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REVIEW: UTILIZATION OF DOMESTIC WASTE (FRUIT) AS A RAW MATERIAL SOURCE FOR THE PRODUCTION OF ECO-ENZYMES, WHICH ARE USED AS LIQUID ORGANIC FERTILIZERS AND ANTIBACTERIAL AGENTS

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ABSTRACT

Domestic waste generated from households, particularly food scraps as well as vegetable and fruit residues, represents a major environmental problem when not properly managed. One alternative solution to reduce domestic waste while producing value-added products is the conversion of household organic waste into eco-enzymes. This study aimed to describe the processing of domestic waste into eco-enzymes and to evaluate their potential applications as antibacterial agents and liquid organic fertilizers. Eco-enzymes were produced through a fermentation process using domestic waste, molasses, and water at a ratio of 1:3:10 for a period of three months. The fermentation process resulted in a dark brown liquid with a characteristic acidic aroma, indicating successful microbial activity. The resulting eco-enzymes exhibited antibacterial properties and contained various macro and micro nutrients essential for plant growth, suggesting their effectiveness as disinfectants and organic liquid fertilizers. In conclusion, eco-enzymes derived from domestic waste offer a sustainable and environmentally friendly approach for waste management while providing multifunctional products with potential applications in sanitation and agriculture.

Keywords: Eco enzyme, Antibacterial, Liquid fertilizers, Domestic waste

ABSTRAK

Limbah domestik yang dihasilkan dari rumah tangga, khususnya sisa makanan serta residu sayuran dan buah-buahan, merupakan masalah lingkungan utama jika tidak dikelola dengan baik. Salah satu solusi alternatif untuk mengurangi limbah domestik sekaligus menghasilkan produk bernilai tambah adalah konversi limbah organik rumah tangga menjadi enzim ramah lingkungan. Studi ini bertujuan untuk mendeskripsikan pengolahan limbah domestik menjadi enzim ramah lingkungan dan mengevaluasi potensi aplikasinya sebagai agen antibakteri dan pupuk organik cair. Enzim ramah lingkungan diproduksi melalui proses fermentasi menggunakan limbah domestik, molase, dan air dengan rasio 1:3:10 selama tiga bulan. Proses fermentasi menghasilkan cairan berwarna cokelat tua dengan aroma asam yang khas, menunjukkan keberhasilan aktivitas mikroba. Enzim ramah lingkungan yang dihasilkan menunjukkan sifat antibakteri dan mengandung berbagai makro dan mikro nutrisi penting untuk pertumbuhan tanaman, menunjukkan efektivitasnya sebagai disinfektan dan pupuk organik cair. Kesimpulannya, enzim ramah lingkungan yang berasal dari *limbah domestik menawarkan pendekatan yang berkelanjutan dan ramah lingkungan untuk pengelolaan limbah sekaligus menyediakan produk multifungsi dengan potensi aplikasi di bidang sanitasi dan pertanian.*

Kata kunci: *Eco-enzim, Antibakteri, Pupuk cair, Limbah domestik*

Introduction

The issue of waste management in Indonesia is increasingly serious, as the volume of waste continues to rise and is frequently disposed of directly into the environment without proper treatment. This condition is highly concerning because the accumulation of waste in significant quantities and concentrations can have detrimental effects on environmental quality (Salsabila, 2023a)**.** Waste is generated from a wide range of sources, including residential areas, traditional markets, green open spaces, drainage systems, plantations, and other locations (Istanti, Indraloka & Utami, 2023). In general, waste is categorized into organic and inorganic fractions. Approximately, 57-60% of total waste consists of organic waste, predominantly food residues such as fruit and vegetable scraps. If not managed appropriately, organic waste can cause various environmental problems. However, due to its biodegradable nature, organic waste has considerable potential as a source of soil nutrients, supplying macro- and micro-nutrients, enriching humus content, and helping to improve soil structure (Istanti, Indraloka & Utami, 2023).

Organic waste originates from plant material and other living organisms, including fruit peel waste, which is one of the most commonly generated forms. (Illahi et al., 2023). When organic waste is allowed to accumulate without adequate management, it can lead to unpleasant odours, deterioration of water and soil quality, and the emissions of methane gas, which contribute significantly to environmental degradation (Novianto, 2022; Panataria et al., 2022). One effective approach to addressing this issue is convertion of organic waste into value-added products, such as eco-enzymes, which are used as organic liquid fertilizers (OLF). This approach not only reduces the negative impact of household organic waste but also supports the creation of a cleaner and healthier environment (Septinar et al., 2024).

