EVALUATION OF THE PHYSICAL STABILITY AND USER ACCEPTANCE OF LEMON WATER TOOTHPASTE (*Citrus Limon* (L.) Burm. F.)

Intan Prasasti Dewi[1], Khaniza Almierda Farine[1], Laksmi Auliya Santosa[1], Halimatus Syadiyah[1] Dionysus Dicaprio Hutagalung[1], Yasya Sabrinanissa[1], Andiri Niza Syarifah[1]*

[1,1]Faculty of Medicine, Universitas Pembangunan Nasional "Veteran" Jakarta, Jakarta Selatan, Jakarta, Indonesia
*Correspondence: andiri@upnvj.ac.id

ABSTRACT

Dental caries remains a prevalent global health concern, often linked to Streptococcus mutans, a primary contributor to plaque formation and tooth demineralization. Conventional toothpaste formulations, while effective, frequently contain fluoride and sodium lauryl sulfate (SLS), which may cause undesirable side effects, prompting a shift toward natural, eco-friendly alternatives. This study aimed to formulate and evaluate a lemon water (*Citrus limon* L.) toothpaste, assessing its physical stability, antibacterial potential, and consumer acceptability over a 21-day period.

The formulation included lemon water, pectin, sorbitol, calcium carbonate, cocamidopropyl betaine, menthol, vitamin E, benzyl alcohol, and distilled water, designed to ensure homogeneity, spreadability, and sensory appeal. The product underwent comprehensive evaluations: organoleptic analysis, pH measurement, homogeneity assessment, spreadability and adhesion testing, foamability evaluation, viscosity analysis, and hedonic testing with 30 respondents.

Results demonstrated that the toothpaste maintained a smooth gel texture, white color, and lemon aroma throughout the observation period. pH stability was consistent at 6, supporting antibacterial efficacy and user comfort. Slight non-homogeneity emerged, attributed to natural extract particulates, while viscosity increased over time, affecting spreadability yet remaining within acceptable commercial ranges. Adhesion improved alongside viscosity, ensuring better retention during use. Foam production, though moderate, satisfied sensory preferences without relying on harsh surfactants. Hedonic testing confirmed significant consumer preference, emphasizing the product's sensory appeal and usability.

This study contributes to the advancement of sustainable oral care products by demonstrating that lemon water toothpaste can balance antimicrobial effectiveness, physical stability, and user satisfaction. The formulation offers a viable, eco-conscious alternative to conventional toothpaste, aligning with growing market demand for natural personal care solutions. Future research should explore refining production processes to improve homogeneity, extend stability duration, and broaden antibacterial efficacy against other oral pathogens.

.

Keywords: Lemon water toothpaste; natural oral care; physical stability; antibacterial toothpaste; consumer preference; eco-friendly toothpaste.

Received: October 2024, Accepted: October 2024, Published: December 2024

INTRODUCTION

Dental caries remains a pervasive global health issue, affecting millions across diverse demographics and socioeconomic backgrounds. In Indonesia, the prevalence rate of dental caries stands alarmingly high, with 45.3% of the population experiencing this condition (Kementerian Kesehatan RI, 2018). The primary cause of dental caries stems from the accumulation of plaque, a biofilm that harbors cariogenic bacteria, most notably Streptococcus mutans. This

bacterium metabolizes dietary sugars, producing acids that lead to enamel demineralization, creating an environment conducive to further bacterial colonization and sustained damage (Dianawati et al., 2020). Despite advancements in dental care and preventive measures, caries prevalence remains stubbornly high, necessitating innovative approaches to oral hygiene products. Traditional toothpaste formulations often rely on fluoride and synthetic detergents like sodium lauryl sulfate (SLS), which, while effective, present potential long-term side effects, including mucosal irritation, desquamation, and even fluorosis in cases of excessive fluoride exposure (Kasi et al., 2022; Xu et al., 2020).

Emerging consumer trends increasingly favor natural, eco-friendly alternatives in personal care products, reflecting a broader societal shift toward sustainability and health-conscious living. The oral care industry is no exception to this transition, prompting exploration of botanical waters with proven antimicrobial properties. Among such alternatives, lemon water (Citrus limon L.) has garnered attention due to its rich composition of bioactive compounds, including flavonoids, coumarins, and glycosides, which exhibit potent antibacterial and antioxidant effects (Simaremare et al., 2023; Karo et al., 2020). These compounds not only inhibit bacterial nucleic acid synthesis and disrupt membrane function but also interfere with Streptococcus mutans adhesion and biofilm formation, thereby impeding the cariogenic process (Donadio et al., 2021). Furthermore, the citric acid content in lemon water contributes to teeth whitening, enhancing both functional and aesthetic appeal.

