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A REVIEW ON HERBAL pH-RESPONSIVE GEL FOR EARLY CARIES DETECTION AND CONTROL.

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Abstract: The oral pH plays a critical role in the development of dental caries. This review discusses the rational for a novel, 100% natural, pH-sensitive herbal tooth gel that incorporates anthocyanin-rich plant extracts (e.g., a pigmented fruit source peel, a pigmented flower source) for foam colour change in response to oral pH. Additionally, it explores the antibacterial potential of an herbal antimicrobial agent and a natural antimicrobial herb, which are known to exhibit enhanced activity in acidic conditions. While this paper reviews the scientific background and existing literature, the proposed formulation is yet to be experimentally developed. The formulation and evaluation will be carried out as part of our upcoming research work, aiming for a potentially patentable product in natural oral care.

Index Terms - Acid-triggered therapy, Antibacterial activity, Anthocyanin sensors, Foam-based visualisation, Oral microbiome control, Smart oral care.

1. INTRODUCTION:

Dental caries, commonly referred to as tooth decay, is one of the most prevalent chronic diseases worldwide, affecting individuals across all age groups. It arises primarily due to the prolonged exposure of tooth surfaces to acids produced by bacterial fermentation of dietary sugars. This acidic environment, particularly when the pH level drops below 5.5, leads to the demineralisation of tooth enamel and the initiation of carious lesions. Despite the widespread availability of oral hygiene products, the early detection of such acidic conditions within the oral cavity remains limited. Traditional oral care solutions, such as toothpaste and mouthwashes, mainly focus on the mechanical removal of plaque and generalised antimicrobial action. However, they cannot inform users about the pH status of their oral environment, especially at a local level where decay often begins. Visual and real-time pH monitoring through daily oral care routines could be a transformative step in preventive dentistry.

In recent years, growing interest in natural, chemical-free, and sustainable products has led researchers to explore plant-derived ingredients for oral care. Anthocyanins, the pH-sensitive pigments found in various fruits and flowers, offer a unique solution by undergoing distinct colour changes across different pH ranges. This visibly alerts users to harmful acidic conditions through colour changes in foam during brushing. At the same time, plant-based actives like an herbal antimicrobial agent (an herbal antimicrobial agent) and a natural antimicrobial herb (a natural antimicrobial herb) have been extensively studied for their antimicrobial, anti-inflammatory, and antioxidant properties. Interestingly, these compounds demonstrate enhanced antibacterial action in acidic conditions, which often correspond to areas of decay within the mouth. Thus, incorporating them into a pH-sensitive formulation adds a dual-action benefit — detection and treatment. This review consolidates current knowledge on the pH-responsive anthocyanins property, which can be harnessed to create a pH-responsive gel that, especially those derived from a pigmented fruit source peel and a pigmented flower source, along with the oral health benefits of an herbal antimicrobial agent and a natural antimicrobial herb. It proposes a novel, 100% herbal formulation that combines foam-based pH visualisation with localised antibacterial action for early caries intervention. The actual formulation and experimental validation are yet to be performed and will form the next phase of this ongoing research project. The review also explores the patent landscape to support the novelty and potential patentability of this concept. (Abedi-Firoojah et al, 2022; Choi et al, 2017; Gtie`rrez et al, 2022; Ke et al, 2024; Ndwandwe et al, 2024; Xu et al, 2025)

2. ROLE OF pH IN ORAL HEALTH:

The pH of the oral cavity plays a critical role in maintaining dental and periodontal health. A healthy oral environment typically maintains a neutral pH range between 6.5 and 7.5. This balance is essential for preserving the integrity of tooth enamel, preventing demineralisation, and limiting bacterial overgrowth. When the pH drops below 5.5, an acidic environment is created, often due to bacterial metabolism of dietary sugars. This acidic condition favours the growth of acidogenic and aciduric bacteria such as Streptococcus mutans and Lactobacillus species, which are strongly associated with dental caries.

