

Natural dishwashing liquid from fermented grapefruit peel solution

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Abstract:

The release of significant amounts of chemical detergents into the environment due to human activities raises concerns regarding environmental issues and human health. This study investigates the development of an eco-friendly dishwashing liquid derived from a fermented grapefruit peel solution, aiming to reduce organic waste and promote sustainable cleaning alternatives. The formulation involves fermenting a mixture of three parts grapefruit peel, one part brown sugar, and ten parts water in a sealed container for one month. The resulting solution effectively removes 89.2% of lard from plastic surfaces, eliminates 96.6% of bacteria, and produces foam comparable to that of commercial dishwashing liquids. Although no hydrolytic enzyme activity was detected using the well diffusion agar method with the respective substrates, the detergent effect of the fermentation broth likely arises from organic acids and biosurfactants, rather than from hydrolytic enzymes. The pH value of fermentation fluid decreased to 3 to 4.5 from the initial neutral pH. Consumer feedback highlights its potential as a safe, skin-friendly, and environmentally sustainable substitute for synthetic cleaners, contributing to broader environmental conservation efforts.

Keywords: eco-cleaning, fermentation, grapefruit peels, natural dishwashing liquid, sustainability.

Classification numbers: 3.1, 3.5, 5.3

1. Introduction

The growing demand for natural, biodegradable alternatives to synthetic chemical products is driven by increasing environmental and health concerns. Most commercial dishwashing liquids rely on synthetic compounds that are resistant to microbial degradation, thereby contributing to environmental pollution and posing potential health risks through residual exposure [1, 2].

Research by L.C. Wen, et al. (2021) [3] demonstrates that fermentation solutions derived from fruit and vegetable waste offer biodegradable, mineral-rich cleaning agents with effective detergent properties. These solutions, produced through fermentation by lactic and acetic acid bacteria, represent a sustainable alternative to conventional chemical-based cleaners [3, 4]. Yeast is the most prevalent microorganism found in fermented fruit and vegetable waste, constituting 85% of microbial isolates from fermented

substrates. The microbial community in this nutrient-rich medium primarily consists of the genera *Saccharomyces*, *Bacillus*, and *Candida*. Additionally, the presence of ammonium in the waste can promote the growth of specific bacteria, such as lactic acid bacteria [4]. Furthermore, the product derived from fermented organic waste exhibits antibacterial and antifungal properties and can help remove residual deposits in water pipes to prevent clogs [5]. Grapefruit extract diluted 1,000-fold in phosphate-buffered saline (PBS) was effective in inactivating both *Salmonella infantis* and *Escherichia coli* within five seconds [6]. Citrus fruit peels, including those from oranges, tangerines, lemons, and grapefruits, have a pleasant aroma and possess antibacterial properties, making them ideal for household cleaning. To create a detergent product, these peels are typically combined with brown cane sugar and clean water in a ratio of 3:1:10 (peels, sugar, and water) for fermentation prior to use [7].

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Despite these advantages, many organic dishwashing liquids remain prohibitively expensive, limiting their widespread adoption. The commercial dishwashing liquid made from fermented grapefruit peel (Enzyme Sang, Metta Garden) is currently priced three times higher than quality synthetic dishwashing liquids of equivalent volume. Furthermore, scientific studies have not extensively demonstrated the effectiveness of the fermented grapefruit peel dishwashing liquid in the literature. This study seeks to address this limitation by developing an affordable and effective natural dishwashing liquid using grapefruit peel - an abundant agricultural byproduct in Vietnam, where grapefruit was cultivated across 27.900 hectares in 2020 [8]. Rich in carbohydrates and bioactive compounds, grapefruit peel is an ideal substrate for fermentation, enabling waste valorisation while yielding a safe, scalable cleaning product. This research supports both environmental sustainability and the economic growth of the agricultural sector.

2. Materials and methods

2.1. Research diagram

Grapefruit peel (fresh or dried) → Fermentation → Filtration → Additive blending → Evaluation (sensory, foaming, grease removal, bacteria elimination, enzyme activity) using biochemical and microbiological methods.

2.2. Materials

The main raw materials used to produce the natural dishwashing liquid are fresh grapefruit peels and dried grapefruit peels. Fresh and dried peels from green-skinned grapefruits, brown sugar (Bien Hoa city), and Minh Hong natural dishwashing liquid (positive control) were sourced in Da Nang city, Vietnam. Sudan III dye, Creon 25000 tablets (Abbott, containing digestive enzymes (α -amylase, trypsin, lipase)), Lugol's solution, Tributyrin (Merck - Germany), soluble starch (Xilong, China), agar (Hai Long Company, Vietnam), and other additives (Organic International Joint Stock Company, Ho Chi Minh city, Vietnam) are used.

