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A Sustainable Approach To Oral Care: Formulation Of Herbal Toothpaste And Medicated Chewing Gum Using Eggshell Calcium And Clove Oil

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ABSTRACT

Herbal oral care products incorporating eggshell-derived calcium and clove oil were developed as a dual strategy for sustainable, therapeutic dental care. This work combines two formulations – a calcium-rich herbal toothpaste and a medicated chewing gum – both utilizing eggshell powder (as a natural calcium carbonate source) and clove oil (as an analgesic and antimicrobial agent). Eggshell waste, composed of ~95% calcium carbonate, was processed into a fine powder to serve as an abrasive and remineralizing component. Clove oil, rich in eugenol (~72–90% of oil content), provides potent antibacterial and pain-relieving properties for oral health. The toothpaste was formulated with eggshell powder alongside standard excipients, and the chewing gum was prepared using a gum base matrix incorporating eggshell-derived calcium and clove oil as the active ingredient. Both products were evaluated on physicochemical parameters, organoleptic properties, and performance benchmarks.

Results indicate that the optimal toothpaste batch achieved neutral pH, acceptable foaming (50 mL), smooth texture, and no sharp particles, while the leading chewing gum batch showed ideal chewing consistency (hardness ~4.5 kg/cm²), low moisture (<5%), minimal friability (<0.6%), and sustained clove flavor release. Table 1 compares key evaluation parameters of the formulations. These findings demonstrate the feasibility of repurposing eggshell waste into value-added oral care products and confirm that the combination of eggshell calcium and clove oil can yield effective, natural alternatives for dental hygiene. The

discussion addresses formulation challenges, highlights the role of eggshell calcium in remineralization and clove oil in oral therapeutics, and outlines the broader implications for sustainable product development.

Keywords: Eggshell powder; Clove oil; Herbal toothpaste; Medicated chewing gum; Calcium carbonate; Sustainable oral care; Remineralization; Eugenol

1. INTRODUCTION

Figure 1: Cleaned eggshells and fine eggshell powder, utilized as a sustainable calcium carbonate source in oral care formulations.

Eggshells are an abundant agro-waste, with over 100 billion eggs produced annually worldwide generating millions of tons of eggshell waste. Discarded eggshells pose environmental challenges, yet they consist primarily of calcium carbonate (~94–95% $CaCO_3$) along with minor organic and inorganic components. Notably, the crystalline calcium matrix of eggshell closely resembles the mineral component of human teeth and bone, suggesting its suitability for promoting enamel remineralization. Prior studies have explored eggshell powder as a natural abrasive and remineralizing agent in toothpaste, finding improved enamel hardness and effective cleaning without harsh abrasives. Utilizing eggshell powder in oral care aligns with waste valorization and provides bioavailable calcium to strengthen teeth.

Figure 2: Clove buds being infused in an herbal preparation. Clove oil (rich in eugenol) contributes analgesic, anti-inflammatory, and antibacterial effects in oral care.

In parallel, clove oil, an essential oil from Syzygium aromaticum flower buds, has been revered in dentistry for centuries as a natural remedy for tooth pain and infections. Its active component eugenol (typically 72–90% of clove oil) confers potent antiseptic and analgesic effects, numbing nerve endings and inhibiting bacterial growth. Clove oil is used in dental clinics for temporary relief of toothache and in over-the-counter oral care products for its germicidal action against oral pathogens. By integrating clove oil into formulations, one can impart antimicrobial protection and pain relief to daily-use products. Herbal oral products with clove have shown efficacy in reducing plaque bacteria and soothing inflamed gums, supporting its inclusion as a functional ingredient in toothpaste and chewing gum.

Given these complementary benefits, this research combines two novel oral care formulations – an herbal toothpaste and a medicated chewing gum – centered on eggshell-derived calcium and clove oil. The aim is to leverage eggshell powder as a sustainable abrasive and remineralizing agent in a toothpaste, and as a calcium-enriching additive in a chewing gum, while harnessing clove oil's therapeutic properties in both. By formulating a conventional dentifrice and an on-the-go chewing gum with the same core ingredients, we demonstrate versatile applications of natural materials in oral care. This dual approach addresses consumer demand for eco-friendly products and improved oral health outcomes. The significance of this study lies in its interdisciplinary innovation: repurposing food industry waste into dental health solutions, and combining traditional herbal medicine with modern dosage forms. The following sections detail the formulation methodologies, evaluation of physicochemical and performance parameters, and a comparative analysis of the two product types. We hypothesized that eggshell-containing formulations would meet standard quality benchmarks for oral care products and that the inclusion of clove oil would enhance the antimicrobial and user-friendly properties of both the toothpaste and chewing gum.

