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Research Article

Physical Properties of Toothpaste Base Formulations

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KEYWORDS

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ABSTRACT

Introduction: Dental caries is a prevalent oral disease resulting from enamel demineralization caused by acidogenic bacterial activity. Toothpaste plays an important role in caries prevention through a combination of ingredients such as calcium carbonate, sorbitol, glycerin, gum arabic, sodium carboxymethyl cellulose, sodium fluoride, citric acid, and peppermint oil. This study aimed to evaluate the physicochemical properties of an experimental toothpaste base formulation.
Material and Methods: This study employed a laboratory-based experimental design with a descriptive observational approach. The physicochemical properties, including pH, viscosity, and homogeneity, were evaluated on a toothpaste base formulation and compared with a commercially available toothpaste.
Results and Discussion: Both the toothpaste base formulation and the commercial toothpaste exhibited pH values within the range of 7.80–7.85, meeting the requirements of the Indonesian National Standard (SNI). The toothpaste base formulation demonstrated a substantially lower viscosity (56.232 cP) compared to the commercial toothpaste (182.872 cP). Differences in viscosity may be attributed to variations in formulation composition and thickening agents. Homogeneity testing confirmed that both formulations were physically homogeneous, indicating uniform distribution of ingredients and acceptable physical stability.
Conclusion: The toothpaste base formulation met the evaluated physical parameters and exhibited characteristics comparable to those of a commercial toothpaste. Although its viscosity was lower than that of the commercial product, it remained within the range commonly reported for toothpaste formulations. Further optimization of the formulation, particularly its rheological properties, is warranted to improve product performance and consumer acceptability.

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INTRODUCTION

Dental caries remains one of the most prevalent oral health diseases worldwide. Data from the 2023 Indonesian Health Survey indicate that the prevalence of dental caries in Indonesia reached 82.8%.[1] Dental caries is characterized by a pathological imbalance between enamel demineralization and remineralization processes, primarily driven by cariogenic bacteria that metabolize dietary carbohydrates into organic acids.[2–4] These acids induce enamel surface erosion, resulting in mineral dissolution and subsequent development of carious lesions.[5]

Tooth enamel constitutes the outermost and largest component of the dental crown and is recognized as the hardest and most highly mineralized tissue in the human body.[6,7] However, acid-induced demineralization compromises enamel structural integrity, thereby increasing susceptibility to mechanical and chemical damage.[8,9] Accordingly, preservation of enamel strength and integrity represents a critical cornerstone in the prevention of dental caries.[10–12]

Within this context, effective caries prevention relies predominantly on the maintenance of optimal oral hygiene, particularly through regular and proper toothbrushing using toothpaste.[7,13] Toothpaste formulations typically comprise multiple components, each fulfilling a distinct functional role.[14,15] Abrasive agents, predominantly calcium carbonate, represent the major fraction of toothpaste formulations and function to remove dental deposits and polish tooth surfaces without causing enamel abrasion.[16] Humectants, such as glycerin and sorbitol, are incorporated to retain moisture and improve rheological properties.[15] Thickening agents, including sodium carboxymethyl cellulose, are utilized to maintain formulation stability and ensure uniform dispersion of ingredients.[17] Flavoring agents, such as peppermint oil, enhance sensory acceptability by providing a refreshing taste and masking undesirable flavors.[18] In addition to these base components, toothpaste formulations should contain therapeutic agents, particularly fluoride, which remains the gold standard for effective caries prevention.[18,19]

Given the importance of formulation performance, the development of toothpaste preparations necessitates a comprehensive evaluation of their physical properties to ensure quality, stability, and consumer acceptability. Key assessments include pH, viscosity, and homogeneity testing.[20] pH evaluation is essential to confirm that the formulation can effectively neutralize acidic conditions within the oral cavity without inducing mucosal irritation.[21] Viscosity testing is performed to achieve an optimal consistency that enhances user comfort and facilitates application.[17] Homogeneity testing assesses the uniform distribution of components within the formulation.[22] Although numerous studies have investigated toothpaste formulations containing various active ingredients, limited evidence is available regarding the physical properties of toothpaste base formulations prior to incorporation of additional bioactive compounds. Therefore, this study aimed to evaluate whether the formulated toothpaste base meets established standards for ensuring the quality and reliability of the final product.

MATERIALS AND METHODS

This study was approved by the Ethics Committee under approval number 921/S1/KEPK/FKG/6/2025. The study employed an experimental laboratory design with a descriptive observational approach. The study included two experimental groups: one toothpaste base formulation and one commercially available toothpaste used as a comparator. The pH measurement was performed in triplicate for each toothpaste sample, whereas viscosity and homogeneity testing were performed once for each sample. The study was conducted between July and August 2025 at the Laboratory of Pharmaceutics and Pharmaceutical Technology, Universitas Indonesia.