In this state:

- Enamel demineralisation begins, increasing the risk of cavities.
- Remineralisation is hindered due to the loss of calcium and phosphate ions.
- Pathogenic bacteria thrive, leading to biofilm formation, inflammation, and potential gum disease.

Moreover, fluctuations in salivary pH throughout the day — caused by food intake, microbial activity, or systemic health — can go unnoticed by individuals until visible signs of decay or discomfort appear. This is why real-time monitoring of oral pH becomes essential in preventive dental care. Recent advancements in oral care are exploring pH-sensitive materials and delivery systems that respond dynamically to the oral environment.

Such systems could help:

- Visually indicate acidic conditions during brushing through colour changes.
- Activate targeted antimicrobial ingredients (e.g., an herbal antimicrobial agent, a natural antimicrobial herb) only in low pH conditions, reducing unnecessary exposure.
- Encourage users to adjust their oral hygiene behaviour (brushing frequency, diet, etc.).

Thus, a pH-responsive tooth gel not only offers therapeutic benefits but also serves as an early-warning diagnostic tool, empowering individuals to act before irreversible damage occurs. (Dawes, 2008; Featherstone, 2004; Kuriakose & Sundaresan, 2014; Shellis et al, 2014; Ten Cate, 2001; Turtola et al, 1985)

3. ANTHOCYANINS AS NATURAL pH INDICATORS:

Anthocyanins are naturally occurring water-soluble pigments that belong to the flavonoid group of polyphenolic compounds, abundantly found in plants such as a pigmented fruit source, a pigmented flower source (butterfly pea), a pigmented botanical source, Rosa sinensis, a natural anthocyanin source, and a naturally pigmented source. They are responsible for the red, purple, and blue hues in fruits and flowers, and have emerged as promising natural pH indicators due to their unique colour-changing properties in response to pH fluctuations. The pH-responsive behaviour of anthocyanins is due to their ability to undergo structural transformations at different pH levels.

These changes affect their visible colour:

- Acidic pH (< 3): Bright red (flavylium cation form)
- Slightly Acidic (pH 4–6): Purple to violet (quinoidal base form)
- Neutral to slightly alkaline (pH 7–8): Blue (anionic form)
- Alkaline pH (> 9): Green/yellow (chalcone form)

In our upcoming research project, we aim to harness anthocyanins as natural pH indicators in the development of a 100% natural, pH-sensitive herbal tooth gel. The color change will not only visually represent the oral pH (especially acidic conditions indicating potential enamel demineralization or bacterial growth), but also signal the activation of herbal antibacterial agents, such as an herbal antimicrobial agent (an herbal antimicrobial agent) and a natural antimicrobial herb (a natural antimicrobial herb).

We intend to:

- Extract anthocyanins from natural sources like a pigmented fruit source peel, a pigmented flower source, or a pigmented botanical source.
- Incorporate these into a gel base (e.g., aloe vera, xanthan gum) along with natural antimicrobial herbs.
- Evaluate the pH-dependent colour change of the foam during brushing.
- Assess stability, bioactivity, and user acceptance of the formulation.
- Investigate the synergistic antibacterial effect of anthocyanins and herbs against acid-producing oral pathogens.

This approach may not only help in the early detection of acidic oral environments (a risk factor for tooth decay) but also offer a natural, eco-friendly, and patient-friendly oral hygiene product. (Alizadeh et al, 2020; Khoo et al, 2017; Talukder et al, 2019)

4. FOAM-BASED pH VISUALIZATION:

Foam plays a significant role in oral hygiene products, not only by improving user experience and cleansing efficacy but also as a potential visual feedback medium. In conventional toothpastes and gels, foam formation is primarily a result of surfactants like sodium lauryl sulfate (SLS). However, in natural formulations, milder plant-based surfactants (e.g., plant-based surfactants or natural foaming agents) can be used to achieve foaming while maintaining biocompatibility and safety.

