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Formulation and Evaluation of a Mucoadhesive Polyherbal Dental Gel Enriched with Herbal Extracts for Management of Oral Microbial Disorders

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Abstract

This study aimed to formulate and evaluate a polyherbal mucoadhesive dental gel containing guava leaf extract, neem extract, aloe vera gel, pomegranate peel extract, eucalyptus oil, and clove oil for improved oral health management. The gel was prepared using Carbopol 940 as a mucoadhesive polymer along with suitable pharmaceutical excipients. Four formulations (F1–F4) were developed and evaluated for physicochemical properties, phytochemical composition, antimicrobial activity, and stability. The results showed acceptable pH, viscosity, spreadability, and stability in all formulations. Formulation F3 demonstrated an optimal balance of antimicrobial activity and desirable physical characteristics. The study suggests that the developed polyherbal dental gel could serve as a safe and effective alternative for the prevention and management of oral infections.

Keywords: Polyherbal dental gel, Mucoadhesive formulation, Herbal extracts, Antimicrobial activity, Oral health.

Introduction

Oral health is an integral component of overall human wellness, influencing nutrition, communication, and quality of life. The increasing prevalence of dental caries, gingivitis, periodontitis, oral ulcers, and halitosis has intensified the demand for safe and effective oral care products. Conventional dental formulations such as toothpastes and gels commonly contain synthetic preservatives, detergents (e.g., sodium lauryl sulfate), artificial sweeteners, and abrasive agents. Although effective, these components may sometimes cause oral mucosal irritation, hypersensitivity reactions, taste alteration, and disruption of the natural oral microbiome.

As a result, there is growing consumer preference for herbal-based oral care products that offer therapeutic benefits with fewer adverse effects.[1,2,3]

Herbal medicine has been utilized for centuries in traditional systems such as Ayurveda, Unani, and Traditional Chinese Medicine for maintaining oral hygiene and treating dental disorders. Plant-derived extracts possess diverse pharmacological properties including antimicrobial, anti-inflammatory, antioxidant, analgesic, and wound-healing effects. These characteristics make herbal ingredients highly suitable for incorporation into dental gels and other oral formulations. Scientific validation of these traditional remedies has further strengthened their credibility in modern dental research.[4,5]

Neem (*Azadirachta indica*) is widely recognized for its potent antibacterial and anti-plaque properties. Studies have demonstrated its effectiveness against cariogenic organisms such as *Streptococcus mutans*, which plays a key role in the initiation of dental caries. Similarly, guava leaf (*Psidium guajava*) extract exhibits strong antimicrobial activity against oral pathogens and contributes to plaque control. Aloe vera (*Aloe barbadensis Miller*) has gained attention in dentistry due to its anti-inflammatory, soothing, and wound-healing properties, making it beneficial in managing gingivitis and oral ulcers.[6,7,8]

Pomegranate peel (*Punica granatum*) contains polyphenols and tannins that provide antioxidant, antimicrobial, and astringent effects, supporting gum health and reducing microbial colonization. Clove oil (*Syzygium aromaticum*), rich in eugenol, has long been used in dentistry as a natural analgesic and antiseptic agent for toothache relief. Eucalyptus oil (*Eucalyptus globulus*) also exhibits antimicrobial and anti-inflammatory properties while contributing to breath freshness. The synergistic combination of these herbal extracts in a polyherbal formulation enhances therapeutic efficacy by targeting multiple pathways involved in oral diseases.[9,10]

In addition to selecting appropriate herbal ingredients, the method of drug delivery plays a critical role in therapeutic effectiveness. Conventional gels and rinses may be rapidly washed away by saliva, reducing contact time with oral tissues. To overcome this limitation, mucoadhesive drug delivery systems have been developed. Mucoadhesive polymers such as Carbopol 940 adhere to the oral mucosa by forming hydrogen bonds and electrostatic interactions with mucin glycoproteins. This adhesion prolongs the residence time of the formulation at the site of application, allowing sustained release of active constituents and improved local therapeutic outcomes.[11]

The pharmacokinetic behavior of herbal dental gels is primarily localized. Active phytoconstituents act topically within the oral cavity with minimal systemic absorption, thereby reducing the risk of systemic side effects. The prolonged retention provided by mucoadhesive polymers ensures continuous antimicrobial and anti-inflammatory action, promoting plaque control, gingival health, pain relief, and tissue regeneration.