The instruments used in this study included beakers, laboratory stirrers, a digital analytical balance (Pioneer™ Precision, Ohaus®, Parsippany, New Jersey, United States), a pH meter (Aquasearcher™, Ohaus®, Shanghai, China), a rotational viscometer (K447-BL-CP Rotational Viscometer, Cole-Parmer®, Vernon Hills, Illinois, United States), microscope slides (Microscope Slides 7105, Yazumi®, China), and toothpaste containers.

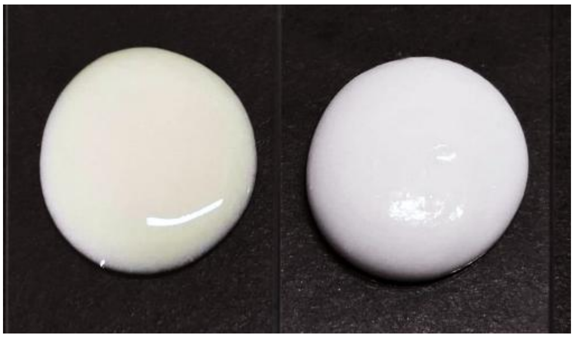
The materials used were calcium carbonate (Magnesia 4491, Lüneburg, Germany), sorbitol (Sorbitol 70% Solution, Across Biotech Jinan Co., Ltd, China), glycerin (Emprove® Expert, Merck KGaA, Darmstadt, Germany, K56696228), gum arabic (Gum Arabic Powder KB-120, Jumbo Trading Co., Ltd, Thailand, 3652101), sodium carboxymethyl cellulose (SidleyCel® Sodium Carboxy Methyl Cellulose (CMC), China), sodium fluoride (Emsure®, Merck KGaA, Darmstadt, Germany, B1965549), citric acid (Citric Acid Monohydrate, PT Pancasakti Putra Kencana, Tangerang, Indonesia, 500A030522), peppermint oil (Young Living Essential Oil, United States, 361317), and distilled water.

Toothpaste preparation was performed by sequentially mixing the ingredients in a beaker. Gum arabic and sodium carboxymethyl cellulose were dissolved in hot distilled water and stirred until uniformly dispersed, followed by the addition of glycerin and continued mixing until a homogeneous solution was obtained. The mixture was allowed to stand for 1–2 hours until clear, after which calcium carbonate was gradually incorporated while stirring continuously. Subsequently, citric acid, sodium fluoride, and sorbitol were added and mixed thoroughly until uniform. Peppermint oil was then added, and the formulation was stirred again until a homogeneous toothpaste was obtained.

Physical property testing was conducted on both the formulated toothpaste and the commercial toothpaste as a positive control. pH was measured with a pH meter after dissolving 1 g of toothpaste in 20 mL of distilled water.[23] The pH electrode was immersed in the sample solution, and the pH value was recorded once a stable reading was obtained.[24] Viscosity testing was conducted using a rotational viscometer, with 25–100 g of sample placed in the sample container.[25] The spindle was immersed and rotated within the toothpaste sample, and measurements were carried out at room temperature. Viscosity values were recorded in centipoise (cP). Homogeneity testing was performed by weighing 1 g of each sample, spreading it thinly on a microscope slide, and visually examining the sample under light.[26]

RESULTS AND DISCUSSIONS

The samples used in this study consisted of a toothpaste base formulation and a commercially available toothpaste, as illustrated in Figure 1.



(A) (B)

Figure 1. Samples of (A) toothpaste base formulation and (B) commercial toothpaste.

The toothpaste base formulation was prepared using a composition comprising calcium carbonate, glycerin, sorbitol, gum arabic, sodium carboxymethyl cellulose, sodium fluoride, citric acid, peppermint oil, and water, as detailed in Table 1.

Table 1. Toothpaste base formulation composition

Ingredient	Function	%
Calcium carbonate	Abrasive	25%
Glycerin	Humectant & sweetener	20%
Sorbitol	Humectant & sweetener	30%
Sodium fluoride	Anticaries agent	0.1%
Gum arabic	Binder	0.5%
Sodium carboxymethyl cellulose	Binder & thickening agent	1%
Citric acid	pH regulator	3%
Peppermint oil	Flavoring agent	0.5%
Water	Solvent	ad 100%

The results of the physical property evaluations, including pH, viscosity, and homogeneity, are presented in Table 2.