In our planned research, we propose to utilise foam as a real-time visual indicator of oral pH, leveraging its colour-changing potential through the incorporation of pH-sensitive natural dyes, especially anthocyanins. Anthocyanins, when dissolved in aqueous gels and then agitated during brushing, can cause the resulting foam to change colour based on the acidity of the oral environment: In an acidic mouth (pH < 5.5), the foam would appear pink or red, indicating potential enamel demineralisation or early-stage tooth decay. In a neutral or healthy pH (6.5–7.5), the foam remains purple or blue, suggesting a balanced oral microbiome. In a more alkaline pH (>8) (less common), the foam may turn greenish or yellow, indicating an environment unfavourable for decay-causing bacteria. This approach combines sensory alertness with clinical significance, empowering users to monitor oral health dynamically at home. Our future research aims to formulate a natural, foaming tooth gel using saponins or other plant-derived surfactants. Incorporate stable anthocyanin extracts from sources like a pigmented flower source, a pigmented fruit source peel, or a natural anthocyanin source. Optimise pH response ranges to target clinically relevant thresholds for oral health (particularly the critical pH of 5.5 for enamel demineralisation).

Study colour stability, foam density, and user response under varying pH conditions using in vitro simulated saliva models. Combine this with antibacterial herbs like a natural antimicrobial herb and an herbal antimicrobial agent, which activate in acidic environments and combat oral pathogens. (Abedi-Firoozjah et al, 2022; Song et al, 2020)

5. ANTIBACTERIAL AGENTS IN HERBAL ORAL CARE:

Oral infections such as dental caries, gingivitis, and periodontitis are primarily caused by the proliferation of pathogenic bacteria, particularly in acidic microenvironments. Herbal medicine offers a sustainable, biocompatible, and effective alternative to synthetic antimicrobials, which are increasingly challenged by issues like bacterial resistance and cytotoxicity. A number of medicinal plants have shown strong efficacy in inhibiting acidogenic and proteolytic bacteria such as Streptococcus mutants, Lactobacillus acidophilus, Porphyromonas gingival is, and Antinomies spp.

In our upcoming research, we propose incorporating pH-activated herbal agents that show enhanced action in acidic environments, aligning with early detection and treatment of dental caries.

1. A herbal antimicrobial agent (an herbal antimicrobial agent) Major active compound: an active herbal compound. Actions: Broad-spectrum antibacterial, anti-inflammatory, antioxidant. Specifics: Effective against S. mutans and P. gingivalis; an active herbal compound-loaded formulations are known to be more active at slightly acidic pH levels, making it ideal for caries-prone conditions.
2. A natural antimicrobial herb (a natural antimicrobial herb) Major active compounds: an active plant compound, ursolic acid, rosmarinic acid. Actions: Antibacterial, immunomodulatory, antifungal. Specifics: Inhibits S. mutans, Candida albicans, and several anaerobic pathogens linked to halitosis and gingivitis. (an herbal antimicrobial agent and a natural antimicrobial herb; both the herbs act more potently in acidic environments, making them ideal for targeting decayed areas.)
3. A plant-based extract (a plant-based extract) Actions: Potent antibacterial and antifungal agent with astringent properties. Specifics: Used in mouthwashes and gels; inhibits S. mutans adhesion and biofilm formation.

4. A natural root extract (a natural root extract) Actions: Antimicrobial, demulcent, and anti-inflammatory Specifics: Glycyrrhizin in a natural root extract inhibits L. acidophilus and S. mutants and reduces plaque Accumulation.
5. A botanical antimicrobial (a botanical antimicrobial) Active: an active plant compound. Actions: Strong antibacterial and analgesic; commonly used in dental pain relief.
In our proposed research, we aim to explore how these herbal actives behave in varying pH environments, particularly whether they exhibit increased antibacterial activity in acidic saliva conditions, thereby offering targeted therapy for early-stage dental lesions. This aligns with our concept of a pH-responsive herbal tooth gel where both visual (colour change via anthocyanins) and therapeutic (antibacterial via an herbal antimicrobial agent, a natural antimicrobial herb) actions are activated under acidic conditions. Combining natural pH indicators with pH-responsive antibacterial herbs may result in a truly intelligent oral care formulation—one that not only shows users the problem (acidic saliva) but also initiates treatment at the site. (Cury & Tenuta, 2017; Patil & Patil, 2010; Prakash & Gupta, 2005)