Escherichia coli ATCC 25922 is supplied by the Biotechnology Laboratory, University of Science and Technology, The University of Danang.

2.3. Methods

Production of dishwashing liquid from fermented grapefruit peel extract: Grapefruit peels, encompassing

both the green and white varieties, are harvested from green-skinned grapefruits and subsequently cleaned to remove moisture until they reach a level below 14%. A quantity of 3 kg of fresh or thoroughly dried grapefruit peel is placed in a 15 L container alongside 1 kg of brown sugar and 10 kg of boiling water, which is then allowed to cool [9]. Post-fermentation, 100 ml of the fermented liquid is filtered and mixed with 1 ml of green tea extract, 1 ml of aloe vera extract, 6 ml of soapberry extract, 3 ml of cocamide diethanolamine (foaming agent), and grapefruit essential oil. The pH is adjusted as needed, and 50 ml of the final product is diluted in 250 ml of distilled water for testing.

Grease cleaning efficacy: Grease removal was assessed qualitatively using a Sudan III/methylene blue reagent [10] on oil-coated polypropylene containers. Sudan III is an oil-soluble dye, while methylene blue is a water-soluble dye. The appearance of a red colour on the surface stained with this solution indicates that excess oil remains on the surface after washing. Cleaning efficiency was quantitatively assessed by measuring the amount of lard removed from a high-adhesion plastic surface, specifically low-density polyethylene [11]. Warm water (40-50°C) served as the control.

E. coli elimination: Ceramic bowls coated with 0.5 ml of cooking oil and 1 ml of *E. coli* inoculum at 10⁶ CFU/ml were rinsed with 10 ml of detergent. Subsequently, the remaining bacteria on the surface of the bowls were collected by swabbing and spreading onto Luria-Bertani medium agar plates. Colony-forming units (CFU) were counted after overnight incubation at 37°C, with efficacy calculated relative to a warm water control.

Foamability: The foamability is measured by shaking 200 ml of the washing solution, prepared as described above, in a 500 ml beaker using a stirrer (IKA, C-MAS HS 7, Germany) at a speed of 800 rpm. After 2, 4, 6, and 8 minutes, the foam is allowed to stabilise for 2 minutes, and then the height is recorded using a ruler [11].

Sensory evaluation: A double-blind experimental design was utilised to evaluate the sensory characteristics of a dishwashing liquid fermented with grapefruit peel. A commercial natural dishwashing liquid was used as a control. Ten volunteers tested both types of dishwashing liquids. The products were labelled, and the order in which

the dishwashing liquids were applied was randomised. Data collection and analysis were carried out by another volunteer who was unaware of the product labels. The questionnaire assessed various factors, including scent, colour, cleaning efficacy, foaming, consistency, and skin irritation, using a scale from 1 to 5.

Enzyme activity: amylase [12], lipase [13], and protease [14] activities were tested using well diffusion agar with starch, tributyrin, and casein substrates, respectively. Clear zones around the sample wells indicated enzyme presence after 24 hours of incubation at 35-37°C.

Statistics and data analysis: Data from three replicates were analysed in Excel 365 and presented as means ± standard deviations. ANOVA and Tukey’s HSD tests were conducted to identify statistically significant differences at the 0.05 significance level. The assumptions of ANOVA, which include the normality of the data set and homogeneity of variance, were evaluated using the Shapiro-Wilk test and Levene’s test, respectively; the assumptions were deemed satisfied with a p-value greater than 0.05. These statistical tests were performed using R (version 4.3.3) with the agricolae package for post-hoc tests.

3. Results and discussion

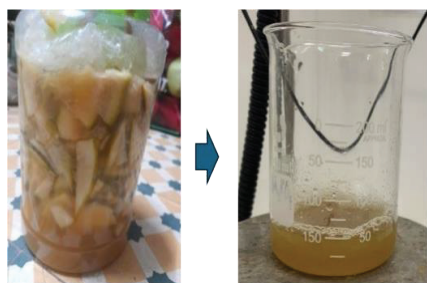


Fig. 1. Fermentation of grapefruit peels and dishwashing liquid product from fermentation liquid.