Recent research emphasizes the importance of developing evidence-based herbal dental formulations that meet quality, safety, and efficacy standards. Evaluation parameters such as pH, viscosity, spreadability, stability, antimicrobial activity, and mucoadhesive strength are essential in determining product performance. An ideal herbal dental gel should maintain a near-neutral pH (6.5–7.5), exhibit good consistency, and ensure patient acceptability through pleasant taste and aroma.[12,13]

Thus, the formulation of a polyherbal mucoadhesive dental gel represents a promising approach in contemporary dental care. By integrating traditional botanical knowledge with advanced pharmaceutical technology, such formulations provide a natural, safe, and effective alternative to synthetic oral care products. Continued scientific validation and clinical evaluation will further establish the role of herbal mucoadhesive dental gels in preventive and therapeutic dentistry.

2. Materials and Methodology for Formulation

2.1 Materials Required for Formulation

The formulation was developed using selected herbal extracts and pharmaceutical-grade excipients. The herbal drugs incorporated in the study included guava leaf extract, neem extract, aloe vera gel, pomegranate peel extract, eucalyptus oil, and clove oil. These botanicals were chosen based on their reported antimicrobial, anti-inflammatory, antioxidant, and wound-healing properties. All herbal extracts were procured from authenticated suppliers and standardized prior to use. Fresh aloe vera gel was collected and filtered to remove fibrous material, while essential oils (eucalyptus oil and clove oil) were stored in airtight amber containers to prevent oxidation and volatilization.[14,15,16]

The excipients used for gel formulation included Carbopol 940 as a gelling agent, polyethylene glycol (PEG-400) as a solvent and humectant, sorbitol as a sweetening and moisturizing agent, triethanolamine (TEA) as a neutralizing agent, sodium benzoate as a preservative, chlorophyll extract as a natural coloring agent, and distilled water as the vehicle. All excipients were of pharmaceutical grade and used as received. The compatibility of herbal extracts with excipients was assessed prior to formulation to ensure physical stability and homogeneity of the final product.[17]

The formulation was prepared by dispersing Carbopol 940 in a measured quantity of distilled water with continuous stirring to avoid lump formation, followed by hydration for adequate swelling. PEG-400 and sorbitol were then incorporated into the hydrated gel base under constant stirring. The herbal extracts and aloe vera gel were added sequentially, followed by essential oils dissolved in a small quantity of PEG-400 to ensure uniform distribution. Sodium benzoate and chlorophyll extract were subsequently mixed into the formulation. Finally, triethanolamine was added dropwise to adjust the pH and achieve the desired gel consistency. The prepared formulation was evaluated for physical appearance, pH, viscosity, spreadability, and stability under controlled storage conditions.[18]

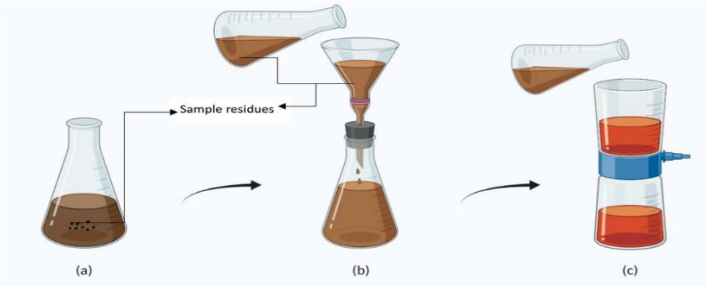
2.3 Extraction Process of Active Ingredients

