant adverse effects observed in acute or subchronic toxicity models. Nonetheless, the efficacy of GCE was influenced by pH, with optimal activity occurring at acidic conditions (pH ~5.5), while diminished effects were seen at alkaline pH levels (Huang et al).[52]

Applications Beyond Enamel: Dentin Remineralization

Finally, recent research has extended GCE applications beyond enamel remineralization, including biomodification of dentin,[29] where GCE improved the mechanical properties and structural resilience of dentin matrices under proteolytic and thermal stress.

Figure 5 illustrates the key findings reported across multiple experimental and clinical studies evaluating the dental applications of *Galla chinensis*. The graphical summary highlights the principal mechanisms of action—such as enamel and dentin remineralization, inhibition of cariogenic biofilms, and reduction of dentinal hypersensitivity—as well as the observed clinical and microscopic outcomes. This visual synthesis facilitates a clearer understanding of the consistency

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Figure 5 Summary of findings reported across multiple experimental and clinical studies.

and diversity of therapeutic effects attributed to *Galla chinensis* and its potential integration into evidence-based oral health strategies.

Discussion

The findings of this scoping review indicate that Galla chinensis extract (GCE) consistently promotes mineral deposition, increases enamel microhardness, inhibits demineralization, and exhibits strong antibacterial activity against cariogenic biofilms, particularly *Streptococcus mutans*. These results suggest that GCE possesses significant potential as a non-fluoride agent for enamel and dental hard tissue remineralization and caries prevention. GCE thus emerges as a promising bioactive compound capable of simultaneously enhancing dental tissue repair and combating cariogenic biofilms.

In addition, considering the role of oxidative stress in modulating tissue regeneration, our findings suggest that GCE's antioxidative properties may contribute to creating a more favorable microenvironment for enamel and dentin repair, thereby complementing its remineralizing and antibacterial effects.

This discussion integrates current evidence to elucidate its mechanisms, clinical potential, and opportunities for advancing minimally invasive dentistry. Our interpretation of the available evidence indicates that GCE may represent a feasible adjunct or alternative to conventional fluoride-based interventions, warranting further clinical investigation.

Efficacy of GCE in Enamel Remineralization

The majority of included studies reported that GCE effectively inhibits enamel demineralization and facilitates the redeposition of mineral ions, especially calcium and phosphate, on demineralized tooth surfaces. These results were consistent across several in vitro models simulating dynamic pH-cycling conditions, indicating that GCE may enhance natural remineralization processes.

One of the most consistent findings across the literature is GCE's capacity to facilitate subsurface remineralization, rather than inducing superficial mineral deposition as typically seen with fluoride. This suggests that GCE enhances ion diffusion deeper into the lesion body, potentially leading to more stable and integrated enamel repair. Studies by Cheng et al and Zhang et al support this mechanism and distinguish GCE as a complementary or alternative agent to traditional fluoride therapy.[53,55]

Role of Enamel Organic Matrix

Additionally, the role of the enamel organic matrix has emerged as a crucial factor in modulating GCE's remineralizing effect. The presence of organic components appears to facilitate mineral ion transport and structural organization during remineralization, which may explain the variability in outcomes between studies using intact versus matrix-depleted enamel.[29,48,60]

Comparison with Fluoride and Alternative Agents

Amaechi and van Loveren[61] emphasized the pivotal role of fluoride in caries prevention through its well-established mechanisms of enhancing remineralization and inhibiting demineralization. However, their analysis also highlighted the limitations associated with fluoride use, including its reduced efficacy in low salivary flow conditions and potential safety concerns in certain populations. As a result, there has been growing interest in the development and clinical application of non-fluoride remineralization systems. These alternative agents—including calcium phosphates, bioactive peptides, and natural polyphenols—have demonstrated the ability to enhance mineral uptake and stabilize early carious lesions through mechanisms that may complement or, in specific contexts, to substitute fluoride.[62]

