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InnoClean Bio: Emulsion Engineering of Mangosteen and Pineapple Peel Extract as an Organic Cleaner Supporting the Circular Economy

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ABSTRACT

Pineapple peel (*Ananas comosus)* and mangosteen peel (*Garcinia mangostana*) waste have significant potential as raw materials for organic cleaning products due to their bioactive compounds. Pineapple peel contains bromelain and other organic compounds that may support cleaning activity, while mangosteen peel is rich in xanthones and phenolic compounds with potential antimicrobial and antioxidant properties. This study aims to develop an eco-enzyme-based organic cleaning product by utilizing pineapple and mangosteen peel waste to produce an effective, environmentally friendly, and sustainable cleaning product. The product was prepared by fermenting 150 g of pineapple peel powder, 90 g of mangosteen peel powder, and 1,500 mL of water for 14 days. After fermentation, 2 tablespoons of vinegar and 3 mL of essential oil were added. Product characterization included pH, homogeneity, stability, and cleaning effectiveness tests. The results showed that the product pH decreased from 5 to 4, exhibited good homogeneity and stability, and produced minimal foam during use. InnoClean Bio was effective for cleaning glass and mirrors, household floors, appliances, and motor vehicles. Furthermore, the fermentation residue has the potential to be utilized as organic fertilizer, thereby minimizing production waste. These findings indicate that InnoClean Bio has potential as an effective and environmentally friendly alternative cleaning product while supporting the implementation of a circular economy by transforming organic waste into useful, value-added, and sustainable products.

Introduction

Waste is a byproduct of various human activities consisting of organic and inorganic materials that are disposed of into the environment. Waste generation and management remain challenges in many countries, including Indonesia, as human activities increase and the volume of materials produced from daily activities grows (Kurniawan *et al.*, 2022).

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According to data from the Ministry of Environment/Environmental Management Agency, Indonesia's national waste generation in 2023 reached 56.63 million metric tons per year. Of this total, approximately 34.54 million metric tons per year or 60,99% remains poorly managed. This situation indicates that waste management in Indonesia still requires more effective efforts, particularly through the reduction and reuse of waste materials at the source (Ministry of Environment/Environmental Management Agency, 2025).

One category of materials that has the potential to increase household waste is organic matter, such as vegetable scraps and fruit peels. These materials are generally discarded directly without undergoing any further utilization or processing. If not managed properly, the accumulation of organic materials can lead to poor environmental conditions and support the growth of pathogenic microorganisms that can potentially cause health problems, such as fungal infections, typhoid, cholera, and diarrhea (Dondo *et al*., 2023). Therefore, proper management and utilization of vegetable scraps and fruit peels are necessary to reduce the amount of organic material that ends up as waste while minimizing environmental impacts and potential risks to human health.

One alternative for utilizing household organic waste is to process it into eco-enzymes through fermentation. Eco-enzymes are products resulting from the fermentation of organic materials that can be used as natural cleaning agents and have the potential to add value to materials that were previously unused. This utilization not only helps reduce the generation of household organic waste but also supports the implementation of more sustainable resource management. Thus, processing vegetable scraps and fruit peels into eco-enzymes can be an alternative to reducing waste problems while producing a more (Irmawan *et al*., 2025).

Mangosteen (*Garcinia mangostana* L.) is a tropical fruit widely cultivated in Southeast Asia, including Indonesia. In Indonesia, mangosteen is widely cultivated; however, its peel is often discarded as agricultural waste despite its potential economic value (Aisyah, 2020). According to data from the Central Statistics Agency (BPS), mangosteen production in Indonesia produces approximately 341,850 tons. Because mangosteen peel accounts for approximately 70% of the total fruit weight, the estimated national mangosteen peel waste reaches 239,295 tons per year.

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Mangosteen peel contains several beneficial compounds, including saponins, xanthones, tannins, and flavonoids (Maulida *et al*., 2021). Mangosteen peel saponins act as emulsifiers (detergents) that can dissolve organic and inorganic debris and reduce surface tension (Krisanjaya *et al*., 2025). Other mangosteen peel compounds, such as xanthones, flavonoids, and tannins, also have antibacterial properties that work synergistically with saponins, potentially preventing and inhibiting the growth of pathogenic bacteria such as Staphylococcus aureus and Escherichia coli, as well as eliminating microorganisms in tooth cavity debris. Therefore, the valorization of mangosteen peel waste into value-added products, such as eco-friendly organic cleaners, represents a sustainable approach to waste management and supports the principles of the circular economy (Humaira & Srikandi, 2021).