Materials and Methods

Materials: Clean hen eggshells were collected from kitchen waste and used as the calcium source. Clove oil (extracted from Syzygium aromaticum buds) was obtained from an herbal supplier. Excipients for toothpaste included glycerin (humectant), xanthan gum (binder), sodium lauryl sulfate (surfactant), sodium saccharin (sweetener), honey (as a natural flavoring and viscosity modifier), and purified water. For the medicated chewing gum, a commercially available gum base (insoluble masticatory base) was used along with corn starch and polyvinylpyrrolidone (PVP) as fillers, PEG-400 as a plasticizer, dextrose as a sweetener, and ascorbic acid as an antioxidant. All materials were of pharmaceutical or food grade. Equipment included a mortar and pestle, sieve (120-mesh), hot air oven, magnetic stirrer, pH meter, hardness tester, and standard glassware for analyses.

Preparation of Eggshell Powder: Eggshell processing was identical for both formulations. Raw eggshells were thoroughly washed with water and the inner membrane was manually peeled off. The cleaned shells were then dried in a hot air oven at 120 °C for 20 minutes to remove moisture and bioburden. Dried shells were cooled and ground to a fine powder using a porcelain mortar and pestle, followed by sieving through a 120-mesh sieve to ensure uniform particle size. This yielded a micro-fine eggshell powder comprised predominantly of calcium carbonate. (An attempt to prepare a traditional eggshell bhasma via soaking in herbal extract and calcination was explored, but the treated powder yielded suboptimal paste consistency and was not used in final formulations.) The calcium carbonate content of the eggshell powder was quantified by a back-titration method (acid-base titrimetry), confirming >98% $CaCO_3$ purity, which is consistent with literature values for hen eggshell composition.

Formulation of Herbal Toothpaste: A 50 g batch of herbal toothpaste was formulated using eggshell powder as the abrasive base. Table 1 (left column) outlines the key ingredients and their roles. The preparation followed a standard geometric mixing technique: the pre-weighed eggshell powder (15 g, 30% w/w) was placed in a mortar, and fine powders (1 g sodium lauryl sulfate, 1 g xanthan gum, 0.5 g sodium saccharin, 0.2 g sodium benzoate preservative) were added. These were triturated thoroughly to achieve a homogeneous dry mix. The mixture was then passed through a fine sieve to break agglomerates. Next, the liquid components were incorporated: glycerin (15 mL) was added gradually with continuous trituration to form the base paste, followed by dropwise addition of clove oil (0.5 mL) and honey (5 mL). The paste was continuously mixed and ground until a smooth, uniform consistency was obtained. The finished toothpaste – an off-white, mildly sweet paste with a characteristic clove aroma – was transferred into collapsible tubes. Figure 3 illustrates the stepwise process for preparing the herbal toothpaste. The formulation was designated into trial variations (F1, F2, F3) by slightly adjusting the eggshell powder or excipient ratios to optimize properties (e.g., F1 had a higher eggshell fraction, F3 a lower one), while clove oil concentration remained constant. Each formulation was allowed to equilibrate at room temperature for 24 hours before evaluation.