2.3.1 Psidium guajava (Guava Leaf Extract)

Fresh guava leaves were shade-dried and pulverized into coarse powder. Approximately 150 g of powdered material was packed into a filter paper thimble and subjected to Soxhlet extraction using 500 mL of 70% (v/v) ethanol as solvent. The extraction process was carried out at 60°C for 6 hours until the siphon tube solvent became colorless, indicating exhaustive extraction. The ethanolic extract was concentrated under reduced pressure using a rotary evaporator to remove the solvent, yielding a thick, semi-solid mass rich in

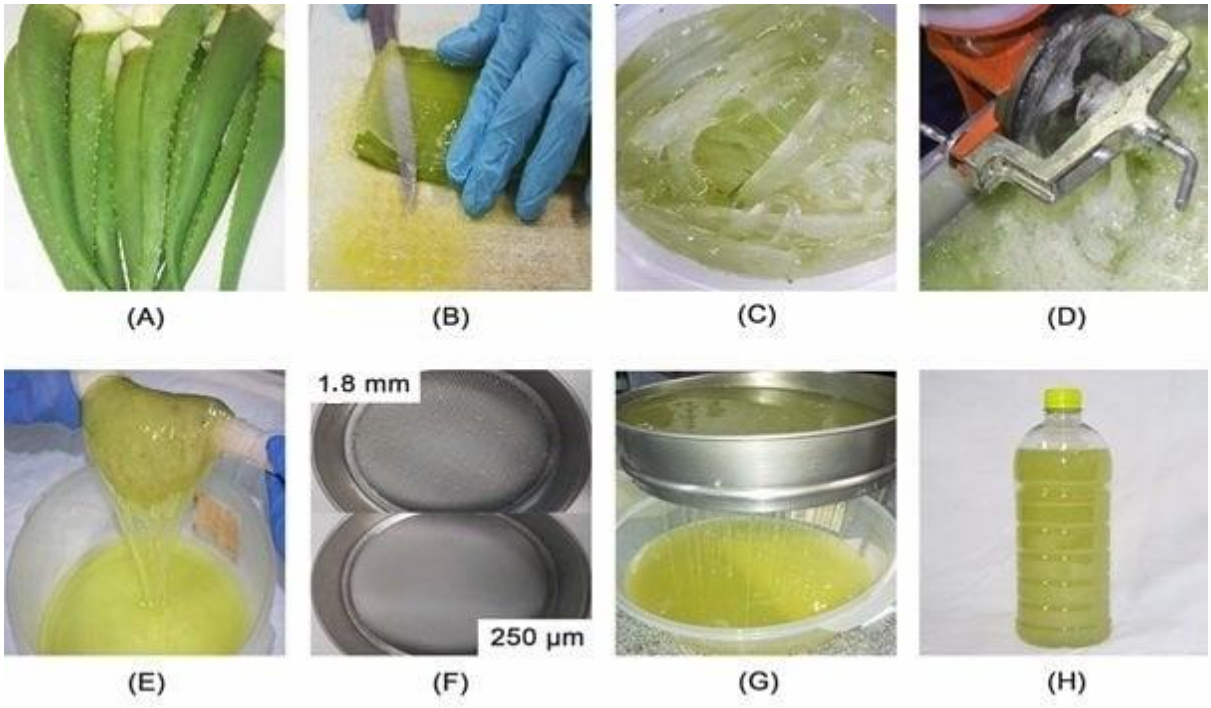
bioactive constituents such as flavonoids, tannins, and phenolic compounds. The concentrated extract was stored in airtight containers at 4°C until further use.[19,20,21]

2.3.2 Azadirachta indica (Neem Extract)



Dried neem leaves (125 g) were finely powdered using a mechanical grinder. The powdered material was soaked in 600 mL of 80% ethanol and subjected to maceration for 24 hours with intermittent stirring to enhance solvent penetration and phytochemical release. The mixture was filtered through muslin cloth followed by Whatman filter paper. The filtrate was concentrated under vacuum at 45°C to obtain a semi-solid extract. The extract was preserved in sterile amber-colored containers to prevent photodegradation.

