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*Original article*

# Pharmaceutical Evaluation of Physical Properties and Antimicrobial Activity of Selected Commercial Toothpaste Formulations in Tripoli Market

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**Abstract**
*Nowadays, there is a wide range of toothpaste formulations available, each designed to address specific oral health concerns and sourced from different countries at different prices. This variety can often create confusion for consumers, as differences in composition, functional properties, and claimed benefits make it difficult to choose the best product for optimal oral hygiene with desirable attributes. This study aimed to evaluate and compare the physical, organoleptic, and antimicrobial properties of twelve toothpaste formulations in the Tripoli market to assess their quality, consistency, suitability for consumer use, and therapeutic potential from a pharmaceutical perspective. Samples were compared and evaluated according to their organoleptic characteristics qualitatively (appearance, color, odor, texture, extrudability, and taste), physical parameters quantitatively were performed (spreadability, foaming ability, pH, and moisture content). Antimicrobial efficacy was also evaluated using the agar well diffusion method. All formulations demonstrated acceptable properties, most of which exhibited a paste-like appearance and pleasant odors. Spreadability ranged from 4 to 7.1 cm, pH values ranged from 5.83 to 9.47, indicating mildly alkaline to highly alkaline formulations. Foaming ability varied significantly from 50 to 81 ml, with sample 9 showing the highest foam volume, and moisture content varied from 25.77% to 38.01%. Antimicrobial testing revealed significant activity in selected formulations, with inhibition zones reaching up to 19.22 mm against Streptococcus aureus, 14.55mm against Streptococcus mutans, 12.31 mm against Fusobacterium nucleatum, and 11.23mm against Candida albicans. Toothpaste number 4 demonstrated superior inhibition zones against all microorganisms but was characterized by an acidic pH of 5.83 and a high moisture content of 38.01%. In contrast, toothpastes like 11 and 12 showed minimal antimicrobial activity. Substantial differences were observed among the tested toothpaste while most met acceptable criteria. Several products showed promising inhibitory effects against common oral pathogens, suggesting added therapeutic benefits. These findings emphasize the importance of combining physicochemical evaluation with microbiological testing in quality control and standardization of semisolid pharmaceutical formulations such as toothpaste to ensure consistent efficacy and patient safety.*
***Keywords:*** *Toothpaste, Pharmaceutical Evaluation, Physicochemical Properties, Antimicrobial Activity*

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## Introduction
Toothpaste, classified as a semi-solid substance utilized to eliminate accumulated residues on teeth and enhances an individual's oral health without causing harm to surrounding tissues [1]. In addition to improving taste and smell, toothpaste and its use in conjunction with a toothbrush are responsible for the removal of bacteria and dental plaque from the oral environment [2]. By acting as an abrasive to remove food particles and dental plaque from teeth, toothpaste helps to benefit the oral cavity by maintaining health and appearance [3,4]. Since ancient times, toothpaste has been an irreplaceable component of oral health care [5].
Issues such as tooth decay, bad breath, tooth sensitivity, periodontal gum disease, and dental caries can arise because of microbial activity within the oral cavity [6,7]. Microbial dental plaque is commonly recognized as the main cause of dental caries and periodontal diseases, both of which are prevalent in societies at a high frequency [8]. Moreover, toothpaste has been recognized as the most valuable, widely used cosmetic and therapeutic agent in daily life, containing a variety of active and inactive ingredients in different amounts [9,10].
Nowadays, toothpaste is made by manufacturing companies in different forms for a specific purpose. Some manufacturers market low-fluoride toothpaste for kids that contains less than 600 ppm fluoride. Sensitive toothpaste is formulated to relieve the pain. Whitening toothpaste has fluoride and an enzyme system. Natural toothpaste made from herbal extracts. Toothpastes consist of abrasives, detergents, flavouring, coloring agents, sweeteners, binding agents, humectants, preservatives, fluoride, antiplaque agents, anti-calculus agents, herbal extracts, and water. The following ingredients make them up, though the quality and quantity of each ingredient differ between brands [4,11]. To overcome the problem of bacterial infection,