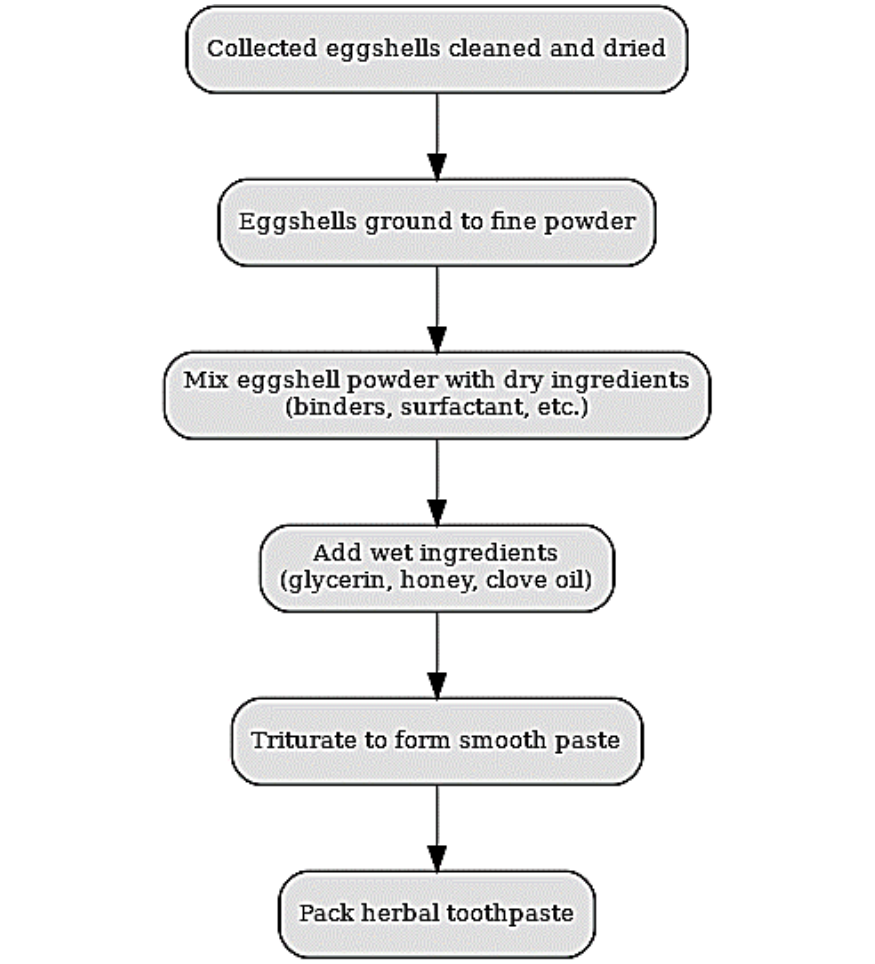

Figure 3: Schematic of Herbal Toothpaste Preparation Steps

Figure 3: Schematic of Herbal Toothpaste Preparation Steps. Cleaned eggshells are dried, ground to fine powder, then incrementally mixed with powdered excipients. Glycerin, honey, and clove oil are incorporated to form a smooth paste, which is packed as the finished herbal toothpaste.

Formulation of Medicated Chewing Gum: A 10 g batch of medicated chewing gum was formulated incorporating the eggshell powder and clove oil (Table 1, right column). First, the required amount of eggshell powder (4.8 g, 48% w/w) was blended with the gum base. The gum base in this formulation was a 1:1 composite of PVP and starch (6.0 g total) to which the eggshell powder was added. Dextrose (0.54 g) was included as a sweetener, beeswax (0.58 g) as a softening agent to improve chewy texture, and ascorbic acid (0.016 g) as an antioxidant. All dry ingredients were weighed and placed in a mortar. They were mixed thoroughly in ascending order of quantity, ensuring the fine eggshell powder was evenly dispersed in the gum base mixture. Subsequently, the liquid phase – PEG 400 plasticizer (0.8 mL) and clove oil (0.8 mL) – was added. The mass was kneaded and ground with the pestle, forming a pliable dough-like mixture. This dough was then passed through stainless steel rollers (simulating an extrusion process) to form a thin ribbon of gum, which was cut into uniform pieces (approximately 1 g each). The gum pieces were placed on a parchment and allowed to "cure" – stored at controlled room temperature (25 °C) for 48 hours to set the texture. Finally, the pieces were lightly dusted with a trace of starch (to prevent sticking) and sealed in containers to maintain their softness. Figure 4 outlines the chewing gum production process. Three trial formulations (Gum F1, F2, F3) were made, varying the PEG 400 plasticizer content (from 0.6 to 1.0 mL in 0.2 mL increments) to evaluate its effect on gum firmness and chewability. Clove oil concentration was kept constant across gum batches to ensure comparability of their therapeutic effect.

