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Organoleptic Perspective of Coffee Skin Eco-enzyme as a Zero Waste Alternative in Plantation Areas

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Abstract

Coffee was a high-value plantation commodity in Indonesia, contributing significantly to farmers' income and the national economy. However, increased coffee production also generated coffee skin waste that was often discarded, creating challenges in organic waste management. This study aimed to process coffee skin waste into eco-enzyme through fermentation process, which could be utilised as organic fertiliser and natural cleaner. For four months, organoleptic observations were made on the eco-enzyme produced, including, colour, pH, volume, and texture. Results showed that the colour of the solution transitioned from light brown to dark brown. pH decreased from 7 to 4 as microbial activity increased. The volume of the solution decreased from 500 mL to 240 mL due to gas release during fermentation. These findings suggested that processing coffee skin waste not only reduced environmental pollution but also increased the economic value of coffee industry by-products. This study provided insight into the potential for sustainable utilisation of coffee waste and supported environmentally friendly agricultural practices.

Introduction

Indonesia is the fourth-largest coffee producer in the world, with Arabica and Robusta as the two main varieties that are highly valued in the international market (Ashardiono & Trihartono, 2024; Ramadhana, 2024). High coffee production contributes significantly to farmers' income and the national economy. However, as coffee production increases, the amount of coffee husk waste generated also continues to grow. Most of this waste goes unutilised and is left to rot, which can cause environmental problems such as air pollution as well as health risks related to microbial growth. Poorly managed coffee skin waste also produces methane gas, which contributes to global warming (Lee et al., 2023). To solve this problem, coffee skins can be processed into eco-enzyme through fermentation process, which offers an eco-friendly solution to utilise organic waste while providing economic and environmental benefits (Mérida et al., 2021; Quyen, 2023).

Coffee productivity in Indonesia is quite high and is one of the high-value plantation commodities that contributes significantly to farmers' income and the national economy. Indonesia, as the world's fourth-largest coffee producer, has a wide range of coffee varieties, especially Arabica and Robusta, which are highly valued in the international market (Ashardiono & Trihartono, 2024; Ramadhana, 2024). Data from the Central Statistics Agency (BPS) indicates fluctuations in coffee production from 2020 to 2022. In 2020, coffee production reached 762.38 thousand tonnes, increasing to 786.19 thousand tonnes in 2021, or an increase of 3.12 percent. However, in 2022, coffee production fell to 774.96 thousand tonnes, a decrease of 1.43 percent (Statistik, 2023).

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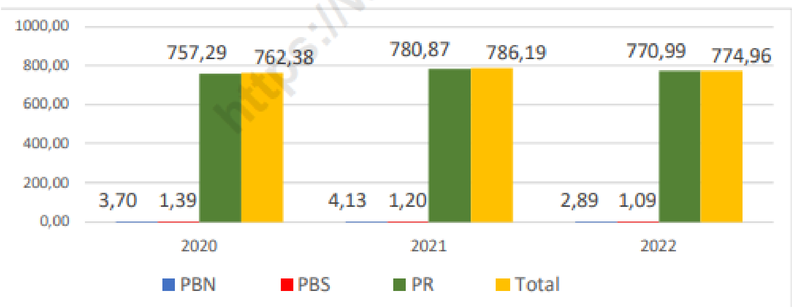

Figure 1. coffee production volume 2020-2022) (Source: (Statistik, 2023)

As coffee production increases, the generation of coffee skin waste has also risen significantly, as processing primarily utilizes coffee beans while the skins are often discarded or left to decompose, creating challenges for effective organic waste management. This accumulation of waste can lead to environmental issues, including air pollution and health risks associated with microbial growth, as over 6 million tons of coffee waste are produced annually (Muslimaini, 2024). Fortunately, coffee skin waste can be transformed into eco-enzymes through fermentation, presenting a viable solution for utilizing this by-product. These eco-enzymes have potential applications as organic fertilizers and natural cleaning agents (V. A. Mirón-Mérida et al., 2021) which helps reduce waste volume while positively contributing to agriculture and environmental sustainability. Additionally, innovative techniques such as composting coffee skin waste have demonstrated significant promise in enhancing soil quality while reducing overall waste volume. For instance, utilizing coffee skin waste as compost has led to significant improvements in soil fertility and reduced reliance on chemical fertilizers (Maryanti, 2023). In conclusion, while coffee skin waste poses notable environmental challengeecon, its treatment and utilization offer promising solutions that can mitigate these issues while providing economic benefits to communities.