3.1. Cleaning efficacy of fermented grapefruit peel dishwashing liquid

The fermentation time for fruit peel juice has varied significantly in previous studies, ranging from 7 days to 3-4 months [15, 16]. In this study, we decided to stop the fermentation after 1 month, at which point a thin layer of bacterial biofilm had formed on the grapefruit peel, and the sugar concentration (Brix) had dropped below 1%. Extending the fermentation period beyond this point leads to the juice becoming sour and developing an off-putting odour, which can be unappealing to consumers. Additionally, a shorter fermentation time maintains a higher pH in the fermented juice, ranging from 5.8 to 6.4 after 2 weeks. This pH level indicates the production of insufficient organic acids necessary for effective cleaning. After one month, the fermented solution was formulated into a dishwashing liquid (Fig. 1). The cleaning efficacy of the fermented liquid was assessed through tests focused on its ability to eliminate grease and bacteria from plastic surfaces.

The natural dishwashing liquid, formulated from a one-month fermentation of grapefruit peels (3:1:10 - peel:sugar:water ratio), demonstrated robust cleaning performance across multiple metrics. Qualitative assessment using Sudan III/methylene blue reagent revealed that the liquid derived from fresh grapefruit peels effectively removed grease from polypropylene surfaces, leaving only faint traces of water-soluble methylene blue (Fig. 2C). The blue colour was also observed in the same experiment using commercial dishwashing liquid (Fig. 2B). In contrast, the dried peel variant retained residual oil, as indicated by crimson staining (Fig. 2D), despite being lighter than the dye with oil (Fig. 2A), suggesting that fresh peels yield a superior fermentation substrate, likely due to higher moisture and bioactive content [5].

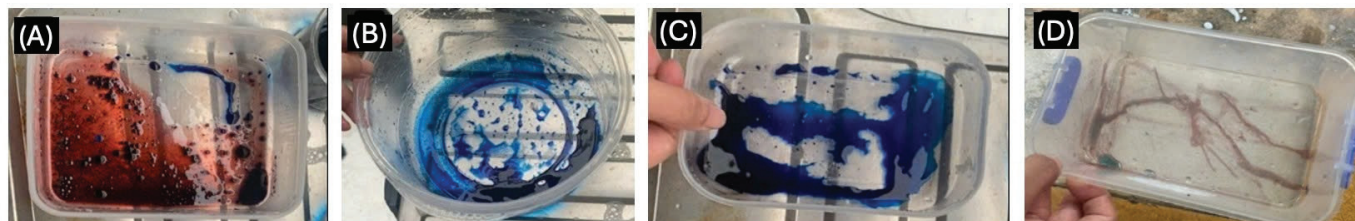


Fig. 2. Qualitative results of the cleaning efficiency of biological dishwashing liquid with Sudan III/methylene blue reagent. (A) Plastic container with unwashed oil; (B) Plastic containers with oil washed using commercial dishwashing liquid; (C) Plastic containers with oil washed using fermented dishwashing liquid from fresh grapefruit peels; (D) Plastic containers with oil washed using fermented dishwashing liquid from dried grapefruit peels.

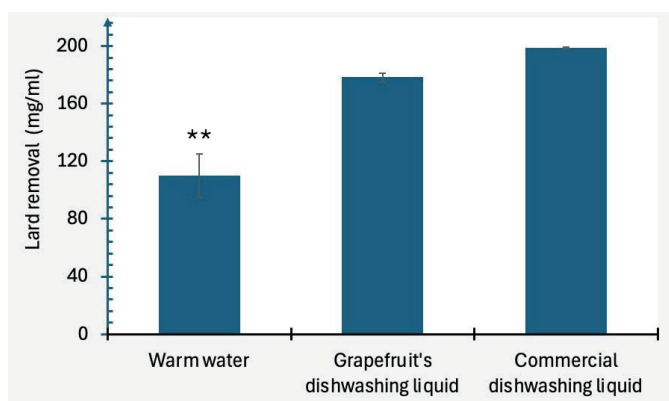


Fig. 3. Lard removal of dishwashing liquid from grapefruit peel fermentation liquid. The amount of fat removed is calculated for 1 ml of cleaning solution or warm water. The result is the mean \pm standard deviation of the 3 repetitions shown. **p-value<0.01 represents a statistically significant difference by the ANOVA one-way test followed by Tukey's HSD test.