2.3.3 Aloe barbadensis miller (Aloe Vera Gel)



Fresh Aloe vera leaves (150 g) were thoroughly washed with distilled water to remove adhering impurities. The outer rind was carefully removed, and the inner mucilaginous gel was collected. The gel was homogenized and filtered through muslin cloth to eliminate insoluble fibers. To prevent oxidative degradation and microbial contamination, 0.5% (w/w) citric acid was incorporated as a preservative. The prepared gel was stored at refrigerated conditions (4°C) until formulation.

2.3.4 Punica granatum (Pomegranate Peel Extract)

Dried pomegranate peels (100 g) were ground into a fine powder. The powdered material was soaked in 500 mL of 80% ethanol and macerated for 24 hours with occasional shaking. The mixture was filtered, and the solvent was removed under reduced pressure using a rotary vacuum evaporator at 40°C. The concentrated extract, rich in polyphenols and tannins, was collected and stored in airtight amber containers until use.

2.3.5 Eucalyptus globulus (Eucalyptus Oil)

Fresh eucalyptus leaves (50 g) were subjected to steam distillation for 4 hours using a Clevenger-type apparatus. The condensed vapors were collected, and the essential oil was separated from the aqueous phase using a separating funnel. The obtained oil was dried over anhydrous sodium sulfate to remove moisture and stored in amber-colored bottles at room temperature to prevent oxidation and photodegradation.

2.3.6 Syzygium aromaticum (Clove Oil)

Dried clove buds (40 g) were subjected to steam distillation for 4 hours. The distillate was collected, and the essential oil layer was separated from the aqueous layer. The extracted clove oil, containing eugenol as the principal bioactive component, was stored in amber-colored airtight containers at ambient temperature to maintain stability.

2.4 Formulation of Polyherbal Gel

Four different formulations (F1–F4) were prepared to optimize the concentration of active ingredients and excipients. Carbopol 940 was used as the gelling agent, PEG-400 as a co-solvent and humectant, sorbitol as a sweetening and moisturizing agent, triethanolamine as a pH adjuster, and sodium benzoate as a preservative. Chlorophyll extract was added as a natural coloring agent. Distilled water was added quantity sufficient (q.s.) to make 100 g of each formulation.

Table 10: Formulation Composition (per 100 g)

Ingredient	F1	F2	F3	F4
Guava Leaf Extract	2 g	3 g	5 g	6 g
Neem Extract	2 g	3 g	4 g	5 g
Aloe Vera Gel	10 g	7 g	5 g	4 g
Pomegranate Peel Extract	1.5 g	2 g	3 g	4 g
Eucalyptus Oil	0.5 g	0.7 g	1 g	1.2 g
Clove Oil	0.3 g	0.5 g	0.8 g	1 g
Carbopol 940	0.8 g	1 g	1.2 g	1.5 g
PEG-400	10 g	12 g	15 g	18 g
Sorbitol	5 g	7 g	8 g	10 g
Triethanolamine	0.5 g	0.7 g	1 g	1.2 g
Sodium Benzoate	0.2 g	0.3 g	0.3 g	0.3 g
Chlorophyll Extract	0.3 g	0.5 g	0.8 g	1 g
Distilled Water	Q.S. to 100 g	Q.S. to 100 g	Q.S. to 100 g	Q.S. to 100 g

The variation in concentrations across F1–F4 allowed comparative evaluation of physicochemical properties, stability, antimicrobial activity, and overall formulation performance.

2.5 Method of Preparation

The herbal dental gel was formulated using a systematic stepwise procedure to ensure uniformity, stability, and optimal therapeutic performance. The preparation method is summarized in Figure and described below.

2.5.1 Step 1: Preparation of the Aqueous Phase

Initially, 50% of the required quantity of distilled water was transferred into a sanitized mixing vessel. Continuous stirring was initiated to facilitate the dissolution of **Sodium Benzoate** as a preservative. Subsequently, **Sorbitol** and **PEG-400** were added and mixed until complete dissolution was achieved. Chlorophyll extract was then incorporated into the solution under constant stirring to ensure uniform dispersion.