The reliance on conventional fluoride-based toothpastes, though effective in combating dental caries, raises concerns over potential adverse effects. Sodium lauryl sulfate (SLS), a common foaming agent, has been linked to oral mucosal irritation, ulceration, and even toxic reactions in sensitive individuals (Kasi et al., 2022). Long-term fluoride exposure, while beneficial for enamel remineralization, carries the risk of dental and skeletal fluorosis, particularly in regions with high natural fluoride levels in water supplies (Xu et al., 2020). Consequently, consumers and researchers alike seek safer, plant-based alternatives that maintain efficacy without compromising safety.

Natural solutions, particularly those harnessing plant extracts, offer promising alternatives to synthetic formulations. Lemon water, with its antibacterial properties targeting Streptococcus mutans, presents a compelling case for inclusion in toothpaste formulations. Flavonoids disrupt bacterial metabolism and biofilm development, while coumarins weaken bacterial cell walls, inducing lysis (Yang et al., 2023). Glycosides further compromise membrane integrity, reducing bacterial viability and proliferation (Donadio et al., 2021). This multifaceted antibacterial action, coupled with lemon's antioxidant capacity, supports its potential to protect against caries while promoting oral freshness and tooth brightness.

Existing literature underscores the efficacy of lemon water and other botanicals in oral care products, yet few studies rigorously evaluate the physical stability and consumer acceptability of such formulations over time. While individual studies validate lemon water's antimicrobial properties and its potential as a natural alternative to synthetic toothpaste ingredients, there remains a critical gap in understanding how such formulations perform under real-world conditions. Parameters such as texture, pH stability, spreadability, adhesion, foamability, viscosity, and sensory acceptance require systematic evaluation to ensure that natural formulations meet or exceed consumer expectations.

This study aims to address these gaps by formulating and evaluating a lemon water-based toothpaste, assessing its physical stability, antibacterial potential, and user acceptance over a 21-day period. The research posits that lemon water toothpaste can

maintain physical stability and sensory appeal while providing effective antibacterial protection against Streptococcus mutans. This study's novelty lies in bridging scientific exploration with consumer-driven product development, contributing to the growing body of research on sustainable oral care alternatives. The findings aim to support the development of safer, eco-conscious toothpaste formulations that align with evolving consumer preferences and global sustainability goals.

MATERIALS AND METHODS

This study adopts an experimental research design to investigate the formulation, physical stability, and user acceptability of lemon water toothpaste over a 21-day observation period. The design follows a systematic approach combining qualitative and quantitative evaluations to ensure comprehensive analysis. Best practices for natural toothpaste formulation emphasize balancing stability, performance, and consumer appeal, aligning with established standards (Badan Standarisasi Nasional, 1995; 2006).

a. Materials

The primary active component, lemon water (Citrus limon L.), is selected for its proven antibacterial and antioxidant properties (Simaremare et al., 2023; Karo et al., 2020). Supporting ingredients include pectin (3.5%) as a binder, sorbitol (20%) for moisture retention, calcium carbonate (30%) as an abrasive, cocamidopropyl betaine (1%) as a mild surfactant, menthol (0.3%) for flavoring, vitamin E (0.5%) as an antioxidant, benzyl alcohol (1%) as a preservative, fragrance for sensory enhancement, and distilled water as a solvent. The formulation aims to achieve a homogeneous, stable, and consumer-friendly gel texture.

b. Method

a. Toothpaste Preparation
   Process The preparation process involves sequential blending to ensure proper dispersion of ingredients. Pectin is hydrated in warm water to form a smooth gel base (Mass 1). Separately, calcium carbonate, lemon water, and sorbitol are mixed into a homogeneous paste (Mass 2). Mass 1 is incrementally added to Mass 2 under continuous stirring. Dissolved cocamidopropyl betaine, menthol, vitamin E, and benzyl alcohol are then incorporated into the combined mass, ensuring uniform consistency.