Agricultural waste, such as pineapple peels, is widely generated in Indonesia. Pineapple production in Indonesia reaches 74,815 tons per year (Nurcholis *et al*., 2020). The resulting waste accounts for 21.73–24.48% of the total fruit weight; considering that pineapples have an average weight of 600–800 g, it is estimated that 40–50 kg of peel waste can be obtained from 200 kg of whole pineapples (Marjenah *et al*., 2017). This waste generation will continue to increase alongside growing economic activities and production volumes. Pineapple peels are not merely organic waste, as they contain various phytochemical compounds with potential functional properties. This provides opportunities to develop creative, value-added products such as antibacterial soap. Efforts to utilize pineapple peel waste as a primary ingredient for antibacterial products are not new. Pineapple peel exhibits antibacterial activity against several types of bacteria, including Staphylococcus aureus (Puspitasari *et al*., 2025).

Pineapple peel is known to contain a high concentration of bromelain, a proteolytic enzyme that has the ability to hydrolyze proteins. This enzyme functions as an antibacterial agent. Pineapple peel has the potential to be used as an antibacterial soap. This is because pineapple peel contains bioactive compounds such as flavonoids, tannins, and saponins, which are effective as antibacterials. As a liquid dishwashing soap, the bioactive compounds in pineapple peel extract can act as an antibacterial, working by disrupting bacterial cell membranes and cell wall structures, leading to bacterial inhibition

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or cell death. One type of bacteria commonly found on plate surfaces is gram-positive bacteria. Some examples of gram-positive bacteria that can be found on plates or kitchen utensils include Staphylococcus aureus, Bacillus subtilis, and Clostridium perfringens. These bacteria are pathogenic bacteria that can cause disease if present in large enough quantities and if not destroyed through proper cooking or sanitation (Puspitasari *et al*., 2025).

Eco-enzymes are an environmentally friendly technology that can be a solution for community-based organic waste management. These bio-based products are produced through the fermentation process of fruit peel waste, brown sugar, essential oils, and water, producing a multipurpose liquid that can be used as a cleaning agent. Enzymes are easy to make, requires minimal equipment and resources, and can converting organic waste into value-added products. Thus, eco-enzymes have the potential not only to reduce pollution but also to directly reduce the volume of fruit peel waste, particularly mangosteen and pineapple peels (Harefad *et al*., 2025).

The use of mangosteen and pineapple peels as active ingredients in organic cleaners through emulsion techniques is in line with the principles of the circular economy, which is a system that emphasizes the reuse of waste into valuable products that have economic value. Mangosteen and pineapple peels, which have been considered organic waste, contain bioactive compounds that can be used as environmentally friendly cleaning agents. The process of processing this fruit peel waste into an innovative product in the form of an emulsion-based organic cleaner can reduce the amount of organic waste dumped into the environment and also reduce pollution levels.

Using emulsion engineering methods, active compounds such as xanthones in mangosteen peel and bromelain, as well as organic acids in pineapple peel, can function better thanks to greater stability, homogeneity, and efficiency. Therefore, fruit peel waste is not only reused but also transformed into a more economically valuable material. The resulting natural cleaning products can be an alternative to synthetic cleaners, which are often associated with low biodegradability and potential environmental impacts.

Thus, this research aims to develop an emulsion-based organic cleaning product from mangosteen peel and pineapple peel extracts that not only act as a solution in organic waste management, but also support environmental sustainability

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through waste reduction, efficient resource utilization, and the development of environmentally friendly products that are in line with the principles of a circular economy and sustainability.

Materials and Methods

Location and Time of Research

This study was conducted at the Biology Laboratory, Medan State University. Research activities included the preparation of raw materials, the production of eco-enzymes, physicochemical and biochemical characterization, and testing the product's effectiveness as an organic cleaner. The study was conducted from April to June 2026, with a 14-day fermentation process carried out at room temperature.

Tools and materials

The equipment used in this study included a measuring cylinder, beakers, a digital analytical balance, a blender, a sealed fermentation container, a stirring rod, a funnel, storage bottles, a pH indicator, filter paper, and documentation tools.

The materials used in this study consisted of mangosteen peel waste (*Garcinia mangostana* L.), pineapple peel waste (*Ananas comosus* L.), brown sugar, clean water, essential oils, and other supporting materials.