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it is recommended for the patient to use toothpaste with antibacterial activity. Active and inactive ingredients, like the excipient, are found in the majority of toothpastes on the market today. The majority of people do not understand the long-term effects of using commercial toothpastes, which is currently the issue. This is because the marketed toothpastes contain substances that are considered unhealthy and could cause future health problems [4]. Various synthetic chemical agents having antimicrobial activity in cosmetic products like toothpaste are a critical issue in our world today because of their adverse effects on human health [12,13].
The performance of toothpaste is determined by its composition and its physicochemical properties. Important factors that affect the products therapeutic effectiveness, stability, and consumer compliance include pH, spreadability, foaming ability, and moisture content. To prevent bacterial growth and maintain the integrity of enamel for instance a slightly alkaline pH should be maintained. The product sensory appeal and user satisfaction are enhanced by suitable foaming and organoleptic qualities while sufficient spreadability guarantees even application across the tooth surface [14,15].
Despite the widespread use of toothpastes from different manufacturers with various prices, there is limited comparative data on the physical and sensory properties of different commercial toothpaste formulations, especially in emerging markets. The present study aims to evaluate and compare twelve commercially available toothpaste products in the Libyan market based on key physical, organoleptic, and formulation parameters, as well as assessing antimicrobial activities against four pathogens associated with dental caries and periodontal diseases using the agar well diffusion method. The goal was to provide pharmacists with valuable insight into the quality and consistency of these products, identify any significant differences, and highlight the importance of standardized formulation in ensuring efficacy and consumer acceptability, as well as provide therapeutic potential beyond cleaning.

## Materials and methods

### *Sample collection*

A group of twelve toothpastes from different manufacturing brands containing different materials according to the country of manufacture was collected randomly and purchased from various local markets in Tripoli to conduct several tests for their quality by different methods of analysis. All samples were within their shelf life and stored at room temperature in their original packaging before analysis.
The general information of each marketed toothpaste was listed in (Table 1), and the ingredients of each toothpaste were listed in (Table 2).

### *Sample coding and evaluation*

The collected toothpastes were numbered and evaluated regardless of the names and sources according to the standard specifications, for their physicochemical properties, including organoleptic characterization, pH measurement, spreadability, and moisture content percentage. Also, to assure the quality of the products, specific tests for toothpastes, including determination of foaming ability, extrudability, antimicrobial activity, as well as label information, were carried out. All tests were conducted under standardized conditions and three times for all parameters measured to ensure reliability.

### *Materials and equipment's*

Material used includes distilled water, 0.9% NaCl saline solution, 0,2% chlorohexidine evaporating dish, oven, measuring cylinder 250 ml, nutrient agar plates, and butter paper.

***Table 1: General information on twelve different Toothpastes used during the research work***

| Product code | Batch No. | Manufacture Date | Expire Date | Price LYD | Manufacturer |
|---|---|---|---|---|---|
| 1 | LOTS2024 | 7-2022 | 7-2025 | 30 | Cerdanyola Spain |
| 2 | P0601217 | 8-2022 | 8-2025 | 6 | North American market |
| 3 | P1121E112 | 11-2022 | 11-2025 | 7 | Germany |
| 4 | 012302888 | 5-2022 | 5-2025 | 10 | Germany |
| 5 | JFN | 6-2022 | 6-2026 | 68 | USA |
| 6 | 20B03 | 3-2021 | 3-2024 | 25 | Spain |
| 7 | DR8225 | 4-2022 | 5-2026 | 32 | Spain |
| 8 | 190024 | 4-2022 | 5-2026 | 12 | Spain |
| 9 | 21P07 | 6-2022 | 6-2024 | 20 | Spain |
| 10 | S009 | 5-2021 | 4-2023 | 14 | Japan |

| | | | | | |
|---|---|---|---|---|---|
| 11 | BNB25 | 8-2022 | 8-2025 | 6 | UK |
| 12 | 17B06 | 3-2020 | 3-2024 | 16 | Spain |