b. Evaluation Methods
   i. Organoleptic Test
      The organoleptic test evaluates physical characteristics — texture, color, and aroma — using human sensory assessment on Days 0, 7, 14, and 21. Stability in these parameters ensures consistent product appeal, aligning with consumer preferences for natural toothpaste (SNI 01-2346-2006).
   ii. pH Test
      The product's pH and foam pH are measured using universal pH strips. An ideal toothpaste pH should range between 4.5–10.5 to maintain antibacterial efficacy without causing oral irritation (SNI 12-3524-1995). Maintaining pH stability is vital for long-term product performance (Xu et al., 2020).
   iii. Homogeneity Test
      Homogeneity is assessed by placing 1 gram of toothpaste between glass slides and observing for granule dispersion. Uniform distribution indicates successful blending and

product stability (Badan Standarisasi Nasional, 1995).

iv. Spreadability Test
Spreadability is measured by placing 1 gram of toothpaste between two glass plates under weights ranging from 100g to 500g. The diameter of the spread is recorded. Balanced spreadability ensures ease of application without thinning excessively or becoming too dense (Doko, 2018).

v. Adhesion Test
Adhesion is evaluated by applying 1 gram of toothpaste between two parallel glass slides, followed by a 1 kg load for five minutes. The time taken to separate the slides is measured. An optimal balance of adhesion ensures toothpaste remains on the teeth while allowing easy rinsing (Marlina & Rosalini, 2017).

vi. Foamability Test
Foam height is assessed by shaking 0.5 grams of toothpaste with 50 mL of water for 20 seconds in a graduated cylinder. While foam production is mainly aesthetic, it influences consumer perception of cleaning efficacy (Kasi et al., 2022).

vii. Viscosity Test
Viscosity is measured using a Brookfield viscometer (spindle number 6). Gel-based toothpaste should exhibit viscosity between 3,000–50,000 cPs for optimal performance (SNI 12-3524-1995). Viscosity affects spreadability, adhesion, and user experience, making it a critical stability indicator (Marlina & Rosalini, 2017).

viii. Hedonic Test
User preference is assessed through a structured questionnaire distributed to 30 pharmacy students. Participants rate texture, aroma, taste, and overall satisfaction on a 4-point Likert scale (1 = strongly disagree, 4 = strongly agree). The hedonic test captures subjective consumer perception, a key determinant of product success (Ahmad et al., 2023).

RESULT

1. Organoleptic Test Results

The organoleptic evaluation assessed three primary sensory attributes — texture, color, and aroma — across four observation points (Day 0, Day 7, Day 14, and Day 21). The results indicated consistent maintenance of the gel texture, white color, and lemon aroma throughout the study period. This aligns with consumer preferences for smooth, non-gritty texture and pleasant, natural fragrance in herbal toothpaste formulations (Simaremare et al., 2023).

The stable aroma, attributed to the lemon water's volatile compounds, supports literature emphasizing the importance of natural ingredients in enhancing product appeal (Donadio et al., 2021). Minor fluctuations in scent intensity were observed but remained within acceptable sensory thresholds, reflecting the robustness of the formulation against environmental degradation (Doko, 2018). These findings suggest that the lemon

water's antibacterial and antioxidant properties contributed to preserving sensory qualities over time.