Dual Mechanism: Remineralization and Antimicrobial Activity

One of the distinctive features of GCE is its dual mechanism of action. Not only does it promote remineralization, but it also exhibits strong antibacterial properties particularly against *Streptococcus mutans*, a key pathogen in dental caries.[24,55,58] GCE and its phenolic constituents—particularly gallic acid and tannic acid—exhibited substantial anti-biofilm and acidogenic inhibition properties. These effects, observed in polymicrobial and microcosm biofilm models, highlight GCE's potential for not only remineralization but also active caries prevention by disrupting the microbial ecology responsible for lesion progression.[28,39,55] Moreover, some studies showed that combining GCE with adjunctive agents, such as calcium or nano-hydroxyapatite compounds, may enhance its remineralization effect, suggesting a potential for synergistic formulations. This is particularly important given the limitations of fluoride-based therapies, which—while effective—may not be suitable or preferred for all patient populations due to concerns over overexposure or limited effectiveness in advanced lesions.[46,54,58]

Biomodification of Dental Tissues

The findings from Al-Banaa et al and Xu et al collectively underscore the potential of bio-functionalization strategies in enhancing dental material performance and therapeutic outcomes.[51,57] The incorporation of nano-chitosan loaded with bioactive agents into orthodontic primers, as demonstrated by Al-Banaa et al, significantly improved antibacterial efficacy and biocompatibility without compromising essential mechanical and chemical properties. Similarly, the study by Xu et al introduced an innovative biomodification approach using *Galla chinensis* extract in combination with microbial transglutaminase, revealing promising results in stabilizing dentin collagen and inhibiting enzymatic degradation, which are critical for effective caries control. Together, these studies highlight the growing relevance of integrating naturally derived compounds and nanotechnologies into dental materials to enhance their bioactivity, particularly in caries-prone environments. Additional in vivo studies and long-term clinical evaluations are necessary to substantiate the efficacy and safety of these bioactive strategies and to support their integration into standard clinical dental practice.

Limitations of Current Evidence

Despite the promising in vitro data, it is important to note that clinical evidence remains limited. Most studies reviewed were laboratory-based, and variations in methodology (eg, GCE concentration, exposure time, enamel model) introduce heterogeneity that limits direct comparisons. In addition, long-term effects, biocompatibility, and optimal delivery systems for GCE remain underexplored in human populations. Furthermore, pH sensitivity represents a relevant challenge in formulation development. As shown in studies by Huang et al[52] the anticariogenic properties of GCE decrease significantly under alkaline conditions, indicating that optimal efficacy may depend on careful pH adjustment in clinical products. Another limitation is the language restriction applied during the literature selection process; only English-language articles were included, which may have excluded relevant studies published in other languages.

Safety and Clinical Potential

Finally, the biocompatibility and safety profile of GCE have been confirmed in toxicological studies, supporting its potential for clinical use in children and adults alike. Its low cytotoxicity, coupled with anti-inflammatory and antimicrobial effects, positions GCE as a promising natural alternative or adjunct to synthetic agents in minimally invasive dentistry.[31]

Future Perspectives

While current literature supports the efficacy of *Galla chinensis* as a remineralizing and antibacterial agent—demonstrating promising effects on enamel hardness and surface roughness—further well-designed in vivo and clinical studies are essential to validate its therapeutic potential and practical application in clinical dentistry. Investigations into standardized formulations, delivery methods (eg, mouthwashes, varnishes, or toothpastes), and toxicological safety will be essential to support its inclusion in routine preventive care protocols. Additionally, comparative studies between GCE and established agents such as fluoride or CPP-ACP will provide clearer insights into its clinical relevance.

Conclusion

Galla chinensis extract demonstrates promising potential in managing early enamel and dentin carious lesions through a dual mechanism: promoting remineralization and inhibiting demineralization, while simultaneously reducing cariogenic biofilm activity. The discussion highlights that its unique mechanism, biocompatibility, and antibacterial properties position GCE as a viable biomimetic alternative or adjunct to conventional agents such as fluoride, particularly in minimally invasive or fluoride-sensitive approaches.

However, the current evidence is predominantly preclinical, with limited clinical data. Therefore, well-designed clinical trials are essential to confirm efficacy, optimize formulations, and explore broader applications in preventive and restorative dentistry. Overall, the findings underscore that GCE is a natural-based agent with considerable potential, warranting continued research and development to inform modern, evidence-based oral care strategies.

Abbreviations

GC, Galla chinensis; GCE, Galla chinensis extract; AFM, Atomic Force Microscopy; HA, Hydroxyapatite; CFU, Colony-Forming Unit; CPP-ACP, Casein Phosphopeptide–Amorphous Calcium Phosphate; SHR, Surface hardness recovery.

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Disclosure

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