

Innovation Eco Enzyme Based on Orange Peel Waste (*Citrus Sinensis* L.) and *Citrus limon* L. Burm in Making Environmentally Friendly Halal Detergent

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Abstract

The dual challenge of environmental degradation and the global demand for halal-certified products highlights the urgent need for sustainable and Sharia-compliant innovations in household cleaning agents. This study addresses the specific problem of formulating a detergent that is both environmentally friendly and halal by utilizing fermented orange peel waste (*Citrus sinensis* (L.)) and *Citrus limon* (L.) Burm. f to produce eco enzymes. Employing an experimental quantitative approach, the research investigates the production, formulation, and performance evaluation of eco enzyme-based detergents. Key tests included fermentation kinetics, pH analysis, organoleptic properties, and compliance with the Indonesian National Standard (SNI) for detergent quality specifically assessing cleaning efficacy, pH balance, foam stability, and user acceptability. The resulting eco enzyme exhibited a pH of 3 and a characteristic citrus aroma, while the formulated detergent demonstrated effective cleaning power and met all SNI criteria. This research not only offers a practical solution for reducing reliance on synthetic surfactants but also contributes to the growing body of halal green chemistry.

Keywords: Eco enzymes, halal education, detergent, organic waste, environmentally friendly

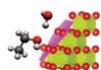
1 Introduction

The global rise in environmental degradation and the growing awareness among Muslim consumers regarding halal compliance have jointly created a pressing demand for innovations in eco-friendly and Sharia compliant household products. A critical yet often overlooked contributor to environmental pollution is the mismanagement of organic waste particularly citrus peel waste which releases methane, contributes to greenhouse gas accumulation, and poses public health risks if untreated [1-4]. At the same time, the halal industry continues to expand rapidly, driven by an increasing Muslim population with heightened awareness of critical halal control points, even in non-food items such as detergents [5,6].

One emerging solution at the intersection of sustainability and halal integrity is the use of eco enzymes a fermented product derived from

organic waste, sugar, and water as a natural, biodegradable ingredient in cleaning agents. Eco enzymes are an innovative solution that can overcome the problem of organic waste while providing an environmentally friendly alternative to making detergents [7,8]. Orange peel waste (*Citrus sinensis*) and *Citrus limon* (L.) Burm, abundant in many regions including Panyileukan Indonesia, contains potent bioactive compounds such as essential oils rich in limonene, flavonoids (e.g., hesperidin, naringin), pectin, and citric acid, all of which have proven functional roles in detergency from degreasing to viscosity enhancement and antimicrobial action [9,10].

In making detergents, synthetic surfactants such as sodium lauryl sulfate (SLS) and sodium laureth sulfate (SLES), which are often used because of their ability to reduce water surface tension and increase cleaning ability, can be replaced with natural enzymes contained in eco



enzymes [11]. Eco enzymes include protease, lipase, and amylase, which effectively break down proteins, fats, and starch, providing a gentler and environmentally friendly cleaning solution. In addition, synthetic antibacterial agents such as triclosan and triclocarban, which can disrupt aquatic ecosystems and trigger bacterial resistance, can be replaced with flavonoid compounds and essential oils in eco enzymes [12].

Among the various organic wastes, citrus peels, particularly from lemon (*Citrus limon*), sweet orange (*Citrus sinensis*), and sunkist orange (a cultivated variety of *Citrus sinensis*), are highly promising due to their rich content of limonene. Limonene is a major component of citrus essential oils known for its strong degreasing ability, natural antimicrobial effects, and pleasant aroma. Lemon peels typically exhibit the highest limonene concentration, offering exceptional solvent power and antibacterial properties, whereas sweet orange and sunkist varieties combine good cleaning efficiency with a softer, more appealing fragrance profile [13].

Additionally, previous studies on enzymes in detergent making have shown the presence of natural enzyme producing isolates such as amylase, lipase, cellulase, and protease from soil samples supporting the feasibility of enzyme use in natural detergent formulations [14].