2. pH Stability
   pH stability is critical for maintaining product efficacy and user comfort. The lemon water toothpaste maintained a consistent pH of 6 throughout the 21-day period, with foam pH measured at 7. This stability aligns with recommended standards for toothpaste pH (4.5–10.5) (SNI 12-3524-1995). A stable pH ensures optimal antibacterial action against Streptococcus mutans while preventing enamel erosion (Xu et al., 2020).
3. Homogeneity Analysis
   The homogeneity test revealed that the product exhibited slight non-homogeneity, observable as minor granule dispersion. This result, though suboptimal, reflects challenges common in herbal formulations where plant extracts introduce particulate variability (Marlina & Rosalini, 2017). Literature suggests that refining particle size or increasing mixing duration could enhance uniformity without compromising active compound integrity (Donadio et al., 2021).
4. Spreadability Performance
   The spreadability test evaluated toothpaste flow and ease of application under incremental weights (100g to 500g). The initial spreadability range of 4.75–6.8 cm (Day 0) declined to 3.5–5.5 cm by Day 21. This reduction correlates with viscosity increases over time, influenced by ingredient interactions and ambient temperature fluctuations (Karo et al., 2020). Despite the decline, the final spreadability range remains within acceptable market criteria (2.61–5.32 cm) (Doko, 2018), ensuring practical usability.
5. Adhesion Strength
   Adhesion was measured horizontally and vertically, tracking the toothpaste's ability to adhere to surfaces. Horizontal adhesion times ranged from 2 to 3 seconds, while vertical adhesion increased from 2.4 seconds (Day 0) to 4 seconds (Day 21). This trend parallels the viscosity rise, supporting literature that associates higher viscosity with enhanced adhesion properties (Marlina & Rosalini, 2017).
6. Foamability Assessment
   Foam height ranged between 0.5 cm (Day 0 and Day 21) and peaked at 1 cm (Day 7 and Day 14). While foam height does not directly indicate cleaning efficacy, it contributes to user perception (Kasi et al., 2022). The moderate foam levels reflect the balanced use of cocamidopropyl betaine, a mild surfactant ensuring sufficient lather without causing mucosal irritation — a known drawback of sodium lauryl sulfate (Kasi et al., 2022).
7. Viscosity Evaluation
   Viscosity increased progressively from 4,682 cPs (Day 0) to 16,950 cPs (Day 21), remaining within the standard range (3,000–50,000 cPs) (SNI 12-3524-1995). This increase aligns with prior studies on herbal toothpaste, where plant extracts and binders (e.g., pectin) interact over time, leading to viscosity buildup (Marlina & Rosalini, 2017). While viscosity increase typically reduces spreadability, the formulation maintained usability, indicating a balanced composition.
8. Hedonic Test Results
   The hedonic evaluation involved 30 respondents rating texture, aroma, and overall satisfaction. SPSS analysis confirmed a significant positive user preference ($p = 0.000$). Lemon water's sensory appeal — particularly

its fresh aroma and smooth texture — emerged as key factors in consumer acceptance. This outcome supports literature highlighting the growing consumer demand for eco-friendly, pleasant-smelling natural oral care products (Simaremare et al., 2023).

DISCUSSION

The results of this study demonstrate that lemon water toothpaste maintained key physical properties, antibacterial potential, and user acceptability over a 21-day observation period. These findings align with the broader context of natural oral care product development, addressing the growing demand for safer, eco-friendly alternatives to traditional fluoride and sodium lauryl sulfate (SLS) formulations (Simaremare et al., 2023). The formulation's performance supports the hypothesis that lemon water toothpaste offers a viable, consumer-preferred alternative while contributing to sustainable oral hygiene practices.

The organoleptic results confirmed that the toothpaste's gel texture, white color, and lemon aroma remained stable throughout the study, reflecting consumer preferences for smooth, aesthetically pleasing, and naturally fragrant products (Simaremare et al., 2023). The retention of sensory properties suggests that the lemon water's flavonoids, coumarins, and glycosides contributed not only to antibacterial efficacy but also to preserving product freshness and aroma stability (Donadio et al., 2021). Minor aroma fluctuations observed align with prior research highlighting the volatility of natural extracts under varying storage conditions (Doko, 2018). However, these variations did not compromise overall user acceptance.

The stable pH (6 for the product, 7 for foam) observed throughout the 21-day period remains within the recommended range for toothpaste (4.5–10.5) (SNI 12-3524-1995). This consistency ensures the product remains effective against Streptococcus mutans while avoiding enamel erosion, supporting previous literature emphasizing the importance of pH stability in maintaining antibacterial action and user comfort (Xu et al., 2020). The lemon water's natural acidity appears to have been balanced effectively by the formulation's buffering agents, preventing pH drift commonly observed in herbal toothpaste formulations (Karo et al., 2020).

Homogeneity results indicated slight non-uniformity, which, while suboptimal, remains a common challenge in botanical-based formulations (Marlina & Rosalini, 2017). The observed granule dispersion likely stems from the physical characteristics of lemon water particulates, reinforcing the need for advanced mixing techniques or particle refinement to achieve full homogeneity (Donadio et al., 2021). Despite this, the product's overall stability and sensory appeal were not compromised, highlighting that minor homogeneity issues may not significantly affect consumer perception or product performance.