In the following experiments, we exclusively used the fermented solution from fresh grapefruit peels to create the natural dishwashing liquid. Quantitative lard removal tests on low-density polyethylene bowls further confirmed efficacy, with the natural liquid removing $89.2 \pm 1.53\%$ lard, comparable to the commercial control ($99.3 \pm 0.29\%$) and significantly outperforming warm water (55 ± 7.57 mg/ml; $p < 0.01$, ANOVA with Tukey's HSD) (Fig. 3).

The grease-cleaning capacity aligns with findings from L.C. Wen, et al. (2021) [3], who reported that fermentation solutions from organic waste produce surfactants and organic acids effective against hydrophobic residues [3]. The observed performance on polyethylene - a material with microscopic pores that trap triglycerides - underscores the practical utility of this formulation, despite its slightly lower efficacy compared to synthetic detergents. This difference may reflect the absence of industrial-grade emulsifiers, a trade-off for enhanced biodegradability and safety.

Bacterial elimination tests using *Escherichia coli* ATCC 25922 on oil-coated ceramic surfaces showed that the natural liquid achieved a $96.6 \pm 2\%$ reduction in colony-forming units (CFU) relative to the warm water control, compared to 100% for the commercial product (Figs. 4 and 5). While statistically significant compared to water ($p < 0.01$), the slight shortfall relative to the commercial control may stem from lower antimicrobial compound concentrations, such as organic acids (pH 3.6-4.2 post-fermentation). This

efficacy remains sufficient for household use, particularly when combined with mechanical scrubbing and rinsing, as noted in practical dishwashing scenarios. The choice of *E. coli* as a model organism reflects its relevance as a common foodborne pathogen, though future studies could expand to other species (e.g., *Salmonella* or *Listeria*) to broaden applicability.

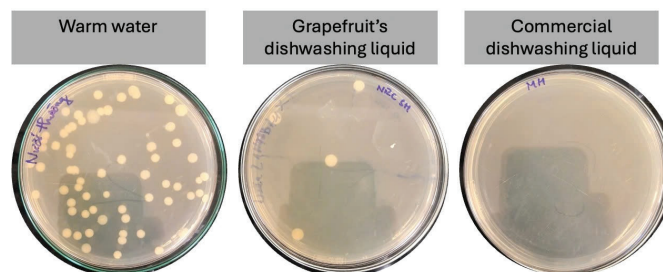


Fig. 4. The amount of *E. coli* bacteria remaining on dishes after washing with various detergents was evaluated. Bacteria were collected, plated on lysogeny broth agar, and incubated overnight at 37°C to determine the number of viable bacteria. Warm water was used as negative control.

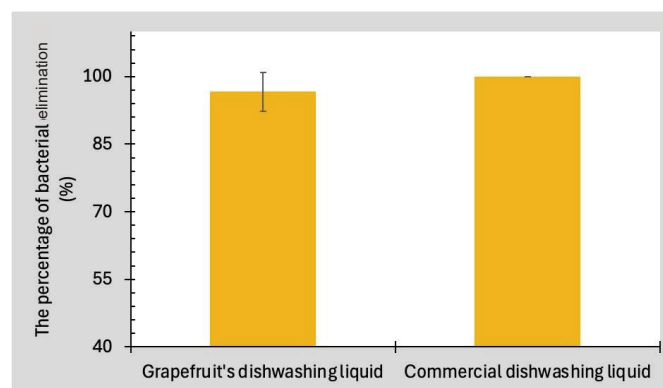


Fig. 5. The quantitative results indicate the percentage of *E. coli* bacteria removed by grapefruit peel fermented dishwashing liquid compared to a commercial dishwashing liquid. These results were calculated by determining the ratio of the difference in the number of bacterial colonies remaining on dishes washed with warm water and the dishwashing liquids against the number of bacterial colonies on dishes washed with warm water (at 45°C). The results presented are the average values and standard deviations from two replicates.

Foaming ability: Foam height measurements indicated that the natural dishwashing liquid (containing cocamide diethanolamine and soapberry extract) produced stable foam comparable to the commercial control, reaching 27 ± 2 mm after 8 minutes of stirring at 800 rpm (Fig. 6). All samples produced foam durability greater than 5 minutes, with the

commercial dishwashing liquid control sample exhibiting finer and more durable foam. Foam enhances surfactant contact time with surfaces, improving grease and dirt capture [11]. This parity with commercial products satisfies consumer expectations for visual cleaning cues, despite potential drawbacks such as skin dryness - an effect not observed in sensory tests (see below). The natural foaming agents used here offer an eco-friendly alternative to synthetic surfactants, aligning with the study's sustainability goals.