2 Method

This study used a laboratory-based experimental method consisting of three stages: (1) preparation and sorting of fresh orange peel waste from the Panyileukan area to obtain clean samples; (2) production of eco enzyme through fermentation by mixing orange peel, molasses, and water in a 3:1:10 ratio, left for three months under anaerobic conditions; and (3) formulation of detergents using eco enzyme, Methyl Ester Sulfonate (MES) (ID00410000278930122) from PT. WILMAR NABATI INDONESIA, glycerin (ID32110001310611222) from PT. SEGER SURYA, and salt. The detergent samples were then tested in the laboratory for pH, foam stability, viscosity following Indonesian National Standard (SNI 06-4075-1996), alongside organoleptic evaluation of color, aroma, and texture [15].

The ingredients for formula F0, F1, F2, and F3 are weighed. Make detergent by following these steps: first, boil 150 grams of water, second, after boiling, divide the water into two containers used to dissolve MES and salt, third, dissolve

MES using boiling water, fourth, filter the MES solution, fifth, dissolve the salt, sixth, add glycerin and eco enzyme to the MES solution, seventh, add the salt solution, eighth, stir the solution until evenly mixed, then add 150 grams of water and stir until it reaches the desired consistency. Repeat the procedure for other formulations.

Table 1. Detergent preparation formulation

Material (g)	Formulation			
	F0	F1	F2	F3
Methyl Ester Sulfonate	30	30	30	30
Glycerin	5	5	5	5
Salt	5	5	5	5
Water	300	300	300	300
Eco Enzymes	0	25	30	35

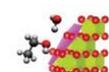
Testing was conducted at the Halal Teaching Factory Laboratory at UIN Sunan Gunung Djati Bandung. Measurements are carried out using a pH meter. A sample of 1 mL was taken, then diluted, and the pH was measured. Homogeneity testing is done by applying detergent to a glass object, gluing it with another, and observing its homogeneity [16,17].

The cleaning power test is done by smearing sauce and lipstick stains on a white cloth, leaving it to dry, then washing it using detergent. Foam height testing is carried out by taking 1 mL of sample and diluting it, then shaking it for a few seconds and letting it sit and measuring. Prerequisite for foam quality is 60-90%. Organoleptic testing is carried out with the main focus of observing physical properties, including color, shape changes, odor, viscosity, impression after use, and reactions [8]. The data analysis was descriptive analysis, which was done by presenting a simple table.

The tools used include a fermenter, stirrer, pH meter, filter cloth, container, scales, macerator, measuring container, spatula, measuring cup, beaker, filter, heater (stove), and pan. The materials used include orange peel waste, water, molasses, Methyl Ester Sulfonate, glycerin, salt, water, and eco enzymes.

3 Result and Discussion

Eco enzymes are produced through fermentation that breaks down organic components in orange peel into active enzymes such as protease, lipase, and amylase. These



enzymes can break down proteins, fats, and starches, thereby increasing the cleaning power of detergents. Meanwhile, using orange peel directly does not provide the same enzymatic benefits because the cleaning components are not activated through fermentation [18].

The initial stage of this study involved the collection and selection of fresh orange peel waste from the Panyileukan area, Bandung City. The orange peels were chosen based on cleanliness and absence of physical contamination to ensure the quality of the fermentation process. The types of citrus used included local orange peel waste (*Citrus Sinensis* (L.) and lemon (*Citrus limon*) all of which are known for their high limonene content, beneficial for detergency.

The selected orange peels were then processed into eco enzyme through a maceration fermentation method. The peels were mixed with molasses and water in a 3:1:10 ratio and placed in a fermentation container (**Fig. 1a**), occupying approximately 60% of the total volume. The fermentation was conducted anaerobically at room temperature over a period of three months, following the adapted method from [19]. Throughout the fermentation process, the containers were monitored to ensure the absence of spoilage indicators such as foul odor or fungal contamination and pH. In addition, from day 1 to day 7 of fermentation, the fermenter was exposed to the sun without opening the lid for 30 minutes.