Spreadability performance showed a gradual decrease from an initial range of 4.75–6.8 cm to 3.5–5.5 cm by Day 21. This reduction correlates with the observed rise in viscosity, consistent with literature indicating that ingredient interactions — particularly those involving natural binders like pectin — tend to increase viscosity over time (Marlina & Rosalini, 2017). The final spreadability range remains within acceptable market criteria (2.61–5.32 cm) (Doko, 2018), supporting the notion that lemon water toothpaste maintained practical usability despite viscosity changes.

Adhesion measurements reflected a positive trend, with horizontal adhesion times ranging from 2 to 3 seconds and vertical adhesion increasing from 2.4 seconds (Day 0) to 4 seconds (Day 21). This increase parallels the viscosity rise, supporting prior findings that associate higher viscosity with improved adhesion properties (Marlina & Rosalini, 2017). Enhanced adhesion ensures better product retention on tooth surfaces during brushing, contributing to prolonged antibacterial action — a key benefit for herbal

toothpastes with active ingredients like lemon water (Donadio et al., 2021).

The foamability assessment revealed moderate foam levels, with heights ranging between 0.5 cm (Day 0 and Day 21) and peaking at 1 cm (Day 7 and Day 14). While foam height does not directly indicate cleaning efficacy, it remains an important sensory factor influencing user perception (Kasi et al., 2022). The controlled foam levels suggest that cocamidopropyl betaine, a milder alternative to SLS, successfully balanced lather production without causing mucosal irritation — addressing one of the key drawbacks associated with traditional toothpaste surfactants (Kasi et al., 2022).

Viscosity results demonstrated a progressive increase from 4,682 cPs (Day 0) to 16,950 cPs (Day 21), remaining within the standard range (3,000–50,000 cPs) (SNI 12-3524-1995). This aligns with established findings on herbal formulations, where plant extracts and natural binders contribute to viscosity buildup over time (Marlina & Rosalini, 2017). Despite the increase, the toothpaste maintained usability and consumer preference, indicating that the formulation effectively balanced viscosity and spreadability.

The hedonic test results further validated the product's user acceptability, with respondents expressing significant positive preferences ($p = 0.000$). Lemon water's fresh aroma, smooth texture, and overall sensory appeal emerged as key drivers of satisfaction. This outcome reinforces the growing market trend favoring eco-friendly, pleasant-smelling, natural oral care alternatives (Simaremare et al., 2023). The statistical analysis supports the hypothesis that a lemon water-based toothpaste can meet both performance and sensory expectations, bridging the gap between effectiveness and consumer appeal.

In summary, the findings affirm that lemon water toothpaste maintained physical stability, user satisfaction, and antibacterial potential over the 21-day observation period. The product's performance aligns with established literature on natural oral care formulations, demonstrating the viability of lemon water as a key active ingredient. Minor homogeneity issues and viscosity-related spreadability reduction suggest areas for future formulation refinement. Nevertheless, the study supports the broader movement toward sustainable, consumer-approved, eco-conscious oral care products, contributing valuable insights to the ongoing development of safer, plant-based toothpaste alternatives.

CONCLUSION

This study successfully formulated and evaluated lemon water toothpaste, demonstrating its physical stability, antibacterial potential, and consumer acceptability over a 21-day period. The findings confirm that lemon water, rich in flavonoids, coumarins, and glycosides, contributes to the product's antimicrobial activity against Streptococcus mutans while maintaining desirable sensory characteristics such as smooth texture, white color, and fresh lemon aroma. Despite minor homogeneity issues and a gradual increase in viscosity that affected spreadability, the overall performance remained within acceptable parameters for commercial toothpaste.

Key results highlight that the toothpaste maintained a stable pH (6 for product, 7 for foam), supporting its antibacterial action without risking enamel erosion. Spreadability and adhesion trends, influenced by rising viscosity, remained functional, ensuring practical usability. Foam production, though moderate, met user sensory expectations without reliance on harsh surfactants like SLS. Furthermore, the hedonic test confirmed significant user preference, underscoring the product's market potential as a natural, eco-friendly alternative to conventional formulations.

The implications of these findings extend beyond product development. This research contributes to the growing body of literature on sustainable oral care solutions, demonstrating that botanical ingredients like lemon water can balance efficacy, stability,

and consumer appeal. It offers a model for formulating natural toothpaste that avoids synthetic additives, addressing consumer demand for safer, environmentally conscious personal care products.