6. DECAY RESPONSIVE ANTIBACTERIAL ACTION:

Dental decay (caries) is closely associated with localised acidification of the oral environment, primarily due to acidogenic bacteria such as Streptococcus mutants and Lactobacillus spp. These organisms metabolise dietary carbohydrates, producing lactic and acetic acids that reduce the pH of plaque biofilm to below 5.5, a threshold at which enamel demineralisation begins. The formulation we aim to create is designed to respond specifically to decayed areas where the pH is low, allowing colour change and localised treatment. This mechanism will be tested during in vitro and possibly ex vivo evaluations as a part of our future experiments. (Bose et al, 2014; Mondal et al, 2009; Prakash & Gupta, 2005; Singh & Majumdar, 1999; Teow et al, 2016)

7. LITERATURE REVIEW AND GAPS:

In recent years, oral care science has seen increasing interest in smart delivery systems capable of responding to physiological triggers like pH fluctuations. pH-sensitive hydrogels, polymers, and films have been extensively studied for drug delivery and wound care, with some applications extending into oral hygiene. Natural pH indicators such as anthocyanins from plant sources (e.g., a natural anthocyanin source, a pigmented fruit source peel, butterfly pea, and a naturally pigmented source) have been shown to exhibit visible colour changes across a wide pH range (3–10). These pigments offer eco-friendly and safe alternatives to synthetic indicators and are being integrated into sensor films, edible packaging, and food-grade diagnostics. A naturally pigmented source of anthocyanins in pH-responsive films: Zhai et al., Food Chem, 2020. Anthocyanin sensors from butterfly pea: Hosseini et al., Sensors & Actuators B, 2021. Meanwhile, herbal extracts such as an herbal antimicrobial agent (an herbal antimicrobial agent), a natural antimicrobial herb (a natural antimicrobial herb), and a plant-based extract (a plant-based extract) have been widely reported for their antibacterial, antioxidant, and anti-inflammatory properties. An herbal antimicrobial agent, in particular, has demonstrated pH-dependent antibacterial activity against Streptococcus mutans, becoming more active in acidic environments. An active herbal compound and acid stress response in S. mutans: a natural antimicrobial herb extract against S. mutans.
While individual studies have explored:
• pH-responsive colourimetric indicators for food and biomedical use,
• Natural antibacterial oral formulations (e.g., gels, pastes, and mouthwashes),
• Anthocyanins in pH-indicating packaging or sensors,
There remains a significant gap in integrating all these elements into a single, user-interactive oral care product.

8. RESEARCH GAPS

1. Lack of pH-Sensitive Colour-Changing Tooth Gels. While colourimetric films and sensors have been developed, no widely reported herbal-based tooth gel formulation exists that combines pH-sensitive foam colour change and targeted antibacterial action for decayed regions.
2. Limited Use of Anthocyanins in Oral Hygiene. Most applications of anthocyanins focus on food freshness detection. Their role in indicating acidic oral microenvironments visually during brushing remains largely unexplored.
3. No Patent-Filed Products Combining Colour Change with pH-Triggered Herbal Antibacterial Effects. While isolated elements like an active herbal compound, gels or herbal pastes exist, an integrated system that visualises oral pH while simultaneously releasing antibacterial agents has not yet been patented or commercialised.

4. Lack of Foam-Based Visual Feedback Mechanisms. Most visual detection methods are surface-based films. Using foam as a visualising medium, where the foam colour changes according to oral pH, is a novel approach with minimal documentation in existing literature.
5. Unexplored Synergy of a natural antimicrobial herb and an herbal antimicrobial agent in Acidic Conditions. Although both herbs are well-known in Ayurveda, their combined, pH-dependent antibacterial performance in tooth gels has not been extensively studied or validated.
This is how Our Proposed Research Will Fill the Gaps, our review highlights the unmet need for a 100% natural, foam-based, pH-sensitive herbal tooth gel that:
• Changes foam colour based on the mouth's pH using anthocyanin indicators,
• Releases antibacterial actives like an herbal antimicrobial agent and a natural antimicrobial herb in response to acidic pH in decayed zones,
• Provides visual self-monitoring and targeted therapy during brushing,
• Can be formulated without synthetic additives, making it safe, eco-friendly, and patentable. This approach bridges cosmetic, diagnostic, and therapeutic dimensions of oral care in one formulation, creating opportunities for preventive healthcare, pediatric oral care, and self-guided caries detection.