***Table 2: Listed ingredients of the selected toothpastes***

| Toothpastes | Ingredients as listed on packages |
|---|---|
| 1 | Aqua, sorbitol, Glycerin, hydrated silica, potassium nitrate, Titanium Dioxide, sodium monofluorophosphate, panthenol, xanthan Gum, PEG-40, hydrogenated Castor oil, hydroxyapatite, sodium lauryl sulfate, Tocopheryl Acetate, Allantoin, sodium Methyl paraben, sodium saccharin, Citric Acid, Aroma, limonene |
| 2 | Sodium fluoride (1450PPMFLUORIDE), zinc sulfate. Sorbitol, hydrated silica, sodium lauryl sulfate, PEG32, aroma, Cellulose Gum, sodium saccharin, sodium fluoride sulfate, sodium Opiate, Eugenol L. hydroxide, synthetic fluorphlog |
| 3 | Aqua, sorbitol, hydrated silica, sodium lauryl sulfate, Cellulose Gum, Aroma zinc citrate, chondrus crispus powder, sodium fluoride, sodium saccharin, hydroxyl Ethyl cellulose, CL77891, sodium citrate, stannous chloride, silica, Glycerin, Limonene, CL74160. |
| 4 | Glycerin, hydrated silica, sodium hexametaphosphate, Aqua, sodium gluconate, sodium lauryl sulfate, Aroma, Carrageenan, Trisodiumphosphate, stannous fluoride, sodium, sodium saccharin, PVP, stannous chloride, Xanthan Gum, cocamidopropyl betaine, sodium fluoride, limonen, sodium hydroxide, sodium benzoate, CL 74260, CL74160. |
| 5 | Potassium nitrate 5% w/w, sodium fluoride 0.25%w/w, water Aqua, silica, xylitol, glycerin, sorbitol, flavor (Aroma), poloxamer 407, sodium lauryl sulfate, carbomer, sodium benzoate, sucralose, xanthan Gum, FD&C Blue No. 1(c142090) |
| 6 | Aqua, sorbitol hydrate, dsilica, Glycerin, titanium dioxide, Aroma, cocamidopropyl betainate, dcastoroil, sodium fluoride, sodium methyl paraben, sodium saccharin, Tocopheryl acetate, sodium propylparaben, cetylpyridinium chloride. |
| 7 | Sorbitol, aqua, hydrated silica, menthapiperitaleaf water, aloe barbadensis, leaf juice, lauryl glucoside, xanthan gum, aroma, sodium fluoride, sodium benzoate, stevia rebaudiana extract, citric acid, potassium sorbate. |
| 8 | Aqua, sorbitol, hydrated silica, sodium lauryl sulfate, cellulose gum, aroma, sodium monofluorophosphate, titanium dioxide, sodium mono fluorophosphates, titanium dioxide, sodium methyl paraben, sodium saccharin, allantoin, sodium |
| 9 | Aqua, sorbitolhydratsilica, glycerin, titanium dioxide, aroma, cocamidopropylbetaine, panthenol, xylitol, xanthan gum, PEG 40 hydrogenated castor oil, sodium fluor-fluoride, sodium methyl paraben, sodium saccharin tocopheryl acetate, sodium. |
| 10 | Aqua, hydrated active ingredients: potassium nitrate 5%, sodium fluride 0.25, novamin, inactive ingredients: potassium nitrate, stannous fluoride, sodium fluoride, penta sodium triphosphate, sodium lauryl sulfate, and other surfactants. |
| 11 | Sodium fluoride 0.22% water, hydrated silica, glycerin, sorbitol PVM, MA copolymer, sodium lauryl sulfate, flavor cellulose, gum, sodium hydroxide, propylene. |
| 12 | Aqua, sorbitol, glycerin, hydrated silica, cocamidoropybetaine, titanium dioxide, xanthan gum, aroma, sodium fluoride 0.22% sodium methyl paraben, chloride Edifluconate 0.12 methanol, sodium saccharin, methyl |

***Organoleptic characters***

Batches under investigation evaluated for their organoleptic characters include colour, appearance visually, texture, odor, taste by sensory and physical evaluations, such as extrudability, measured qualitatively by ease of squeezing from the tube. Results are shown in (Table 3).

***Determination of Grittiness***

The presence of hard, sharp-edged abrasive particles was evaluated by extruding approximately 15 to 20 mm length from a collapsible tube of each sample onto butter paper, then pressing it along its entire length with a finger.

***Determination of pH***
In a 100ml cleaned beaker, 5 grams of the sample were accurately weighed. To this freshly boiled and cooled distilled water was added, and stirred well to get a uniform suspension. The pH was determined within 5 min by using a pH meter. The pH was measured in triplicate, and the results were tabulated in (Table 4).