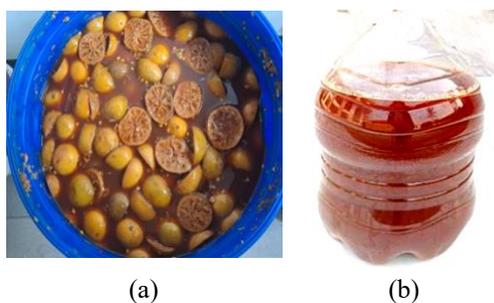


Figure 1. (a) 3 months old eco enzymes (ready to harvest), (b) Eco enzyme aged 3 months after being filtered

After three months, the eco enzyme was harvested, resulting in a clear brownish liquid (**Fig. 1b**) with a fresh citrus aroma and a pH value of approximately 3, indicating a successful fermentation stage.

The acetic acid content in the eco enzymes solution causes the pH value condition to be included in the low category. This liquid has the benefit of being an effective and environmentally friendly cleaning agent. This study processed

orange peel waste through maceration for three months, producing eco enzymes, which were then used in detergent formulations. This formulation replaces synthetic chemicals often used in conventional detergents, which have the potential to damage the environment and human health. Using eco enzymes from orange peel waste in making detergents has several advantages over using orange peels directly. One of the main advantages is higher cleaning effectiveness [18].

Eco enzymes from orange peel also have more potent antibacterial and antimicrobial properties than raw orange peel. Fermentation produces bioactive compounds such as flavonoids and essential oils in a more soluble and easy-to-use form, an effective antibacterial agent [20]. Directly using orange peels may provide some antibacterial benefits but are not as effective as eco enzymes that have undergone fermentation [21].

The fermentation process also changes the chemical properties of eco enzymes, making them more easily dispersed in water and increasing their stability in detergent formulations. Raw orange peel tends to have a texture and composition that is more difficult to disperse evenly in a detergent solution, which can reduce the efficiency and consistency of the final product. Eco enzymes, conversely, are homogeneous liquids that can be easily mixed and standardized in the manufacturing process [22].

Besides functional benefits, using eco enzymes from orange peel is also more environmentally friendly. The fermentation process utilizes organic waste that would otherwise be pollutants, turning it into valuable products. This reduces waste and supports sustainable practices. Using orange peels directly does not provide the same waste utilization solution and can create more organic waste that is difficult to manage [23].

The harvested eco enzyme was subsequently used in the formulation of liquid detergents. Three detergent formulations were prepared by varying the concentration of eco enzyme addition while maintaining consistent proportions of the main surfactant as listed in **Table 2**, Methyl Ester Sulfonate (MES), along with glycerin and salt as supporting agents. Research that has been conducted shows that one of the main ingredients in detergent, namely glycerin, if used on a large scale can also cause damage to the environment and has the potential to come from non-halal sources [24].



Table 2. Detergent quality test

Quality	F0	F1	F2	F3	Conventional detergent
pH	7	3	3	3	9
Foam stability (%)	60	80	70	81	89
Viscosity (cPs)	1,47	4,051	4,083	4,023	4,606
Organoleptics (color, homogeneity, and aroma)	Clear and homogenous, surfactant scented	Dark brown and homogenous liquid, Distinctive citrus aroma	Dark brown and homogenous liquid, Distinctive citrus aroma	Dark brown and homogenous liquid, Distinctive citrus aroma	Green and homogenous, fresh aroma

The pH measurements of the detergent samples indicate significant differences among formulations. The conventional detergent has a pH of 9, which is alkaline and aligns with the Indonesian National Standard (SNI 06-4085-1996) that specifies an acceptable pH range between 6 and 10 for liquid detergents. In contrast, the eco-enzyme-based formulations (F1, F2, and F3) show a pH of 3, indicating a highly acidic nature, while the control formulation (F0) has a neutral pH of 7. This acidic characteristic in F1–F3 is consistent with the inherent properties of eco enzymes derived from fermented citrus peel waste, which are known to produce organic acids such as citric acid during the fermentation process.

While this value does not align with the pH range recommended by the Indonesian National Standard (SNI 06-4085-1996), which typically favors neutral to slightly alkaline detergents, the acidic nature contributes to the product's antimicrobial properties and skin-friendliness. This indicates a trade-off between standard compliance and the natural benefits of eco-enzyme-based formulations. Future research may explore the incorporation of natural buffering agents to align with SNI requirements while preserving the functional efficacy of the eco enzyme [25].