9. INNOVATION STATEMENT:

This work introduces a novel, patentable approach in the field of natural oral care by proposing the development of a 100% herbal tooth gel that combines pH-responsive foam-based colour change with targeted antibacterial action using natural plant extracts such as an herbal antimicrobial agent and a natural antimicrobial herb. While natural ingredients have long been used in dental products for their antibacterial benefits, and anthocyanins are known for their pH-responsive colourimetric properties, no existing formulation integrates these elements into a user-interactive, visual feedback system during brushing.

Our proposed formulation aims to:

• Visually indicate the oral pH condition through colour change in the foam, enhancing user awareness of oral health;
• Activate localised antibacterial action specifically in acidic (decayed) zones, leveraging the enhanced activity of an herbal antimicrobial agent and a natural antimicrobial herb in low pH environments;
• Remain completely natural, avoiding synthetic surfactants, artificial colours, or preservatives.

This innovation bridges diagnostic, preventive, and therapeutic dimensions of oral care within a single product. It presents a novel concept not only in herbal dentistry but also in responsive self-care technologies, with significant potential for patentability, commercialisation, and public health impact, especially for early detection and prevention of dental caries.

10. RESEARCH PLAN:

In our future research project, we propose to:
• Extract and stabilise anthocyanins from a pigmented fruit source peel or a pigmented flower source.
• Prepare an herbal gel base with natural foaming agents.
• Incorporate an herbal antimicrobial agent and a natural antimicrobial herb extract.

Evaluate:

• pH-dependent colour change of foam
• Antibacterial effect at varying pH levels
• Safety and stability of the formulation.

11. PATENTABILITY SCOPE:

The proposed formulation introduces a novel, multifunctional herbal tooth gel with the following unique and patentable features:
1. pH-Sensitive Foam Colour Change: Utilises natural anthocyanin extracts (e.g., a pigmented fruit source peel, a pigmented flower source) to visually indicate oral pH through foam colour, enhancing user awareness of oral hygiene status.
2. Decay-Responsive Antibacterial Action: Incorporates an herbal antimicrobial agent and a natural antimicrobial herb that are activated or more effective in acidic conditions, targeting bacterial activity specifically in decayed or caries-prone areas.
3. 100% Natural & Eco-Safe Composition: Free from synthetic surfactants, colourants, preservatives, or fluoride—suitable for long-term use and safe for all age groups.
4. Dual-Function Mechanism: Combines diagnostic (colour change) and therapeutic (antibacterial) action in a single self-care product, which is currently unexplored in natural oral formulations.

5. User-Interactive Technology: Introduces a visual feedback mechanism via foam, a novel application method not covered by existing natural dental products.

12. PATENTABILITY POTENTIAL

• Novelty: No current marketed or patented product combines natural pH-responsive foam colour change with decay-activated antibacterial action in a 100% herbal tooth gel.
• Utility: Enhances preventive oral care by early identification of acidic conditions.
• Non-obviousness: Integration of pH-indicating foam and herbal antibacterials in one system for visual and localised action is not evident from existing literature or products.
This concept has strong potential for intellectual property protection under categories like:
• Composition of matter
• Method of treatment
• Diagnostic oral care formulation
• Use of specific anthocyanin sources in toothpaste/gel.

13. CONCLUSION:

This review lays the groundwork for a novel herbal tooth gel that functions as both a pH-sensitive diagnostic tool and a site-specific herbal antimicrobial therapy. The formulation is still under development and will be prepared, tested, and validated in our upcoming research work. Once successful, it holds strong potential for patentability and commercialisation in the herbal oral care space.

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