Coffee skin waste, often discarded or left to decompose, presents significant environmental challenges, particularly concerning air pollution and health risks associated with microbial growth. The annual coffee production generates over 6 million tons of waste, exacerbating pollution issues and contributing to the degradation of local ecosystems (Aristy & Rachman, 2023; Hasan et al., 2022). As coffee skins decompose, they release methane a potent greenhouse gas and create breeding grounds for pathogens, posing health risks to nearby communities (Mashami, 2022). Furthermore, the accumulation of untreated coffee waste can lead to soil and water contamination, further threatening public health and environmental integrity. However, innovative solutions such as composting coffee skin waste have shown promise in enhancing soil quality while reducing overall waste volume. For instance, in Tapak Gedung Village, utilizing coffee skin waste as compost has resulted in significant improvements in soil fertility and a reduced reliance on chemical fertilizers (Maryanti, 2023)m. By addressing these environmental challenges through effective waste management strategies, we can mitigate the negative impacts of coffee production while promoting sustainable agricultural practices.

With the increase in coffee production, the amount of coffee skin waste produced is also increasing. Coffee processing only utilises coffee beans, while coffee skins are often left to rot or discarded without being utilised as they are considered worthless. This creates challenges in organic waste management. To solve this problem, coffee skin waste can be processed into eco-enzymes that have the potential to be used in various applications, including as organic fertilisers and natural cleaning agents (Mérida et al., 2021). These waste-generated eco-

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enzymes not only help reduce the amount of waste but also provide benefits to agriculture and the environment.

Eco-enzymes are complex organic solutions produced through the fermentation of organic waste, sugar, and water. This process transforms kitchen waste into a valuable product with numerous applications as natural cleaners and food preservatives. The production of eco-enzymes involves fermenting organic kitchen waste, such as fruit and vegetable peels, combined with sugar (like molasses) and water (Muslimaini, 2024; Nafilah, 2024). The fermentation results in a dark brown liquid, rich in beneficial compounds that enhance various applications in households and agriculture (Muslimaini, 2024). As effective cleaning agents, eco-enzymes can break down organic matter and eliminate odors, serving as practical alternatives to chemical cleaners (Nafilah et al., 2024; Muarief et al., 2024). Their environmentally friendly nature reduces reliance on synthetic products, promoting sustainable waste management practices (Artaya, 2024; Yulistia & Chimayati, 2021). Additionally, the acidic nature of eco-enzymes inhibits microbial growth, making them suitable for food preservation. This natural composition ensures safety for both food and the environment, aligning well with health-conscious consumer trends (Artaya, 2024; Kamaliya & Lusiani, 2023). The versatility of eco-enzymes extends beyond cleaning; they can also enhance agricultural productivity by improving soil health when used as fertilizers. The fermentation process increases nutrient availability in the soil, leading to better crop yields (Brown & Jones, 2022; Larasati et al., 2020; Setiawati et al., 2023). Furthermore, eco-enzymes possess antibacterial and antifungal properties, supporting their use in both household and agricultural settings (Mashami, 2022). Overall, the production and application of eco-enzymes represent a sustainable approach to managing organic waste while providing valuable benefits to communities.

As effective cleaning agents, eco-enzymes are capable of breaking down organic matter and eliminating odors, making them a practical alternative to chemical cleaners (Muarief, 2024; Nafilah, 2024). Their environmentally friendly nature reduces reliance on synthetic cleaning products, thereby promoting sustainable waste management practices (Artaya, 2024)a. Furthermore, the acidic nature of eco-enzymes helps inhibit microbial growth, making them suitable for food preservation. This natural composition ensures safety for both food and the environment, aligning well with health-conscious consumer trends (Kamaliya & Lusiani, 2023; Artaya et al., 2024).

The versatility of eco-enzymes extends beyond cleaning and preservation; they can also contribute to agricultural productivity by improving soil health when used as fertilizers. The fermentation process enhances nutrient availability in the soil, which can lead to better crop yields (Brown & Jones, 2022; Chen & Chen, 2021). Additionally, eco-enzymes have been shown to possess antibacterial and antifungal properties, further supporting their use in both household and agricultural settings (Mashami, 2022). Overall, the production and application of eco-enzymes represent a sustainable approach to managing organic waste while providing valuable benefits to communities.