Data collection technique

Data were collected through laboratory experiments involving material preparation, fermentation, formulation, product characterization, and evaluation of cleaning effectiveness. Mangosteen peel (*Garcinia mangostana* L.) and pineapple peel (*Ananas comosus* L.) were cleaned, dried, and processed into powder. A total of 150 g of pineapple peel powder and 90 g of mangosteen peel powder were mixed with 1,500 mL of clean water. Thus, the fermentation materials were used at a pineapple peel-to-mangosteen peel weight ratio of 150:90 (5:3), with a total of 240 g of fruit peel material in 1,500 mL of water. The mixture was placed in a closed fermentation container and fermented for 14 days at room temperature.

After fermentation, the mixture was filtered to separate the liquid from the fermentation residue. Two tablespoons of vinegar were added to the fermented liquid, followed by the addition of 3 mL of essential oil. The mixture was stirred until all components were evenly mixed. However, the stirring time and speed were not reported in the original procedure; therefore, these parameters should be specified according to the actual

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experimental conditions to ensure reproducibility. The product was then stored in a closed bottle before further testing.

Product characterization included pH, homogeneity, stability, foaming ability, and cleaning effectiveness. The pH was measured before and after 14 days of fermentation. Homogeneity was evaluated visually based on the uniform distribution of the components, the presence or absence of sedimentation, and the occurrence of phase separation. Emulsion stability was evaluated during storage based on the presence or absence of phase separation and changes in color and aroma. Foaming ability was observed during product application. Cleaning effectiveness was evaluated on glass or mirrors, floors, household appliances, and motor vehicles by observing the product's ability to remove dirt.

Antibacterial activity testing was included in the data collection procedure in the manuscript; however, the testing method was not described in the original procedure. Therefore, information on the bacterial strains, test method, culture medium, inoculum and sample concentrations, incubation conditions, controls, and outcome measurement should be added based on the actual experimental procedure. These parameters were not specified in the original manuscript and cannot be determined without the actual experimental data.

All measurements and observations were recorded for each test parameter. The data were then tabulated and analyzed descriptively to characterize the properties, stability, and cleaning effectiveness of InnoClean Bio.

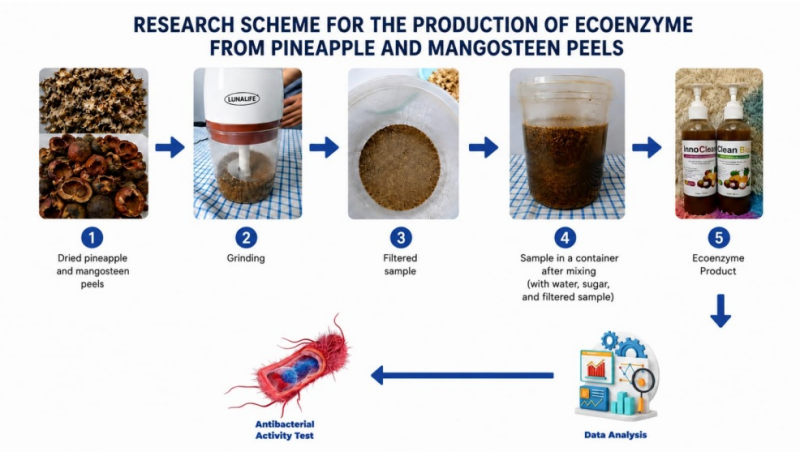

Figure 1. Research Scheme

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Data analysis

Data analysis is an essential component to evaluate the characteristics of the resulting eco-enzyme formulation derived from mangosteen and pineapple peel waste. Data obtained from pH, homogeneity, stability, emulsion stability, phase separation, viscosity, foaming ability, and cleaning effectiveness tests were analyzed descriptively. The research results are presented in tabular and narrative form to illustrate the characteristics of the emulsion-based cleaning product.

Data interpretation was performed by comparing the results of each test parameter, including emulsion engineering parameters such as phase separation and viscosity performance, against the criteria for a good organic emulsion cleaner. This analysis was used to evaluate the potential of eco-enzymes made from mangosteen and pineapple peel waste in emulsion engineering applications as environmentally friendly organic cleaning agents.