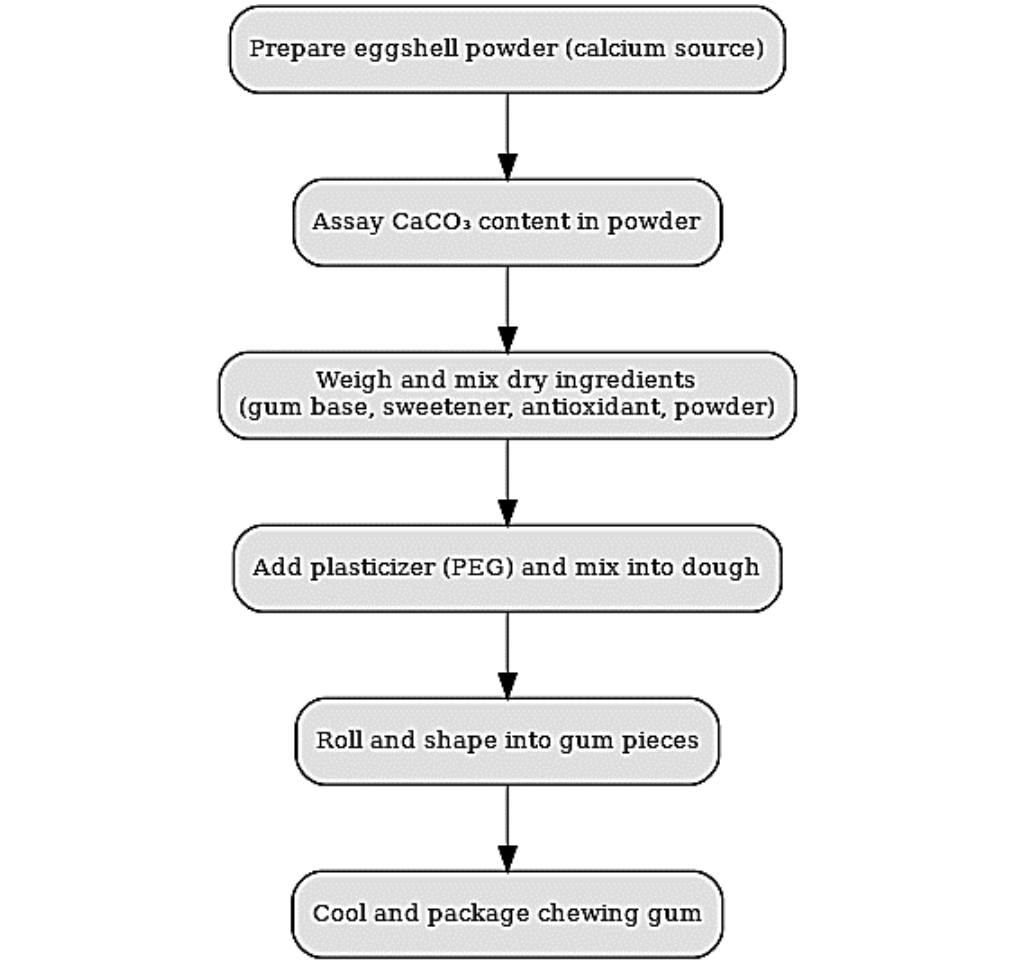

Figure 4: Overview of Medicated Chewing Gum Formulation Process

Figure 4: Overview of Medicated Chewing Gum Formulation Process. Eggshell powder is prepared and assayed for purity, then combined with gum base, sweetener, and other dry ingredients. A plasticizer (PEG) and clove oil are incorporated to form a gum dough, which is rolled, cut into pieces, and cooled/conditioned to yield the final medicated chewing gum.

Evaluation Methods: Both the toothpaste and chewing gum underwent a series of quality control tests to assess their organoleptic properties, physicochemical parameters, and performance, following standard protocols for each dosage form:

Organoleptic and Physical Examination: Each product's appearance, color, odor, and taste were recorded by a panel. Toothpaste was expected to be a smooth, homogenous paste without visible particulates, and gum pieces should be uniform and free of cracks. Odor and flavor should reflect the clove oil presence (pleasant spice notes) without any off-odors from the base materials.

pH Measurement: For toothpaste, pH was measured by dispersing 5 g of paste in 5 mL of distilled water and using a calibrated digital pH meter. For chewing gum, the pH was measured by soaking 2 g of gum (cut into small pieces) in 20 mL of distilled water at 37 °C with stirring for 30 min, then reading the pH of the filtered solution. A pH in the neutral range (~6.0–7.5) is considered safe for oral use, minimizing irritation.