Table 2. Physical property test results

Parameter	Toothpaste Base Formulation	Commercial Toothpaste
pH	7.85 ± 0.03	7.80 ± 0.05
Viscosity	56.232 cP	182.872 cP
Homogeneity	Homogeneous	Homogeneous

Both the toothpaste base formulation and the commercial toothpaste exhibited pH values of approximately 7.8, indicating neutral to slightly alkaline conditions. These values fall within the acceptable range specified by the Indonesian National Standard (SNI No. 8861:2020), which requires toothpaste pH to be between 6 and 10.[23] A neutral to slightly alkaline pH is desirable for oral health, as acidic conditions in the oral cavity can promote enamel demineralization and increase the risk of tooth damage.[20,27] Conversely, toothpaste formulations with mildly alkaline pH values may contribute to neutralizing acids produced by bacterial plaque.[28] The findings indicate that the toothpaste base formulation achieved a pH level comparable to that of the commercial product, suggesting that both formulations are safe for use and unlikely to induce oral irritation or enamel damage.[28]

Viscosity testing revealed a pronounced difference between the two formulations. The toothpaste base formulation exhibited a viscosity of 56.232 cP, whereas the commercial toothpaste demonstrated a substantially higher viscosity of 182.872 cP. These results indicate that the toothpaste base formulation possesses a relatively lower consistency, while the commercial toothpaste is considerably more viscous. In practical use, toothpaste with lower viscosity is generally easier to extrude from the tube; however, it may have difficulty maintaining its shape when applied to a toothbrush.[20] In contrast, highly viscous toothpaste tends to retain a stable ribbon shape upon extrusion and adheres more effectively to the toothbrush, reducing the likelihood of dripping.[17,29] Nevertheless, excessive viscosity may hinder ease of extrusion and require greater force during dispensing.[17] According to SNI No. 12-3524-1995, the optimal viscosity range for toothpaste is approximately 20.000–50.000 cP. However, previous studies have reported that toothpaste viscosity across different formulations may vary widely, ranging from 2.000 to 100.000 cP.[30]

From a formulation perspective, the higher viscosity observed in the commercial toothpaste is likely attributable to a greater proportion of thickening agents, which enhance the consistency and structural stability of the formulation. Previous studies have demonstrated that increasing the concentration of thickening agents in toothpaste formulations improves product stability and enhances adhesion of the paste to tooth surfaces during brushing.[20] This prolonged contact time may facilitate more effective interaction between active ingredients and enamel surfaces, thereby optimizing cleaning efficacy.[20,22] Conversely, the lower viscosity of the toothpaste base formulation may promote easier spreading during brushing, but also increases the risk of rapid dispersion and detachment from the toothbrush during use.[17,20]

Homogeneity testing demonstrated that both toothpaste formulations were homogeneous. Homogeneity indicates uniform dispersion of all components within the formulation, without evidence of aggregation, clumping, or phase separation.[22,26] This characteristic is critical to ensure that each application delivers consistent proportions of active agents and abrasives, thereby maintaining uniform cleaning efficacy and protective effects with each use.[13,31] The results further suggest that both toothpaste formulations underwent adequate manufacturing processes, allowing the desired level of homogeneity to be achieved.

Despite the favorable physical properties observed, this study has several methodological limitations. The evaluation was limited to static in vitro measurements, which may not fully represent toothpaste performance under real-use conditions, particularly for viscosity, as factors such as shear rate, salivary dilution, and mechanical forces during extrusion and brushing were not considered. In addition, the comparison involved only a single commercial toothpaste, which may not reflect the variability among commercial formulations. Future studies should therefore incorporate rheological testing under varying shear conditions, optimize the type and concentration of thickening agents and abrasives to achieve viscosity values closer to commercial standards, and include stability, sensory, and in vivo evaluations to provide a more comprehensive assessment of toothpaste performance and user acceptability.

CONCLUSION

Overall, this study found that the toothpaste base formulation fulfilled the Indonesian National Standard (SNI) requirements for pH, with a pH value of 7.85 ± 0.03, which was comparable to that of the commercial toothpaste. Both formulations also showed homogeneous physical characteristics. The main finding of this study was the substantial difference in viscosity between the two formulations, in which the toothpaste base formulation showed a lower viscosity value of 56.232 cP compared with 182.872 cP in the commercial toothpaste. This lower viscosity may affect the consistency, handling characteristics, and application performance of the toothpaste base formulation. Therefore, further optimization, particularly through adjustment of thickening agents or abrasive components, is recommended to achieve a more suitable viscosity and to improve user acceptability. Further in vivo evaluation is also needed to assess the clinical performance of the developed formulation.

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