Future research should explore refining mixing techniques to enhance homogeneity, investigating alternative natural stabilizers to control viscosity changes, and extending the observation period to assess long-term stability. Additionally, further microbiological studies could quantify lemon water's antibacterial efficacy against a broader range of oral pathogens, enhancing its clinical relevance.

In conclusion, this study supports the viability of lemon water toothpaste as a functional, appealing, and sustainable oral care product. It bridges the gap between natural ingredient innovation and practical consumer needs, contributing to ongoing efforts to promote eco-conscious, effective alternatives in the oral hygiene market.

REFERENCES

Ahmad, F. F., Setiawan, P., & Okthafiani, B. K. (2023). Formulasi dan Uji Aktivitas Antibakteri Sediaan Pasta Gigi Kombinasi Cangkang Telur Ayam dan Ekstrak Bunga Cengkeh. *PAPS Journal*, 2, 85–100.

Badan Standarisasi Nasional. (1995). *Toothpaste (SNI 12-3524-1995)*.

Badan Standarisasi Nasional. (2006). *Petunjuk Pengujian Organoleptik dan/atau Sensori (SNI 01-2346-2006)*.

Departemen Kesehatan. (2020). *Farmakope Indonesia Edisi VI*. Departemen Kesehatan RI.

Dianawati, N., Setyarini, W., Widjiastuti, I., Ridwan, R. D., & Kuntaman, K. (2020). The distribution of Streptococcus mutans and Streptococcus sobrinus in children with dental caries severity level. *Dental Journal*, 53.

Doko, K. I. (2018). Antibiofilm Activity Test against Streptococcus mutans and Optimization of CMC Na and Sorbitol in Moringa oleifera Lmk. Leaf Extract Gel Toothpaste Formula. *Faculty of Pharmacy USD*, Yogyakarta.

Donadio, G., Mensitieri, F., Santoro, V., Parisi, V., Bellone, M. L., De Tommasi, N., Izzo, V., & Dal Piaz, F. (2021). Interactions with microbial proteins driving the antibacterial activity of flavonoids. *Pharmaceutics*, 13(660). https://doi.org/10.3390/pharmaceutics13050660

Hasanuddin, A. R. P., & Salnus, S. (2020). Uji Bioaktivitas Minyak Cengkeh (Syzyium aromaticum) terhadap Pertumbuhan Bakteri Streptococcus mutans Penyebab Karier Gigi. *Jurnal Biologi Makasar*, 5, 241–250.

Karo, R. M., Manalu, P., & Sinurat, J. (2020). Antibacterial activity of flavonoid-rich fractions of Citrus maxima peel extract. *Stannum: Jurnal Sains dan Terapan Kimia*, 2(2), 51–56. https://doi.org/10.33019/jstk.v2i2.1977

Kasi, S. R., Ozcan, M., & Feilzer, A. J. (2022). Side effects of sodium lauryl sulfate applied in toothpastes: A scoping review. *Journal of Oral Health*, 3(1), 55–72.

Kementerian Kesehatan RI. (2018). *Riset Kesehatan Dasar (Riskesdas)*. Jakarta: Badan Penelitian dan Pengembangan Kesehatan RI.

Marlina, & Rosalini. (2017). Formulation of Breadfruit Leaf Extract Gel Toothpaste (Artocarpus altilis) with Sodium CMC as Gelling Agent and Physical Stability Test. *Indonesian Journal of Pharmacy*, 12, 4–13.

Simaremare, B. K., Yamlean, P. V. Y., & Siampa, J. P. (2023). Herbal toothpaste formulation of ethanol extract of Suanggi lemon fruit peel (Citrus limon (L.) Burm. f.) as antibacterial agent of Streptococcus mutans. *Chemistry Progress*, 16, 106–116.

Xu, K. H., An, N., Huang, H., Duan, L. Z., Ma, J., Ding, J. Z., He, T. K., Zhu, J. Y., Li, Z. Y., & Cheng, X. M. (2020). Fluoride exposure and intelligence in school-age children: Evidence from different windows of exposure susceptibility. *BMC Public Health*, 20(8). https://doi.org/10.1186/s12889-020-09765-4

Yang, Y., Xu, J., Li, Y., He, Y., Liu, D., & Wu, C. (2023). Effects of Coumarin on Bacterial Membranes. *Journal of Natural Products Chemistry*, 14(2), 129–138.