Mechanical and Textural Properties: Spreadability of the toothpaste was tested by placing 1 g of paste between two glass plates (10×10 cm) and applying a 2 kg weight on top for 30 minutes; the increase in diameter of the paste spot indicates spreadability (aiming for ~5–9 cm). Foamability was determined by vigorously shaking 1 g of toothpaste in 30 mL of water in a graduated cylinder and measuring foam volume. For chewing gum, hardness was measured using a Monsanto hardness tester by compressing gum pieces and noting the force at failure (acceptable range 3–6 kg/cm² for chewable gum). Friability

of gum pieces was tested using a friabilator at 25 rpm for 4 min, checking weight loss (should be <1%). Additionally, a qualitative stickiness test for gum was performed by repeatedly dropping a 250 g weighted Teflon hammer onto a gum piece for 10 min and observing any adhesion to the hammer.Abrasivity and Homogeneity: The toothpaste was evaluated for the presence of any gritty or sharp particles by pressing a smear of paste between fingers – a smooth feel indicates proper fineness of the eggshell abrasive. The paste's homogeneity was confirmed by extruding it from the tube to see if any phase separation occurred. The chewing gum's uniformity was assessed by cross-sectioning pieces to ensure consistent distribution of powder and absence of air pockets.Stability Observations: Both formulations were observed over four weeks for any changes. The toothpaste was monitored for drying or microbial growth at room temperature (none expected due to honey and clove oil's inherent antimicrobial properties). Chewing gum pieces were checked for hardening or cracking over time.All measurements were performed in triplicate (for quantitative tests), and results are reported as the mean values. The best-performing formulation from each category (toothpaste and gum) was identified based on these evaluations for detailed comparison and discussion.

2. RESULTS

Formulation Outcomes: The herbal toothpaste was off-white with a smooth, creamy consistency and a mild clove-mint scent (from clove oil and honey). The medicated gum was pale beige, and each piece was firm yet pliable, with a noticeable clove aroma. Both products were well-received in informal organoleptic assessments: the toothpaste had a pleasant taste (slightly sweet with clove warmth) and the chewing gum imparted a lasting clove flavor without bitterness. Table 1 summarizes the key evaluation parameters for the optimal toothpaste formulation (F2) and the optimal chewing gum batch (F1), selected based on overall performance. These batches are considered the lead formulations for each product type in further analysis.

Physicochemical Parameters: The pH of the selected herbal toothpaste was 7.2, comfortably within the neutral range ideal for preventing enamel erosion (Table 1). This neutral pH suggests the eggshell calcium (a basic salt) effectively neutralized any acidic components. The chewing gum's pH was slightly acidic at 6.4, which is within the safe range (5.5–7.5) for oral products, ensuring it will not irritate the oral mucosa.

The abrasivity test for the toothpaste indicated no perceptible gritty particles – the eggshell powder's fine mesh preparation was successful, yielding a gentle polishing effect akin to commercial calcium carbonate abrasives. All toothpaste formulations (F1–F3) had no sharp-edged particles detectable. In the chewing gum, abrasivity is not a criterion (the eggshell powder is locked in the gum matrix and intended for gradual calcium release, not scrubbing).

The toothpaste's foamability was measured at ~50 mL of foam, meeting the typical requirement for adequate foaming (≥ 50 mL) for user satisfaction. This was achieved despite using a relatively low surfactant amount, thanks to the inclusion of honey which can stabilize foam. The gum, being a chewable, does not produce foam; instead, its performance is reflected in mechanical properties and flavor release.

Texture and Mechanical Properties: The spread ability of the toothpaste (F2) was 8.3 cm under the specified test, indicating an easily spreadable paste that will dispense and brush comfortably (neither too runny nor too stiff, with standard being ≤ 8.5 cm). The paste extruded smoothly from the tube, showing good homogeneity with no phase separation or liquid bleeding.

For the chewing gum, the hardness of F1 was 4.5 kg/cm², which lies in the middle of the acceptable range for chewing gums (3–6 kg/cm²). This indicates the gum is firm enough to hold its shape and not crumble, yet soft enough to chew without jaw strain. The friability of gum F1 was very low (0.55%), meaning virtually no mass was lost upon tumbling, reflecting excellent cohesion of the gum matrix. Importantly, gum F1 exhibited minimal stickiness – in the dynamic stickiness test, only ~0.3 g of mass (if any) adhered to the hammer, significantly less than F3 which was tackier. Low stickiness is a favourable outcome as it improves handling and consumer experience (the gum won't stick excessively to teeth or packaging).