***Determination of Spreadability***
One gram of toothpaste is placed on a glass slide 10*10, and covered with another glass slide. Then carefully place a 1 kg weight on the covered glass slide. Measure the spreading length and width in cm of the toothpaste after 3 minutes. The experiment was repeated, and the average value of three readings was noted.

***Moisture content***
Moisture content was determined by weighing a known amount of 5 grams of each sample into an evaporation dish, then drying in a hot air oven at 105°C for 2 hours. The percentage of moisture content was calculated based on weight loss. All measurements were performed in triplicate and expressed as mean values.

***Determination of foaming power***
A 1-gram sample was dispersed in 10 ml of distilled water and kept in a 100 ml measuring cylinder, and shaken well for 1 minute. Foam volume was noted and measured in a graduated cylinder after 5 minutes of setting.

***Antimicrobial activity***
The modified agar well diffusion method was used to determine the antimicrobial activity of different toothpaste formulations under investigation. Nutrient agar plates were seeded with 0.2 ml of a 24 h broth culture of *Candida albicans*, *Fusobacterium nucleatum*, *Streptococcus aureus*, and *Streptococcus mutans,* which were obtained from the Microbiology laboratory, Adam Lab. For medical analysis, after solidifying the agar plates, wells were cut at an equal distance in each plate by using a sterile 8mm borer. Toothpaste suspensions were produced by mixing toothpastes with 0.9% saline solution (NaCl) in a ratio of 1:2. A 0.2% chlorhexidine solution served as a positive control, while a saline solution (NaCl) served as a negative control to mimic untreated biofilms. The wells of plates were filled with approximately 0.5 ml of formulation with different concentrations. The plates were then incubated at 37 °C for 24 hours. The antimicrobial activity was evaluated by measuring the diameter of zones of inhibition in mm.

## Results and discussion
A comparative evaluation of twelve commercially available toothpaste formulations was performed to assess their physical and antimicrobial properties. Physical parameters included color, texture, odor, taste, extrudability, spreadability, foaming ability, pH, and moisture content, while antimicrobial efficacy was tested against four representative oral pathogens. (Table 3) summarizes the organoleptic and textural characteristics, while (Table 4) presents quantitative data related to formulation behavior.
As can be seen, all tested toothpastes exhibited a paste-like appearance, with various colors, and predominantly a characteristic pleasant and aromatic odor, such as manitol odor. Textures were generally smooth, and tastes were slightly sweet or salty across samples, likely due to the presence of flavoring agents and fluoride salts. All toothpastes demonstrated easy extrudability, without the presence of hard or abrasive particles.
Spreadability ranged between (4.0 to 7.1 cm), with product number 1 exhibiting the greatest spreadability, 7.1cm, suggesting a softer, more easily applied formulation. The toothpaste should have smooth and uniform spreadability to ensure easy application on the toothbrush and effective coverage on teeth. Poor spreadability can lead to uneven cleaning and reduced antibacterial action [16]. Foaming ability varied from 50ml in product number 1 to 81ml in product 9, likely reflecting differences in surfactant content and concentration. Excessive foaming may indicate the presence of synthetic surfactants. While foam is often associated with cleaning perception by the user, it is not directly correlated with clinical efficacy [17]. This variation offers consumer choice, from low foam brands of product 1, 5 to high foam brands of product 9, 2, 3. Literature indicates that more than 79% of dentifrices have a neutral or basic pH, and only 10% of the marketed dentifrices are of acidic or highly acidic pH levels. But 21% of them are below the critical threshold of demineralization of dentin [18]. However, another study showed that the pH of 21 toothpastes ranged slightly

neutral to basic [19]. Of 200 kinds of toothpaste available on the Canadian market, 80% were neutral and only 15% were acidic, located below the critical threshold for demineralization [20].
Similar results were reported in a Brazilian study, in which the authors showed that the pH of 19 dentifrice brands ranged between 6.8-9.9 [21]. In our study, the pH values of the formulations ranged from 5.83 to 9.47, a remarkably wide range for an oral care product. While most samples 1, 7, 8.9, and 11 were within the recommended oral pH range (6.5-8.5), which supports enamel protection and limits microbial growth. However, products number 3, 10, and 12 exceeded pH 9, which may cause mucosal irritation or enamel demineralization. Acidic toothpaste can lead to tooth sensitivity; however, excessively alkaline formulation may irritate [16]. Moisture contents ranged from 25.77 to 38.01% with product 4 having the highest value. While higher moisture may enhance spreadability and user comfort, it could also reduce product stability by increasing microbial susceptibility [16].