Coffee peels, a by-product of coffee processing, are rich in bioactive compounds such as polyphenols, fibers, and essential minerals, making them promising raw materials for eco-enzymes. These peels contain significant amounts of chlorogenic acids, with concentrations reaching up to 3787.58 mg/100 g dry weight, contributing to their potent antioxidant properties (Machado, 2023). Additionally, the fiber content in coffee by-products aids digestive health and promotes satiety (Santanatoglia et al., 2024). Coffee peels also provide essential minerals that enhance their nutritional profile and potential health benefits (Patel et al., 2022). By

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incorporating coffee peels into eco-enzyme production, we can reduce waste while extracting valuable nutrients that can be utilized in various applications.

Utilizing coffee peels as raw materials for eco-enzymes aligns with sustainable practices by reducing waste and promoting a circular economy within the coffee industry. This approach addresses the environmental challenges associated with coffee waste while enhancing resource efficiency (Faizan et al., 2023). The bioactive compounds extracted from coffee peels can be utilized in nutraceuticals, functional foods, and cosmetics, showcasing their versatility and market potential (Martinez et al., 2022; Zhang et al., 2021). Furthermore, incorporating coffee peels into eco-enzyme production can improve soil health when used as organic fertilizers. The bioactive compounds present can enhance nutrient availability in the soil, promoting better crop yields (Brown & Jones, 2022, 2022). Research has demonstrated that these compounds possess antibacterial and antifungal properties, further supporting their use in agricultural applications (Mashami, 2022). Thus, valorizing coffee peels not only mitigates waste but also opens new avenues for economic development and sustainability within the coffee industry.

Utilizing coffee peels as raw materials for eco-enzymes aligns with sustainable agricultural practices by promoting a circular economy within the coffee industry. This approach not only addresses the environmental challenges posed by coffee waste but also enhances resource efficiency(Faizan et al., 2023). Eco-enzymes derived from coffee peels can serve multiple functions, acting as natural cleaners, fertilizers, and food preservatives. Their multifunctionality makes them an attractive option for both consumers and producers looking to adopt more sustainable practices.

Moreover, the bioactive compounds extracted from coffee peels have significant potential for application in nutraceuticals and functional foods. The antioxidant properties of these compounds can be harnessed in various products aimed at improving health outcomes (Mashami, 2022). Additionally, the versatility of coffee peels extends to cosmetic applications due to their skin-protective properties. As research continues to explore the myriad uses of coffee by-products, it becomes clear that these materials should no longer be viewed as waste but rather as valuable resources that can contribute to sustainability and innovation within the food and beverage industry.

Methods

Research Location and Design

This research was conducted in Semarang City, Central Java Province, during semester 5 of 2023, from September to December. The selection of Semarang City as the research location was based on the availability of coffee skin waste from coffee production centres in the region around Central Java, which is relevant to the focus of this research. In addition, the city has potential as an innovation centre for organic waste management that supports the practical application of eco-enzyme. The availability of easily accessible raw materials and adequate infrastructure make Semarang City an ideal location for this research.

The research design was an experiment designed in a systematic and controlled manner. Systematic in the sense that the research stages including raw material collection, fermentation process, and parameter observation were carried out in a structured manner within a certain time interval. This research was also controlled, by ensuring consistency in the ratio of ingredients (coffee skin, sugar, and water), fermentation conditions (temperature and humidity), and tools used. This study aimed to evaluate changes in eco-enzyme organoleptic parameters (colour, pH, volume, and texture) as a result of the fermentation process.

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Tools and Materials

Tools used in the study consisted of 1.5 litre plastic bottles, scales.

Materials used in research: a) Robusta coffee skin waste 150 grams; b) 500 mL tap water; c) 50 grams brown sugar.

Research Parameters

The assessment was conducted organoleptically, using sensory observation to analyse changes in colour, pH, volume and texture parameters. This method ensures the data collected can accurately describe the effects of fermentation (Fitriyah, 2023).