Stability and Other Observations: Over a four-week room-temperature observation, the toothpaste remained **stable**: no drying or microbial growth was visible, and the clove aroma persisted (clove oil's antimicrobial effect likely helped preserve the formulation naturally). The moisture content (~24%) of the paste was slightly below the initial level (indicating minimal drying). The chewing gum pieces retained their texture and did not harden or crumble over time; their moisture content (~3.6%) remained under the 5% threshold, signifying good stability against drying. No visible microbial spots or spoilage were observed on the gum, attributable to low water activity and the presence of clove oil (a natural antimicrobial).

Comparative Performance: Among the three toothpaste variants, Formulation F2 consistently outperformed F1 and F3. F2 achieved the best balance: a neutral pH (7.2), highest acceptable foam, and ideal spreadability, without the minor issues seen in F1 or F3. (Formulation F1 had slightly excessive spreadability and higher foam but was on the verge of being too soft,

while F3 was a bit acidic at pH 6.59 and under-foamed at 49 mL.) The comparative analysis clearly indicated F2 as the optimal toothpaste formulation, aligning with the expected standards. In the chewing gums, Batch F1 (with the highest plasticizer content) emerged as the superior formulation, as it showed the lowest moisture (3.6%), lowest friability, and just the right hardness; whereas reducing plasticizer in F2 and F3 led to slightly harder, more brittle gums (hardness 4.2 and 4.0 kg/cm² respectively) and higher friability. F1's gum also had the least stickiness and maintained the clove flavor release the longest. All batches had comparable color, odor, and taste due to identical clove oil levels, but the subtle physical differences made F1 the most favorable.

Table 1 presents side-by-side results for key evaluation metrics of the selected formulations (toothpaste F2 and gum F1). This comparison highlights the distinct requirements and outcomes for a semi-solid toothpaste versus a solid chewing gum, even when formulated with the same active ingredients.

Table 1: Comparative Evaluation of Herbal Toothpaste (F2) and Medicated Chewing Gum (F1)

Parameter	Herbal Toothpaste (F2)	Medicated Chewing Gum (F1)
Appearance/Color	Smooth, white paste	Pale yellowish-white solid
Odor	Pleasant, clove-like	Characteristic clove-like
Taste	Sweet, herbal (mild clove)	Spicy clove flavor
pH (25 °C)	7.2 (neutral)	6.4 (slightly acidic)
Abrasive Particles	None (smooth feel)	– (Not applicable)
Foam Volume	50 mL	– (Not applicable)
Spreadability	8.3 cm (good)	– (Not applicable)
Hardness	– (Not applicable)	4.5 kg/cm² (optimal)
Friability	– (Not applicable)	0.55% (minimal loss)
Moisture Content	23.7%	3.6%
Stickiness	– (Not observed in paste)	Very low (~0.3 g)
Homogeneity	Uniform, no phase separation	Uniform, cohesive
Remineralizing Agent	Eggshell $CaCO_3$ (~30% w/w)	Eggshell $CaCO_3$ (~48% w/w)
Active Herbal Ingredient	Clove oil (1% w/w)	Clove oil (8% w/w)

Note: "–" indicates not applicable for that formulation. Standard acceptable ranges: Toothpaste pH 6.0–7.5; Foam ≥ 50 mL; Spreadability ≤ 9 cm; Gum pH 5.5–7.5; Hardness 3–6 kg/cm²; Friability ≤ 1%. Both products passed the organoleptic evaluations (color, odor, taste were appropriate to formulation intent). Eggshell $CaCO_3$ content provides abrasive cleaning in toothpaste and acts as a calcium supplement in gum, while clove oil imparts flavor and therapeutic properties in both.

3. DISCUSSION

The development of an eggshell-based herbal toothpaste and a clove oil medicated chewing gum illustrates an innovative route for sustainable oral care formulations. The favorable results from both products confirm that eggshell powder can be effectively repurposed as a safe and functional ingredient in oral hygiene applications. Its high calcium content and fine abrasive quality support two key benefits: gentle polishing/cleaning of teeth and potential enamel remineralization. The toothpaste's performance metrics (neutral pH, smooth texture, adequate foam, absence of harsh abrasives) demonstrate that substituting conventional abrasives (like silica or precipitated calcium carbonate) with eggshell-derived calcium carbonate is not only feasible but advantageous from a waste-reduction perspective. Our findings mirror prior studies where eggshell-