***Table 3: Physical evaluation of the different tested toothpastes***

| Toothpastes | Color | Appearance | Odor | Extrudability | Texture | After taste |
|---|---|---|---|---|---|---|
| 1 | Off White | Paste- like | Pleasant | Easy | Smooth | Slightly sweet and salty |
| 2 | Pink with microshine crystals | Paste-like | Pleasant | Easy | Smooth | Slightly sweet and salty |
| 3 | White mixed with green line | Paste-like | Aromatic mannitol | Easy | Smooth | Slightly sweet and salty |
| 4 | Greenish blue | Paste-like | Pleasant | Easy | Smooth | Slightly sweet and salty |
| 5 | Light green | Paste-like | Pleasant | Easy | Smooth | Slightly sweet and salty |
| 6 | White | Paste-like | Pleasant | Easy | Smooth | Slightly sweet and salty |
| 7 | Beige | Paste-like | Aromatic | Easy | Smooth | Slightly sweet and salty |
| 8 | White | Paste-like | Aromatic manitol | Easy | Smooth | Slightly sweet and salty |
| 9 | White | Paste-like | Pleasant | Easy | Smooth | Slightly sweet and salty |
| 10 | Dark Grey | Paste-like | Pleasant | Easy | Smooth | Slightly sweet and salty |
| 11 | Red with squares, white crystal | Paste-like | Pleasant | Easy | Smooth | Slightly sweet and salty |
| 12 | White | Paste-like | Pleasant | Easy | Smooth | Slightly sweet and salty |

***Table 4: Physical evaluation by determination of pH, spreadability, foamability, and moisture content%***

| Toothpastes | Moisture content% | Spreadability cm (length –wide) | Foaming ability ml | pH |
|---|---|---|---|---|
| 1 | 25.80% | 7.1 * 7.1 | 50ml | 7.36 |
| 2 | 28.75% | 5 * 5 | 80ml | 8.76 |
| 3 | 25.77% | 5 * 5 | 80 ml | 9.35 |
| 4 | 38.01% | 5 * 5.1 | 77 ml | 5.83 |
| 5 | 25.77% | 6 *6 | 55 ml | 8.14 |
| 6 | 36.34 % | 4.2 *4 | 78 ml | 6.58 |
| 7 | 29.49% | 6.4 * 6.6 | 62 ml | 7.77 |
| 8 | 28.20% | 5.3 * 5.7 | 75 ml | 7.57 |
| 9 | 27.21% | 4.4 , 4.2 | 81 ml | 7.33 |
| 10 | 27.76% | 5.3 * 5.5 | 76 ml | 9.42 |
| 11 | 27.21% | 6.2 * 6.5 | 70 ml | 7.07 |

| | | | | |
|---|---|---|---|---|
| 12 | 27.36% | 6.2 * 6.9 | 60 ml | 9.47 |

***Table 5: Evaluation of antimicrobial activity shows the inhibition zones in mm of the tested toothpastes***

| **Product code** | **Zone of inhibition (mm) in *Streptococcus aureus*** | **Zone of inhibition in *Streptococcus mutans* (mm)** | **Zone of inhibition (mm) in *Fusobacterium nucleatum*** | **Zone of inhibition (mm) in *Candida albicans*** |
|---|---|---|---|---|
| 1 | 16.21 | 10.60 | 10.22 | 8.20 |
| 2 | 15.30 | 11.50 | 9.83 | 7.96 |
| 3 | 17.25 | 13.34 | 12.03 | 10.20 |
| 4 | 19.22 | 14.55 | 12.31 | 11.23 |
| 5 | 14.24 | 10.00 | 8.60 | 7.59 |
| 6 | 14.17 | 9.89 | 8.58 | 6.90 |
| 7 | 16.30 | 11.62 | 10.55 | 8.42 |
| 8 | 12.41 | 8.99 | 7.81 | 6.00 |
| 9 | 11.67 | 9.45 | 7.92 | 6.30 |
| 10 | 15.36 | 10.72 | 10.30 | 8.30 |
| 11 | 10.18 | 9.99 | 7.00 | 8.16 |
| 12 | 10.50 | 7 | 6 | 5.06 |