Results and Discussion

Research result

This study produced an eco-enzyme-based organic cleaner from a combination of 150 g of pineapple peel powder, 90 g of mangosteen peel powder, and 1,500 mL of water through a 14-day fermentation process. After the fermentation process was complete, 2 tablespoons of vinegar were added as an additional ingredient to increase the ability to dissolve grease and dirt, eliminate unpleasant odors, and potentially inhibit bacterial growth. Furthermore, 3 mL of essential oil was added to provide a fresher aroma and increase the product's appeal. The resulting fermented liquid exhibited a yellowish-brown color with a distinctive fermented aroma that becomes more fragrant after the addition of essential oils. The resulting product is liquid, homogeneous, and produces little foam when used as a cleanser.

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Figure 2. Innoclean-Bio Product Results

Table 1. Characterization Results of InnoClean Bio Organic Cleaner

Test Parameters	Results
Initial pH (before fermentation)	5
pH after 14 days of fermentation	4
Homogeneity	Mixed evenly
Stability	Stable, no phase separation occurs
Test the foam	Produces little foam when used
Cleaning Effectiveness	Able to clean glass/mirrors, floors, household appliances, and motor vehicles

Discussion

1. Ph Test

The results showed that the pH of the formulation before fermentation was 5 and decreased to 4 after 14 days of fermentation. This reduction in pH indicates the occurrence of microbial fermentation activity, leading to the production of organic acids. The more acidic conditions after fermentation indicate the formation of compounds that have the potential to aid in the cleaning process and inhibit microbial growth. A final pH value of 4 is considered suitable for household cleaning applications and indicates that the mixture of pineapple peel and mangosteen peel has undergone significant fermentation activity.

2. Homogeneity Test

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The homogeneity test results showed that all product ingredients were evenly mixed without significant sedimentation or phase separation. Good homogeneity indicates that the mixing and fermentation process contributed to the formation of a stable formulation, allowing the bioactive compounds from pineapple and mangosteen peels to be evenly distributed. This condition is crucial for maintaining consistent product quality with each use.

3. Stability and Cleaning Effectiveness Test

Stability testing showed that the product exhibited good stability during storage, indicated by the absence of phase separation and no significant changes in color or aroma. The amount of foam produced by the product was relatively low during use. This suggests the absence or low concentration of synthetic surfactants, as is commonly found in commercial cleaners. However, the low foaming does not reduce the product's ability to clean surfaces. The cleaning process is more influenced by the presence of bioactive compounds such as saponins, flavonoids, tannins, xanthones, and bromelain, which contribute to dirt removal, lipid degradation, and antimicrobial activity. This is in line with the theory that cleaning effectiveness does not always depend on the amount of foam, but rather on the cleaning agent content in the product (Nazhifah *et al*., 2025).

Based on effectiveness tests, the product is capable of cleaning various household surfaces, such as glass or mirrors, household appliances, floors, and motor vehicles. This ability is supported by a combination of bioactive compounds produced during fermentation and the addition of vinegar, which helps dissolve grease and reduce unpleasant odors. Furthermore, the aroma produced by essential oils adds value to the product's quality, making it more comfortable to use.

Overall, the research results indicate that the use of pineapple and mangosteen peel waste as raw materials for organic cleaning products has significant potential in supporting the implementation of the circular economy concept. This concept emphasizes the reuse of waste into useful products, thereby reducing the amount of waste disposed of in the environment. In this study, fruit peel waste, which initially had no economic value, was processed through a fermentation process into an effective and environmentally friendly organic cleaner. In addition to producing a cleaning fluid, the fermentation residue obtained after the filtering process also

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retains its benefits because it contains decomposed organic matter that may provide additional benefits due to its organic matter content and potential application as a soil amendment. The nutrient and organic content in the fermentation residue has the potential to increase soil fertility, improve soil structure, and support plant growth. Thus, all waste processing results can be optimally utilized without producing waste residue. This approach not only provides a sustainable solution for organic waste management but also creates economic and environmental added value through the reuse of resources previously considered waste.

Conclusion

Based on the research results, pineapple and mangosteen peel waste demonstrated potential as raw materials for the development of organic cleaners through a 14-day fermentation process. The resulting InnoClean Bio product exhibited favorable physicochemical characteristics, characterized by a decrease in pH from 5 to 4, good homogeneity, stability during storage, and the ability to produce small amounts of foam. The effectiveness evaluation indicated that the product was capable of cleaning various surfaces, including glass, household appliances, floors, and vehicles. This waste utilization also supports the concept of *a circular economy* because it reduces organic waste and produces useful products.

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