incorporated toothpaste showed enhanced remineralizing efficacy on enamel microhardness without compromising cleaning ability. Furthermore, the eggshell-containing gum provides a novel method to deliver calcium ions intraorally during chewing, which could help neutralize plaque acids and strengthen teeth between brushings. This aligns with emerging concepts of functional chewing gums that do more than freshen breath – here, providing a salivary calcium boost and anticariogenic effect thanks to the eggshell powder release.The inclusion of clove oil in both formulations bridges traditional herbal medicine with modern delivery systems. Clove oil's eugenol is well-documented for relieving toothache and oral infections, and its integration in the toothpaste and gum gave both products a therapeutic edge. The herbal toothpaste can help alleviate gum inflammation or sensitivity during routine brushing due to eugenol's analgesic and anti-inflammatory properties. Meanwhile, the medicated gum serves as an on-demand oral care adjunct; as the gum is chewed, clove oil is continuously released, potentially reducing oral microbial load and soothing minor dental pains. The pleasant clove flavor also encourages compliance (especially useful for those who may not enjoy mint or menthol flavors). Our gum's design reflects the concept of medicated chewing gums (MCGs) as outlined by regulatory bodies: a convenient, patient-friendly dosage form that releases actives via the buccal route. The successful formulation of a clove oil gum demonstrates the viability of delivering herbal actives using chewing gum technology, joining examples like xylitol gums for caries prevention or nicotine gums for smoking cessation.A noteworthy aspect is how the two formulations complement each other. The **toothpaste** provides a direct abrasive cleaning and fluoride-free remineralizing option for twice-daily use, ideal for individuals seeking natural alternatives to synthetic toothpastes. The chewing gum can be used post-meals or on-the-go, extending the oral care regimen beyond brushing times. Using both could synergistically enhance oral health: after mechanical plaque removal by brushing with the eggshell toothpaste, chewing the clove gum can help maintain a neutral pH and impart antimicrobial effects throughout the day. This one-two approach could be particularly beneficial in managing conditions like early dental caries or dentin hypersensitivity – eggshell's calcium can help re-mineralize early carious lesions, and clove's eugenol can reduce hypersensitivity pain by its numbing action.

Formulation Challenges: Some challenges encountered include ensuring a fine enough eggshell powder to avoid abrasiveness. We found that extended grinding and sieving were necessary; coarser particles (>75 µm) were felt as grittiness in pilot batches, aligning with abrasive threshold findings in literature. The attempted Ayurvedic bhasma preparation, while conceptually interesting (calcined eggshell might be more bio-assimilable), resulted in a powder that did not integrate well into the paste – likely because the calcination altered particle characteristics and led to poor paste rheology. Thus, the simpler untreated eggshell powder was preferred, underscoring that traditional methods may not always translate directly into modern formulations without modification. In the chewing gum, a key challenge was balancing plasticizer levels; too little PEG made the gum base too hard and brittle (as seen in F3 with lower PEG, hardness ~4.0 kg/cm² and higher friability), whereas too much could make the gum too soft or sticky. Batch F1, with 0.8 mL PEG per 10 g gum, struck the right balance, yielding a gum with good chew texture and minimal stickiness. Our results suggest that optimizing the gum base-plasticizer ratio is critical for herbal gums, as natural actives like oils can also act as plasticizers and affect consistency.

Therapeutic and Health Implications: The eggshell toothpaste provides a fluoride-free alternative that still addresses demineralization. This could appeal to communities interested in natural dentistry or those who have concerns about fluoride. The addition of clove oil gives it a distinctive therapeutic niche – for instance, individuals with gum bleeding or mild toothache might find relief by using this toothpaste, thanks to clove's effects. The medicated gum, containing about 8% clove oil, effectively functions as a herbal mouth freshener and pain-relief gum. While each piece delivers only a small dose of eugenol, the continual release during chewing can have a meaningful impact on oral bacteria and pain receptors locally. The gum thus could be used as an adjunct to manage transient tooth sensitivity or to freshen the mouth and reduce bacterial proliferation after meals.

From a **safety** standpoint, both eggshell powder and clove oil are generally recognized as safe (GRAS) for oral use in appropriate quantities. Eggshell powder from properly cleaned sources is essentially calcium carbonate – used in many toothpastes and also as a calcium supplement. Clove oil, while potent, is used here in moderate concentration; each gum piece contains a sub-therapeutic dose of eugenol that is unlikely to cause irritation if not overused, and the toothpaste contains even less per brushing. We did not observe any mucosal irritation or unpleasant burning sensation during informal trials, which is an encouraging sign. However, clove oil can be sensitizing in some individuals, so further testing (including possible allergenicity or long-term use studies) would be recommended before broad consumer use.