Research procedures

The fermentation process was carried out for four months, with parameter observations every month. Ingredients were mixed in plastic bottles at a predetermined ratio, then fermented in a controlled environment. During fermentation, gas was released periodically to maintain the pressure inside the bottles. The stages of implementing Eco-enzyme research are:

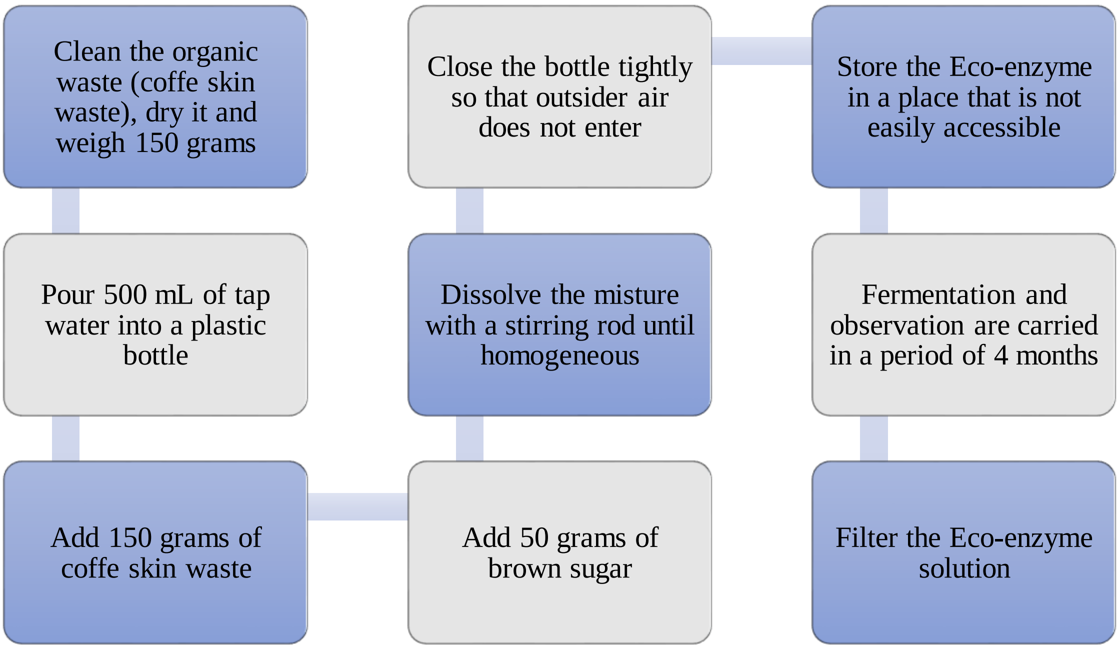

Figure 2. Procedure for making Eco-enzyme from coffee skin waste

Results and Discussion

Organoleptic Observations Over Time

The organoleptic parameters of the eco-enzyme solution were observed monthly for four months, with key changes in colour, pH, volume, and texture. These parameters reflect the transformation of coffee skin waste into a high-quality eco-enzyme.

Table 1. Organoleptic Observations of Eco-Enzyme during Fermentation

Month	Colour	pH	Volume (mL)	Texture
1st Month	Light Brown	7.0	500	Coarse
2nd Month	Brown	6.0	450	Coarse
3rd Month	Dark Brown	5.0	340	Smooth
4th Month	Deep Brown	4.0	240	Smooth

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This table highlights the progressive transformation of the eco-enzyme over four months. The changes in colour (light brown to deep brown) indicate the increasing presence of bioactive compounds as fermentation progressed. The pH reduction from neutral (7.0) to acidic (4.0) reflects successful microbial activity and organic acid production, enhancing the solution's antimicrobial and preservative properties. Volume reduction (from 500 mL to 240 mL) suggests efficient gas release during the process, which concentrated the active components. The texture's transition from coarse to smooth signifies the decomposition of solid particles, resulting in a more homogenous final product.

Colour Transition

The colour of the eco-enzyme solution changed significantly over the four months, indicating the progression of fermentation and the development of bioactive compounds.

Table 2. Colour Transition Observations

Month	Colour	Associated Process
1st Month	Light Brown	Initial mixture of coffee skin and sugar.
2nd Month	Brown	Early microbial activity.
3rd Month	Dark Brown	Increased bioactive compound concentration.
4th Month	Deep Brown	Final product stage with optimal fermentation.

The colour transformation observed in the solution reflects the fermentation's effectiveness. The initial light brown hue, attributed to the starting ingredients (coffee skin and sugar), gradually darkens to deep brown as microbial activity increases. This darkening correlates with the formation of bioactive compounds such as phenolic compounds and organic acids, which enhance the eco-enzyme's efficacy as a natural cleaning agent and fertilizer.

pH Reduction Analysis

The pH levels decreased steadily during the fermentation process, indicating successful microbial activity and organic acid production.