2.5.2 Step 2: Formation of Gel Base

Carbopol 940 was gradually sprinkled into the continuously stirred aqueous solution to prevent lump formation. Stirring was maintained until complete hydration occurred and a smooth, uniform gel-like consistency was obtained. Proper dispersion of Carbopol is critical for achieving the desired viscosity and stability of the formulation.

2.5.3 Step 3: Addition of Active Herbal Components

The active herbal extracts—Guava Leaf Extract, Neem Extract, and Pomegranate Peel Extract—were added gradually into the gel base under continuous stirring. Aloe vera gel was incorporated thereafter. The mixture was stirred thoroughly to ensure homogenous distribution of all herbal components within the gel matrix, preventing phase separation and ensuring uniform therapeutic efficacy.

2.5.4 Step 4: Incorporation of Essential Oils

To enhance solubility, Eucalyptus oil and Clove oil were pre-mixed with a small quantity of PEG-400. This blend was added slowly to the gel base under constant stirring to ensure even distribution and to prevent oil separation. Uniform mixing at this stage is essential to maintain consistency and organoleptic properties.

2.5.5 Step 5: pH Adjustment

The pH of the formulation was measured using a calibrated digital pH meter. The desired pH range (6.5–7.5) was maintained to ensure compatibility with the oral cavity and stability of the formulation. Triethanolamine (TEA) was added dropwise under continuous stirring until the target pH was achieved. Proper pH adjustment also promotes gel neutralization and optimal viscosity development.

2.5.6 Step 6: Final Volume Adjustment and Homogenization

The remaining quantity of distilled water was added to adjust the final weight to 100 g. The formulation was then subjected to homogenization at controlled speed to achieve complete uniformity. The prepared gel was allowed to stand undisturbed for 24 hours to eliminate entrapped air bubbles and to ensure complete hydration and stabilization of the gel network.

3. Evaluation of Formulation

The evaluation of the herbal dental gel was conducted to assess its physicochemical properties, stability, safety, and therapeutic effectiveness. Parameters such as appearance, homogeneity, pH, viscosity, spreadability, extrudability, antimicrobial activity, and stability studies were considered to ensure product quality and performance. Comprehensive evaluation is essential to confirm that the formulated gel meets pharmaceutical standards and is suitable for oral application.

4. Results and Discussion

4.1 Extraction Process

The extraction of herbal raw materials was performed using method-specific techniques to ensure maximum recovery and preservation of bioactive constituents. Soxhlet extraction was employed for *Psidium guajava* (Guava leaf) and *Azadirachta indica* (Neem), enabling exhaustive extraction of moderately polar phytoconstituents such as flavonoids, tannins, glycosides, and alkaloids. The continuous solvent reflux cycle in Soxhlet ensured enhanced mass transfer and improved extraction efficiency compared to conventional maceration.

Pomegranate peel extract was obtained via maceration, a technique suitable for preserving thermolabile polyphenols and ellagitannins while ensuring high yield. Essential oils from eucalyptus and clove were extracted through steam distillation, facilitating isolation of volatile constituents such as eugenol and 1,8-

cineole without significant degradation. Aloe vera gel was processed under cold conditions to prevent denaturation of polysaccharides (acemannan) and enzymatic components responsible for wound healing and anti-inflammatory activity.

Overall, extraction methods were appropriately selected based on phytochemical nature and thermal stability. Preliminary qualitative analysis confirmed acceptable purity and preservation of characteristic phytoconstituents, supporting their suitability for formulation development.

4.2 Evaluation

4.2.1 Phytochemical Analysis

Qualitative phytochemical screening revealed the presence of alkaloids, flavonoids, tannins, saponins, phenolic compounds, terpenoids, and glycosides in varying proportions across the extracts. Phenolic compounds were consistently present in all ingredients, indicating strong antioxidant and antimicrobial potential. Flavonoids and tannins were abundant in guava, neem, and pomegranate extracts, supporting their role in antibacterial and anti-inflammatory activity. Terpenoids were prominent in neem and essential oils, contributing to antimicrobial efficacy.