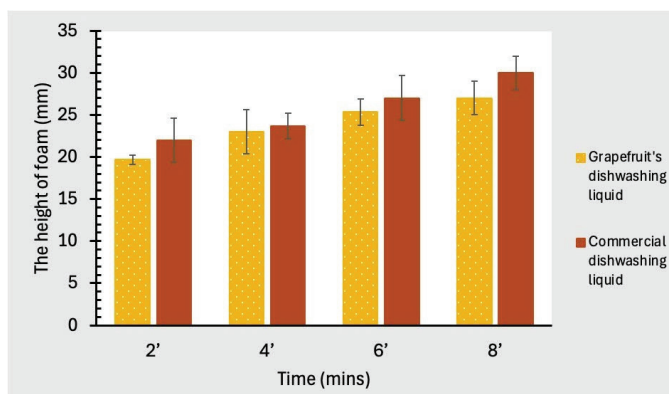


Fig. 6. Foam height measured at different time points (minutes). The results present the mean and standard deviation of three replications. Two-way ANOVA analysis shows the difference in the height of foam at different time points, but not between two dishwashing liquids.

Hydrolytic enzyme activity: Well diffusion agar assays revealed no detectable amylase, lipase, or protease activity in the natural dishwashing liquid, unlike the commercial

control, which exhibited lipase and protease activity (Fig. 7). The absence of clear zones around the natural liquid wells suggests minimal enzyme production during grapefruit peel fermentation. This contrasts with prior studies where fruit peels (e.g., banana, papaya) yielded hydrolytic enzymes under similar conditions [12, 14]. The acidic pH shift (from 6.5-7 to 3.6-4.2) indicates microbial production of organic acids -likely lactic or acetic - rather than enzyme - rich metabolites.

Enzymes are believed to be helpful in cleaning because they can hydrolyse large macromolecules, such as proteins, lipids, and starches - common components found in food - into smaller, more soluble molecules. Lipids, in particular, are notable for their strong adhesion to surfaces, making their removal a priority in cleaning. However, the inclusion of enzymes in dishwashing liquid is not essential. For enzymes to function effectively, they typically require a certain incubation period, which can last for hours to complete the reaction [17]. This is often impractical for dishwashing purposes, as the washing process with dishwashing liquid usually takes less than one minute. Additionally, while controversial, proteinases can cause irritant reactions in some individuals with sensitive skin due to the hydrolysis of skin proteins [18]. Therefore, the surfactants and organic acids in fruit peel fermentation liquid serve as the primary agents for grease removal [19, 20].