Table 3. pH Reduction Progression

Month	Initial pH	Final pH	Change (%)
1st Month	7.0	7.0	0.0%
2nd Month	7.0	6.0	14.3%
3rd Month	7.0	5.0	28.6%
4th Month	7.0	4.0	42.9%

The reduction in pH corresponds to increased organic acid production, which is crucial for the antimicrobial properties of the eco-enzyme. The consistent decline in pH from 7.0 to 4.0 over the four months underscores the active production of organic acids, particularly acetic acid, by microorganisms. This reduction in pH is a hallmark of successful fermentation, enhancing the antimicrobial properties of the eco-enzyme. The steady rate of decrease also indicates optimal conditions for microbial growth and activity, ensuring the production of a high-quality eco-enzyme.

Volume Reduction Trends

Volume reduction was a key observation during the fermentation process, driven by the release of gases (CO_2 and O_2) from microbial activity.

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Table 4. Volume Reduction Details

Month	Initial Volume (mL)	Final Volume (mL)	Reduction (mL)	Reduction (%)
1st Month	500	450	50	10%
2nd Month	450	340	110	24.4%
3rd Month	340	240	100	29.4%
Total	500	240	260	52%

The 52% total volume reduction over four months illustrates the release of gases like CO_2 during fermentation, a natural outcome of microbial metabolism. This reduction signifies the solution's increasing concentration of active compounds, improving its overall effectiveness. The relatively higher reduction percentages in the later months reflect peak microbial activity and the breakdown of complex organic materials.

Texture Transformation

The texture of the solution transitioned from coarse to smooth as fermentation progressed, indicating the breakdown of solid particles into finer components.

Table 5. Texture Evolution

Month	Texture	Observed Change
1st Month	Coarse	Undissolved solids present.
2nd Month	Coarse	Initial breakdown of solids.
3rd Month	Smooth	Particles mostly decomposed.
4th Month	Smooth	Fully homogenized, fine texture.

The texture's transformation from coarse to smooth highlights the breakdown of solid coffee skin particles as fermentation progressed. The smooth texture observed in the third and fourth months indicates that most solid components were fully decomposed, resulting in a homogeneous solution. This refined texture enhances the usability of the eco-enzyme in various applications, such as cleaning and soil enrichment.

Gas Release During Fermentation

Gas release is a significant aspect of the fermentation process, as it directly impacts both volume reduction and microbial activity.

Table 6. Gas Release and Pressure Management

Month	Gas Type	Observed Effect	Intervention
1st Month	CO_2	Minimal gas buildup.	Pressure monitored weekly.
2nd Month	CO_2 and O_2	Increased gas release.	Pressure released weekly.
3rd Month	CO_2 and O_2	Peak gas production.	Pressure released biweekly.
4th Month	CO_2	Declining gas release.	Pressure stable.

This table emphasizes the dynamic nature of gas production during fermentation. The gradual increase in CO_2 and O_2 release, particularly in the second and third months, corresponds to heightened microbial activity. The observed decline in gas production by the fourth month suggests that the fermentation process was nearing completion. Periodic pressure release ensured stability in the fermentation environment, preventing any disruptions that could compromise the solution's quality.

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The fermentation process lasted for four months, with parameter observations made every month. The research materials, namely coffee peels, brown sugar, and water, were mixed in plastic bottles at predetermined ratios. The bottles were sealed, and fermentation was carried out in a controlled environment. During fermentation, the gas produced was released periodically to keep the pressure inside the bottle stable.

Organoleptic observations showed significant changes in colour, pH, volume, and texture parameters during the fermentation process. In the first month, the solution was light brown with a neutral pH (7), which gradually changed to dark brown with an acidic pH (4) in the fourth month. The volume of the solution decreased from 500 mL to 240 mL due to gas release during fermentation. The texture of the solution also changed from rough to smooth in the third to fourth month, reflecting better decomposition of the solid particles. The observation results are presented in table 1 below:

Table 7. Organoleptic observation of Eco-enzyme dried coffee skin waste

Organoleptic observation	**1st mont**	**2nd month**	**3rd month**	**4th month**
Colour	Solution clear chocolate	Light brown	Dark chocolate	Deep chocolate
pH	7	6	5	4
Volume	500 mL	450 mL	340 mL	240 mL
Texture	Rafter	Rafter	Slick	Slick

The treatment of coffee skin waste is essential for mitigating the environmental pollution caused by the coffee processing industry. Coffee processing generates significant amounts of solid and liquid waste, which, if not managed properly, can lead to soil and water pollution. Studies have shown that the wastewater produced during coffee processing can reach up to 20 liters per kilogram of coffee, containing high levels of organic matter and pollutants such as biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Shanthakumar & Chiampo, 2021). This untreated wastewater poses serious risks to local ecosystems and public health, making effective waste management a critical concern (Gómez-Salcedo, 2021).