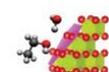
Despite these functional benefits, the highly acidic pH (≈ 3) should be considered a significant formulation limitation rather than merely a trade-off. Sustained exposure to acidic detergents may

lead to gradual fabric degradation, color fading, and potential corrosion of metal components in washing machines. Therefore, future formulation work should not only consider pH adjustment but also evaluate the material compatibility of acidic detergents. More specific natural buffering agents such as sodium bicarbonate or citrate-based buffers (e.g., sodium citrate or potassium citrate) could be explored to increase the pH toward the SNI-recommended range (6–10) while maintaining the beneficial attributes of the eco enzyme [26].

In terms of foam stability, eco-enzyme formulations showed promising results, particularly F1 (80%) and F3 (81%), which are close to the foam stability of the conventional detergent (89%). Foam stability testing was carried out following the SNI 06-4085-1996 procedure, using a 1% (w/v) detergent solution at 25 °C [27]. The initial foam height was 150 mm, and the foam height was recorded after 5 minutes to determine the percentage of stability. According to SNI and previous studies, liquid detergents typically exhibit acceptable foam stability in the range of 60–90%, depending on surfactant characteristics. The results obtained for F1 and F3 therefore fall within the desirable performance range, suggesting that eco enzymes can enhance foam performance when used at optimal concentrations. This is important for consumer perception, as foam stability is often associated with cleaning effectiveness, and the conformity of these results with national standards indicates that eco-enzyme-based detergents can meet recognized quality expectations while maintaining environmental benefits [28].

Thus this can encourage more manufacturers to adopt natural ingredients such as eco enzymes in their products while increasing consumer awareness about the importance of choosing products that are effective and safe for the environment and comply with halal principles [29].

Viscosity which affects how detergents spread and adhere to surfaces, was also relatively high in the coenzyme formulas (ranging from 4.023 to 4.083 cPs), significantly greater than the control sample (F0: 1.47 cPs) and approaching the viscosity of the commercial product (4.606 cPs). These findings demonstrate that eco enzyme detergents can be formulated to achieve comparable physical properties to commercial products, while offering the added benefit of being environmentally friendly and potentially halal-compliant [30].



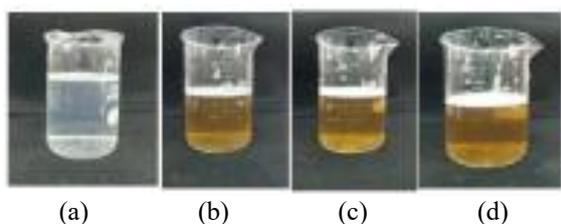


Figure 2. Formulation Detergent: (a) F0 (b) F1 (c) F2 and (d) F3

The eco enzyme-based detergent produced (**Fig. 2b-d**) has physical characteristics of a dark brown, homogeneous liquid, indicating that the fermentation and mixing processes occurred properly without sedimentation or phase separation. Organoleptically, the product has a distinctive citrus aroma derived from natural volatile compounds such as limonene formed during the fermentation of orange peels. This fresh scent was well-received by respondents and is considered an added value, as it suggests the absence of synthetic fragrances. The natural color and citrus aroma further strengthen the perception that the detergent is environmentally friendly and halal, in line with the product's purpose of promoting natural, safe, and *thayyib* principles.

Cleaning power testing using detergent F0, F1, F2, and F3 and conventional detergent using lipstick stains and sauce. The stain is left to dry until it dries and then washed using detergent [8].

Clean power test results show that detergents with eco enzymes can clean stains well, although their effectiveness varies. This is in line with a study by [31], who found that the type of stain greatly influences the cleaning performance of detergents, and detergent formulations need to be adjusted to target specific stains. The effectiveness of detergent is determined based on the ease with which stains are removed when washed, as shown in Table 3. The results show that detergent is effective in removing stains on fabric. However, formulations that do not use additional eco enzymes (F0) still show lipstick stains that do not disappear completely. This could be due to several possibilities, namely the ingredients contained in lipstick and the addition of eco enzymes. Lipstick stains are the most difficult to clean with detergent because they contain a combination of wax and oil, giving them a smooth quality [16,25].