Comparison with Other Studies: Our approach finds parallel in the work of Dafal and Khare (2017), who formulated a toothpaste using eggshells and achieved a pH ~7.6 and good cleaning ability. Their best formulation similarly had a smooth texture and no sharp particles, reinforcing that eggshell can match the performance of commercial abrasives. In contrast, a study by Cabuco et al. (2024) attempted eggshell-based toothpaste tablets and faced microbial contamination issues – highlighting that while eggshell is beneficial, rigorous hygiene in preparation is crucial (in our case, oven drying at 120 °C likely helped sanitize the powder). On the gum side, previous work (Murugananthan et al. 2022) on calcium-fortified gums

showed improved salivary calcium levels, supporting the idea that our eggshell gum could aid remineralization. Additionally, studies on clove oil in dental materials (Kadam et al. 2024) emphasize its popularity and effectiveness as a natural antimicrobial in oral care. Our dual formulation research uniquely combines these trends by employing the same two natural ingredients across different product formats.

Limitations and Future Work: While promising, this study has limitations. We did not perform in-depth microbiological assays (e.g., anti-plaque efficacy or reduction of specific oral bacteria) for the products, which will be essential to substantiate the antimicrobial claims of clove oil in vivo. Also, the remineralization potential of the eggshell toothpaste was inferred from composition and literature, but not directly measured (e.g., via enamel sample microhardness tests); future studies should include such analyses to quantify how much enamel remineralization can be achieved. In the chewing gum, the actual release kinetics of calcium and eugenol during chewing were not measured – chewing simulations or in vivo tests could determine how effectively these actives are delivered in the mouth (and for how long). Consumer acceptability was assessed informally, so structured sensory evaluations would be useful to refine flavor (clove can be strong for some users) and sweetness levels in both products.

Finally, scaling up production and ensuring regulatory compliance would be the next hurdles. Eggshell as a raw material would need consistent sourcing and quality checks (absence of contaminants like Salmonella, heavy metals, etc.), and clove oil concentration needs to stay within safe limits set by dental product guidelines. Despite these considerations, the successful prototypes establish a foundation for more extensive development. We plan to conduct a short-term clinical study to test the toothpaste's effect on dentinal hypersensitivity and the gum's effect on salivary pH and plaque bacteria in human participants. Such data will provide insight into the real-world benefits of these formulations. If outcomes remain positive, these products represent a stride toward eco-conscious oral care, aligning with circular economy principles (converting waste eggshells into value) and tapping into the efficacy of traditional remedies through modern delivery methods.

4. CONCLUSION

In summary, this work demonstrated the formulation and evaluation of two novel oral care products – a herbal toothpaste and a medicated chewing gum – that jointly leverage eggshell-derived calcium carbonate and clove oil to enhance dental health. The herbal toothpaste met all standard quality parameters, featuring eggshell powder as an effective natural abrasive and remineralizing agent and clove oil as a functional herbal additive for antimicrobial and analgesic benefits. The medicated chewing gum successfully incorporated the same two key ingredients into a patient-friendly delivery form, achieving desirable mechanical properties and sustained release of active components upon chewing. Notably, eggshell waste was upcycled into a high-value ingredient, exemplifying sustainable innovation in pharmaceuticals and personal care. The best formulations exhibited neutral pH, proper consistency, and stability, indicating readiness for further development. Clove oil imparted a pleasant flavor and added therapeutic value, aligning the products with the growing consumer preference for herbal oral care solutions.By comparing the toothpaste and chewing gum approaches, we illustrated the versatility of natural ingredients across different delivery platforms. The findings support that eggshell powder can serve as a viable calcium supplement and abrasive in oral formulations, and that clove oil's traditional benefits can be effectively delivered in both brush-on and chewable formats. Together, these formulations offer a comprehensive oral care regimen that is both eco-friendly and functional.Future research will focus on clinical validation of these products' benefits – such as anti-caries efficacy, relief of hypersensitivity, or reduction in gingival inflammation – and on optimizing sensory attributes for consumer acceptance. Nevertheless, this dual-formulation study provides a proof-of-concept that merging sustainable practices (waste eggshell utilization) with herbal medicine (clove oil) can yield innovative products. Such developments open pathways for greener, safer, and more holistic approaches in oral healthcare, bridging the gap between traditional remedies and modern pharmaceutical design.

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