Innovative bioprocesses offer sustainable solutions for treating coffee waste. Techniques such as anaerobic digestion can convert coffee waste into valuable products like biogas and compost, enhancing sustainability in the coffee industry (Costa et al., 2022). Coffee skin waste is particularly rich in nutrients, making it an excellent candidate for composting, which not only improves soil health but also serves as a natural fertilizer (J. Mirón-Mérida, 2021). By implementing these sustainable practices, coffee producers can significantly reduce their environmental footprint while simultaneously enhancing the quality of their agricultural outputs.

Furthermore, utilizing coffee waste for the production of eco-enzymes and fertilizers provides economic benefits to local communities. Transforming waste into valuable products allows communities to generate new income streams while fostering environmental stewardship (Yulistia & Chimayati, 2021). However, challenges such as economic constraints and the need for technological advancements remain significant barriers to widespread implementation. Addressing these challenges through investment in research and development will be crucial for maximizing the potential of coffee waste treatment solutions. Overall, the valorization of coffee skin waste not only addresses pressing environmental issues but also fosters economic resilience within coffee-producing communities (Larasati et al., 2020).

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The fermentation process of eco-enzyme from coffee skin waste lasted for four months, conducted under controlled conditions to ensure consistency in results. The ingredients, including coffee skin waste, brown sugar, and water, were mixed in a standardized ratio and sealed in plastic bottles. To maintain stability, gas was periodically released to prevent pressure buildup. This controlled environment facilitated the systematic development of microbial activity, contributing to the formation of bioactive compounds (Machado, 2023).

The colour of the solution underwent a significant transformation during this process. From a light brown colour in the first month, the solution turned dark brown in the third month, and finally reached a deep brown colour in the fourth month. This colour change reflects the increased concentration of bioactive compounds produced during fermentation. An increase in the concentration of these compounds can enhance the effectiveness of the eco-enzyme as a natural cleaning agent and organic fertiliser (Raman, 2023). Additionally, the decrease in pH from 7 in the first month to 4 in the fourth month indicates an increase in acetic acid produced during the fermentation process. This decrease in pH is an indicator of successful fermentation and shows that the microorganisms have successfully produced organic acids that contribute to the preservative properties of the eco-enzyme (Gómez-Salcedo, 2021).

The volume of the solution also decreased significantly from 500 mL to 240 mL due to the release of gas during the fermentation process. This shows that the fermentation process not only produces new compounds but also reduces the volume of the solution, thus increasing the concentration of active components in the eco-enzyme. The texture of the solution changed from coarse to fine in the third and fourth months, indicating that the solid particles had decomposed well during the fermentation process (Santanatoglia, 2024). Overall, the organoleptic observation results showed that the fermentation process successfully transformed coffee skin waste into high-quality eco-enzyme that has the potential to be used in various environmental and agricultural applications(Nugraha & Setyawan, 2022; Pratama & Nugroho, 2023; Wang et al., 2021).

Eco-enzymes are a versatile solution for addressing various environmental and health challenges associated with waste management. Derived from the fermentation of organic materials such as fruit and vegetable peels, eco-enzymes can be utilized effectively as natural cleaners, disinfectants, insecticides, and food preservatives. The antimicrobial properties of eco-enzymes make them ideal for sanitizing surfaces and reducing the risk of diseases caused by harmful microorganisms. Studies have shown that eco-enzymes inhibit the growth of harmful bacteria, including *Escherichia coli and Enterococcus* species (Vidalia, 2021). This capability is particularly crucial in light of increased public awareness of hygiene practices during the COVID-19 pandemic, where traditional chemical disinfectants may pose health risks due to their harsh ingredients (Ardiansyah & Prasetyo, 2022; Vidalia, 2021).

In addition to their role in sanitation, the residues from eco-enzyme fermentation can be repurposed as organic fertilizers. These residues are nutrient-rich and can significantly improve soil health, promoting sustainable agricultural practices. Research has demonstrated that the application of eco-enzyme residues as fertilizers can enhance soil structure and fertility, leading to better crop yields (Gómez-Salcedo, 2021; Ridwan, 2022). By converting waste into a resource, this approach supports a circular economy model within agriculture, where waste products are reintegrated into the production cycle, thereby reducing environmental impact.