It is important to note that the cleaning performance observed in formulations F1–F3 may result from the combined action of eco enzyme and the synthetic surfactant Methyl Ester Sulfonate (MES), since the detergent base still contains 30 g of MES. Although F0 (MES-only)

was included as a control, its performance requires deeper interpretation to clearly differentiate the individual contribution of eco enzyme from that of MES. The incomplete removal of lipstick stain in F0 suggests a potential synergistic effect when eco enzyme is added; however, the present design does not fully isolate this effect. Future studies should incorporate an additional test using pure or diluted eco enzyme without MES to determine its intrinsic cleaning capability and confirm whether the observed improvements are attributable to the eco enzyme itself or to interactions with MES [32].

Table 3. Clean power test

Formulations	Before		After	
	Lipstick	Sauce	Lipstick	Sauce
F0				
F1				
F2				
F3				
Conventional detergent				
Eco Enzyme				

A key novelty of this research lies in its alignment with the principles of circular bioeconomy and halal green chemistry. By converting orange peel waste into a value-added product, this study supports upstream waste reduction while producing functional household items. The environmental advantages of eco enzyme-based detergents span multiple stages of the product life cycle: Raw Material Sourcing: Citrus peel is an abundant agro-industrial byproduct that does not require dedicated



cultivation, reducing land and water use footprints [33]. Production Phase: The fermentation process operates at ambient temperature and requires minimal energy inputs, significantly lowering carbon emissions compared to chemical surfactant synthesis, which often involves petrochemical derivatives and high-temperature reactions. Usage Phase: Eco enzyme detergents are biodegradable, releasing fewer harmful residues into wastewater streams. Their organic origin reduces risks associated with synthetic surfactants (e.g., SLS/SLES), such as aquatic toxicity and endocrine disruption. End-of-Life: The residuals of eco enzyme detergents are easier to treat in wastewater treatment plants and decompose more efficiently in the environment compared to conventional detergents, thereby reducing cumulative environmental toxicity [34].

Several Life Cycle Assessment (LCA)-aligned benefits can be identified, including the mitigation of: Global warming potential (GWP) due to the avoidance of fossil fuel-derived raw materials. Eutrophication through reduced phosphate loadings in water systems. Human toxicity potential from avoided carcinogenic and allergenic compounds found in synthetic cleaning agents [22].

These alignments affirm the potential of eco enzyme-based formulations as part of sustainable product systems. With proper scaling and integration into household and institutional use, the widespread adoption of such formulations can contribute to achieving Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). This potential is supported by a quantitative indicator showing that eco enzyme based detergents can achieve biodegradability levels above 70% within 28 days based on OECD 301 criteria, demonstrating strong environmental compatibility [35], [36].

4 Conclusion

This study demonstrated the successful innovation of utilizing fermented orange peel waste (*Citrus sinensis* and *Citrus limon*) to produce eco enzymes as a key ingredient in formulating environmentally friendly and halal-compliant liquid detergents. Responding to global concerns over environmental pollution from synthetic surfactants and increasing demand for halal-certified non-food products, the research integrated principles of green chemistry and circular bioeconomy. The eco enzyme,

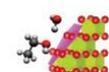
characterized by a pH of 3 and a fresh citrus aroma, was incorporated into three detergent formulations (F1, F2, and F3) with varying concentrations. All eco enzyme-based formulas showed effective stain removal performance, particularly F3, which exhibited high foam stability (81%), viscosity of 4.023 cPs, and strong organoleptic appeal with its dark brown homogeneous appearance and natural aroma. Although F3 recorded the highest performance profile, the viscosity values of F1–F3 (4.051–4.083 cPs) were very close, showing no meaningful practical differences, indicating that all eco enzyme formulations produced a similar rheological behavior, and strong organoleptic appeal with its dark brown homogeneous appearance and natural aroma. While the pH of the eco enzyme detergents fell below the Indonesian National Standard range (6–10), their antimicrobial and biodegradable properties position them as safer alternatives for both skin and the environment. Overall, the findings affirm the feasibility of replacing synthetic surfactants with eco enzyme in detergent manufacturing, aligning with halal and sustainability values. This innovation holds potential for wider application not only in green product development but also in promoting community education and awareness around waste utilization and eco-friendly living.

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