The synergistic presence of phenols, flavonoids, and terpenoids suggests a multi-target antimicrobial mechanism involving membrane disruption, enzyme inhibition, and oxidative stress induction in pathogens. Aloe vera contributed saponins and phenolic compounds, enhancing wound healing and soothing properties. The overall phytochemical profile validates the rationale for combining these extracts in a polyherbal dental gel.

4.2.2 Physicochemical Evaluation

All formulations (F1–F4) demonstrated acceptable organoleptic characteristics, including smooth texture, uniform consistency, and characteristic herbal odor. Progressive darkening of color from F1 to F4 correlated with increasing guava extract concentration.

The pH values (6.8–7.1) were within the physiologically acceptable oral range (6.5–7.5), minimizing risk of enamel demineralization or mucosal irritation. A gradual increase in viscosity (4500–4800 cps) was observed with higher extract concentration, likely due to increased solid content and interaction with the Carbopol 940 polymeric network. Conversely, spreadability and extrudability showed a slight decline with increasing viscosity, although values remained within acceptable limits for patient compliance.

No phase separation, syneresis, or microbial spoilage was observed during stability testing, indicating adequate formulation robustness. The controlled neutralization of Carbopol 940 with triethanolamine contributed to optimal gel consistency and mucoadhesive characteristics.

4.2.3 Microbiological Evaluation

The antimicrobial efficacy of the formulations was assessed against *Streptococcus mutans*, *Staphylococcus aureus*, and *Candida albicans*, key pathogens implicated in dental caries, periodontal infections, and oral candidiasis.

A concentration-dependent increase in antimicrobial activity was observed from F1 to F4. Formulation F4 demonstrated the largest zones of inhibition (20 mm for *S. mutans*, 16 mm for *S. aureus*, and 14 mm for *C. albicans*), indicating superior antimicrobial performance. This enhanced activity may be attributed to higher phytoconstituent concentration, particularly flavonoids, tannins, eugenol (clove oil), and cineole (eucalyptus oil), which exert bactericidal and fungicidal effects via membrane disruption and protein denaturation.

Total microbial load testing showed all formulations were within pharmacopeial limits. F4 exhibited the lowest total bacterial (70 CFU/g) and fungal counts (5 CFU/g), reflecting both effective preservation and intrinsic antimicrobial properties.

The mucoadhesive gel base prolonged contact time between active constituents and oral tissues, potentially enhancing antimicrobial action and therapeutic persistence. The Carbopol-based matrix likely facilitated sustained release of phytochemicals, contributing to prolonged inhibition of oral pathogens.[22,23,24,25,26]

4.2.4 Comparative Analysis of Formulations

Comparative evaluation indicated that F3 provided an optimal balance between viscosity, spreadability, antimicrobial activity, and user acceptability. Although F4 demonstrated superior antimicrobial activity, its higher viscosity and reduced extrudability may slightly affect patient convenience.

F3 exhibited strong mucoadhesive behavior, adequate antimicrobial efficacy (17 mm against *S. mutans*), desirable physicochemical properties, and stability, making it the most suitable formulation for further preclinical and clinical evaluation. The results suggest that moderate concentration optimization enhances performance without compromising handling characteristics.

Overall Discussion

The polyherbal dental gel demonstrated significant antimicrobial, physicochemical, and stability characteristics suitable for oral application. The synergistic combination of plant-derived bioactives provided broad-spectrum antimicrobial activity while maintaining biocompatible pH and acceptable rheological properties.

The incorporation of Carbopol 940 conferred desirable viscosity and mucoadhesion, promoting prolonged retention at the site of action and sustained release of active compounds. The study supports the potential of polyherbal formulations as safer and effective alternatives to synthetic antimicrobial dental products, with reduced risk of adverse effects and microbial resistance.

Further studies involving in vivo evaluation, long-term stability analysis, and clinical trials are recommended to substantiate therapeutic claims and commercial viability.

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