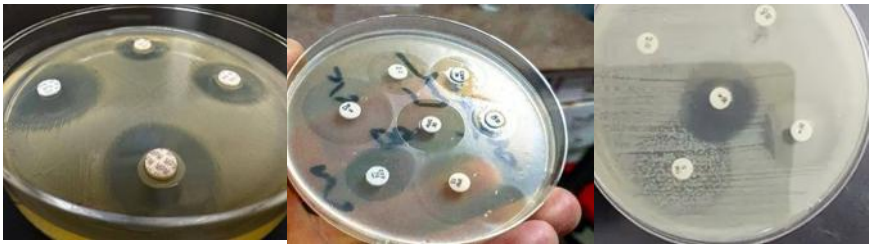

***Figure 1: Antimicrobial activity of different toothpastes under investigation showed zones of inhibition***

Overall, the physical assessment revealed notable variations among formulations, likely due to differences in the type and concentration of surfactants, humectants, and binders, as well as the intended market purpose, such as whitening, sensitivity, or herbal benefits in toothpaste. Several clinical studies have established the inhibitory effect of dentifrice on oral bacterial with different degrees of inhibition [22-25].

In this study antimicrobial efficacy of the toothpaste brands was tested against *Staphylococcus* aureus, *Streptococcus mutans*, *Fusobacterium nucleatum*, and *Candida albicans*. Results as shown in (Table 5) and (Figure 1), Product number 4 demonstrated the strongest antimicrobial performance, showing inhibition zones of 19.22mm, 15,54mm, 13,21, and 10.35mm against *Staphylococcus* aureus, *Streptococcus mutans*, *Fusobacterium nucleatum*, and *Candida albicans*, respectively. Product 3 followed closely, with slightly lower but still strong inhibition values. Both products exhibit broad-spectrum antimicrobial activity, suggesting the presence of potent active ingredients such as fluoride compounds, triclosan, essential oils, or herbal extracts. In contrast, products 8, 9, 11, and 12 displayed weak or negligible antimicrobial activity across all tested microorganisms, likely due to the absence or low concentration of antimicrobial ingredients.

The calculated average inhibition zones confirmed that product 4 achieved the highest antimicrobial performance, followed by product 3 and product 1. However, products 10, 12, and 8 ranked lowest, with inhibition zones below 9mm.

Among all tested formulations, product 4 was the best overall performing toothpaste, combining favorable physical properties, pleasant odor, smooth texture, moderate spreadability 5.1 cm, high foam value 77ml, and slightly acidic pH 5.83 that approaches the critical threshold pH 5.5 for enamel demineralization, raising potential safety concerns for long-term use. However, it has the highest antimicrobial activity. Product 3 ranked the second offering excellent antimicrobial performance and good physicochemical characteristics.

These findings underscore the importance of evaluating both physical and microbiological attributes in toothpaste assessment. While organoleptic and mechanical properties determine consumer acceptability, antimicrobial efficacy is crucial for preventing oral diseases such as caries, gingivitis, and candidiasis.

The marked variability observed among products tested highlights the need for clear labeling of active ingredients and for including antimicrobial testing as a standard part of product quality evaluation in pharmaceutical and regulatory contexts.

## Conclusion

This study demonstrated significant variation among twelve commercial toothpaste formulations in their physicochemical and antimicrobial properties. Most samples met acceptable standards for pH, spreadability, and foaming ability, though extreme values in pH and moisture content may compromise product stability and safety. Only a subset of formulations exhibited strong antimicrobial activity against oral pathogens such as *Streptococcus mutans*, *Staphylococcus aureus, Fusobacterium nucleatum*, and *Candida albicans*. Among the tested samples, toothpaste number 4 demonstrated the best overall performance, despite its relatively high moisture content; this did not outweigh its overall benefits. Toothpaste number 3 also showed promising antimicrobial potential. The observed variability highlights the importance of implementing stringent pharmaceutical-grade quality control and standardization in toothpaste formulation and manufacturing. Products that combine optimal physical properties with proven antimicrobial efficacy should be prioritized for clinical use and consumer recommendation to ensure both safety and therapeutic effectiveness. Further studies may be recommended to prove the safety, stability, and efficacy of different types of toothpastes, additionally, to enhance product performance, consumer acceptance, and regulatory alignment to make it suitable as a commercial product.

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