The dual benefits of eco-enzymes acting as both cleaning agents and nutrient-rich fertilizers underscore their potential for promoting sustainable practices. However, challenges related to economic limitations and the need for technological innovation in eco-enzyme production remain substantial (Gómez-Salcedo, 2021). ddressing these barriers through further research

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and community engagement is essential for maximizing the impact of eco-enzyme applications. Ultimately, eco-enzymes not only contribute to efficient waste management but also support public health and sustainable agricultural systems.

This study underscores the potential of eco-enzyme production from coffee skin waste as a sustainable solution to reduce environmental pollution. The four-month fermentation process demonstrated that coffee skin waste can be transformed into a valuable product—eco-enzyme—which can help mitigate pollution while improving soil quality and plant health. The resulting eco-enzyme is rich in bioactive compounds, making it suitable as a natural cleaner, disinfectant, and food preservative, offering significant economic benefits to farmers and society (Andriani et al., 2023).

Eco-enzymes have diverse applications that support sustainable agriculture. The residue from the fermentation process can be used as an organic fertilizer, which is nutrient-rich and enhances soil fertility. The use of organic fertilizers derived from coffee skin waste reduces dependence on chemical fertilizers, improving soil structure and increasing water retention (Ridwan, 2022). Moreover, eco-enzymes can be employed for natural pest control, reducing the need for harmful synthetic pesticides, which benefits both the environment and human health (Brown & Jones, 2022). Therefore, eco-enzymes have the potential to foster a more sustainable agricultural system.

However, this study also has limitations. One of the main limitations is that this study has not explored other variables that might affect the quality of eco-enzyme. For example, factors such as the type of organic waste used, the ratio of raw materials, and environmental conditions during the fermentation process may affect the final outcome of the eco-enzyme (Gómez-Salcedo, 2021). Further research is needed to understand other potential utilisations of coffee skin waste and to identify these variables in more depth. Further research could also explore the application of eco-enzyme in other industrial contexts or in the treatment of organic waste from different sources.

Challenges such as technological constraints and production costs also need to be addressed to enable the widespread adoption of eco-enzyme manufacturing. Investing in research and development to improve the efficiency of eco-enzyme production and expand its applications across various sectors will be crucial (J. Mirón-Mérida, 2021). In conclusion, the development of eco-enzyme manufacturing methods from coffee skin waste not only addresses the pollution problem but also presents new opportunities for both economic and environmental sustainability.

Eco-enzyme produced from coffee skin waste represents a groundbreaking solution to the organic waste issue, benefiting both the environment and the economy. The four-month fermentation process results in eco-enzyme rich in bioactive compounds, which not only serve as natural cleaners and disinfectants but also as organic fertilizers that improve soil fertility (J. Mirón-Mérida, 2021). Research results show that eco-enzyme is effective in reducing pollution by utilising waste that is usually discarded, thereby reducing the accumulation of waste in landfills and reducing greenhouse gas emissions such as methane (Septiani et al., 2021). In addition, the use of eco-enzymes in agriculture can reduce dependence on chemical fertilisers, providing economic benefits to farmers through increased crop yields and reduced agricultural input costs (Ridwan, 2022). Thus, the development of eco-enzyme manufacturing methods from coffee skin waste not only contributes to environmental sustainability but also improves the economic welfare of farming communitiesItalic.

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Conclusion

CEco-enzyme is a liquid fermented from organic waste that has various functions including floor cleaning, insecticide, and natural food preservatives such as fruits and vegetables. In addition, the residue from fermentation can also be used as fertiliser for soil fertiliser and other agricultural uses. Based on the observations from the organoleptic test, the characteristics of the coffee skin waste Eco-enzyme products produced in this study are as follows: 1) Colour: The Eco-enzyme product has a colour change from clear brown (from the brown sugar used) to cloudy brown; 2) pH: The pH of the Eco-enzyme solution goes from neutral or 7 to acidic which is 4; 3) Volume: There was a decrease in the volume of Eco-enzyme liquid produced due to the process of forced release of O2 and CO2 gases with a percentage of shrinkage volume of 52%; 4) Texture: The Eco-enzyme product produced has a slippery texture.

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