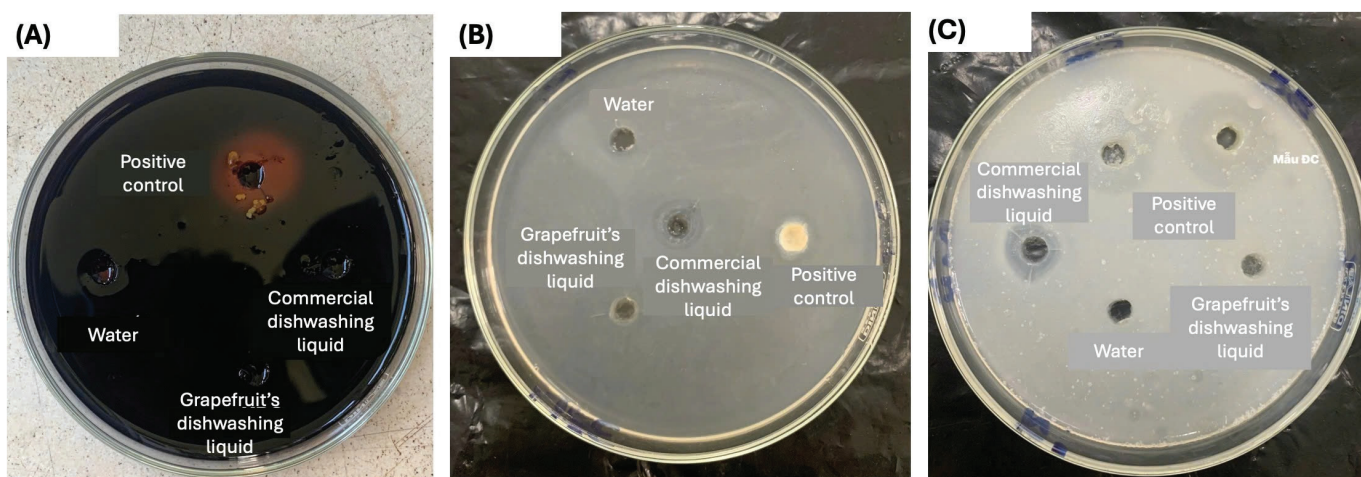


Fig. 7. Hydrolytic enzymes in natural dishwashing liquid, including amylase (A), lipase (B), and protease (C). The presence of amylase activity was confirmed by the appearance of a clear halo around the well after the staining with Lugol. Lipase activity resulted in the appearance of a clear halo around the well. The presence of protease activity was confirmed by the appearance of a clear halo around the well indicating degradation of casein milk. Positive control: Creon 25000.

3.2. Sensory assessment

Sensory data from a double-blind trial with 10 volunteers rated the natural dishwashing liquid highly for cleaning efficacy (4.3 ± 0.7) and foaming (3.9 ± 0.8) on a 1-5 scale, closely matching the commercial control (4.5 ± 0.5 and 4.3 ± 0.7 , respectively) (Fig. 8). No participants reported skin irritation, a key advantage over some synthetic detergents [2], with one allergic individual noting tolerance to the natural product. However, scent (3.5 ± 0.7) and consistency (3.2 ± 0.4) scored relatively low, reflecting an initially strong grapefruit odour and thinner texture. These attributes could be refined with essential oil adjustments and viscosity enhancers, balancing user preference with natural composition.

Sensory Evaluation: Natural vs Commercial Dishwashing Liquid

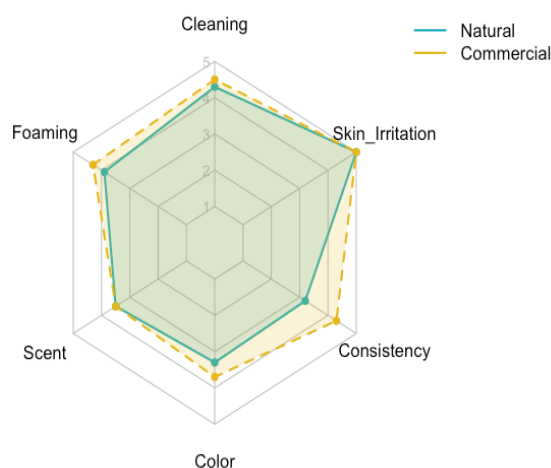


Fig. 8. Sensory evaluation of fermented dishwashing liquid from grapefruit peel and commercial dishwashing liquid. A double-blind experimental design was used. The result of each factor is the mean from ten volunteers.

Implications: The fermented grapefruit peel dishwashing liquid offers a sustainable and effective alternative to synthetic cleaners, leveraging Vietnam's abundant agricultural waste (27,900 hectares of grapefruit cultivation) [8]. Its performance rivals that of commercial products in grease and bacteria removal while avoiding harmful residues, thereby supporting environmental and health objectives [1]. The simple production process is suitable for both household and cooperative scales, enhancing accessibility compared to costly organic alternatives.

Limitations: Limitations include the lack of enzymatic activity, which may restrict efficacy on diverse food residues, and the need for optimisation of sensory attributes. The study's focus on *E. coli* and plastic/ceramic surfaces also warrants broader testing across various pathogens and materials. Future research could explore microbial strain optimisation during fermentation to enhance bioactive yields or incorporate natural thickeners (e.g., xanthan gum) for improved consistency. The product remains stable in activity and does not emit unpleasant odours after two months of storage; however, its shelf life requires evaluation and improvement.

4. Conclusions

The fermented grapefruit peel dishwashing liquid offers a sustainable and effective alternative to synthetic cleaners, excelling in grease and bacteria removal while being safe for users and the environment. Its scalable production process makes it a promising household solution, reducing waste and supporting agricultural economies.

CRedit author statement

Hong Nguyen Pham: Designing, Conducting experiment, Collecting data; Si Hung Ho: Conducting experiment, Collecting data, Preparing figures; Le Thi Huong Len Le: Conducting experiment, Collecting data; Thi Minh Xuan Nguyen: Supervision, Conceptualisation, Writing - Reviewing, Editing manuscript.

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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