Eco-enzymes are liquid solutions produced by fermenting organic waste, such as fruit and vegetable peels, which contain various beneficial enzymes and nutrients (Galintin & Rasit, 2021). The use of fruit peels containing natural organic acids as a base ingredient for eco-enzymes can enrich the nutritional content of the solution (Listiana, Ayuni,& Saputri, 2024). Eco-enzymes have enzymatic activities such as lipase, protease, and amylase, which have potential in wastewater treatment (Galintin & Rasit, 2021). Eco-enzymes also contain organic compounds that can act as natural disinfectants, rich in nutrients essential for plants, including nitrogen (N), phosphorus (P) and potassium (K) (Vidalia et al., 2023). In addition, eco-enzymes also contain organic acids that play a role in the production of plant growth hormones, such as auxin, gibberellin, and cytokinin (Almira, Nurmahni & Halimatus, 2024). Eco-enzymes are a multifunctional solution that is both environmentally friendly and economical. By utilizing readily available organic materials, eco-enzymes support environmental sustainability while offering a variety of applications in the agricultural, industrial, health and energy sectors. In the context of agriculture, eco-enzymes have been

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researched as organic liquid fertilizers that can enhance plant growth (Sarminingsih et al., 2023).

Organic fertilizers play an important role in enhancing the biological, chemical and physical activity of the soil, thereby supporting soil fertility and plant growth. However, many farmers still rely on inorganic fertilizers as their primary choice. The continued use of inorganic fertilizers can have negative impacts, including a decline in soil quality that affects its fertility (Nurnawati et al., 2022). To reduce dependence on inorganic fertilizers, the production of eco-enzymes as Organic Liquid Fertilizers (OLF) is a necessary step. Eco-enzymes have the potential to be used as liquid organic fertilizers because they contain enzymes such as trypsin and amylase, organic acids such as acetic acid (H_3COOH), and minerals that are important for plants such as nitrogen (N), phosphorus (P), and potassium (K), as well as several plant growth hormones such as auxin, gibberellin, and cytokinin. In addition, organic liquid fertilizer from eco-enzymes also contains bacteria that play a role in the decomposition of organic matter, stimulate plant growth, and help control pests and plant diseases. (Susilowati et al., 2021). The advantage of liquid organic fertilizer is that the nutrients it contains are more easily absorbed by plants (Rahmah et al., 2014).

Nutrients such as nitrogen (N), phosphorus (P), and potassium (K) also play a role in plant growth. Nitrogen is an essential nutrient that promotes vegetative growth, protein formation, chlorophyll, and nucleic acids, making it very important for plants (Rahmah et al., 2014). Phosphorus (P) plays an important role in plants by stimulating root growth, flower formation, fruit ripening, and seed production. In addition, phosphorus also functions in storing and distributing energy to all plant cells (Sinaga et al., 2024). Potassium (K) plays an important role in supporting vegetative growth in plants by improving assimilate transport, regulating stomatal opening and closing mechanisms to reduce water use, and increasing plant resistance to pests and diseases (Salsabila, 2023a). Research that has analysed the NPK content in eco-enzyme liquid fertilizers, as conducted by Listiana et al., (2024) obtained a value of N = 0.06%, P total = 0.01% and K = 1565.87 mg/l. In addition, the NPK content in eco-enzyme liquid fertilizer carried out by (Siregar et al., 2024) obtained in Eco-enzyme A with a content of N = 0.8400%, P = 0.2015% and K = 0.2650% and Eco-enzyme B with a content of N = 0.0300%, P = 0.0180% and K = 0.1014%.

Liquid organic fertilizer from eco-enzymes can be applied to plants to stimulate growth. This is because the acids contained in eco-enzymes contribute to the production of phytohormones such as auxin, gibberellin, and cytokinin, which serve to support vegetative and generative growth in plants and accelerate fruit ripening (Septinar et al., 2024). The auxin contained in eco-enzymes accelerates root growth so that plants can absorb water and nutrients more efficiently. Gibberellin helps accelerate flower and fruit formation, increasing overall crop yields. Cytokinin supports plant tissue regeneration and prolongs leaf life, allowing plants to photosynthesise for longer. With these hormone contents, eco-enzymes can replace some of the functions of synthetic fertilizers, which often have a negative impact on the environment (Listiana Ayuni & Saputri, 2024).

In addition to being an organic liquid fertilizer, eco-enzymes can be used as antibacterials because they have antibacterial properties that can inhibit bacterial

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growth. Several studies have analysed the antibacterial properties of eco-enzymes, such as those made from pineapple, which can inhibit the growth of *Staphylococcus aureus* and *Propionibacterium acnes* bacteria (Ramadani et al., 2022). The antibacterial activity of pineapple-based eco-enzymes can also inhibit the growth of *Pseudomonas aeruginosa* and *Staphylococcus epidermidis* bacteria. (Hendri et al., 2023).

Based on the above description, a literature review was conducted on the use of domestic waste (fruit) as a raw material source for the production of eco-enzymes, which are used in the production of organic fertilizers and antibacterial agents.

Methods

This article is a descriptive-analytical literature review. This review article was written by collecting, examining, and comparing the results of previous studies relevant to the title in order to obtain a complete and critical scientific overview. Writing this article review requires first determining the focus and scope of the review, then collecting articles from reliable sources such as books and scientific journals (Scopus, Sinta, Google Scholar, ScienceDirect, ResearchGate, and MDPI) with the keywords: eco-enzyme from fruit waste, eco-enzyme as organic fertilizer, utilization of fruit waste as organic liquid fertilizer. The titles and authors, year of publication, research methods, research results, and advantages and disadvantages of the research were then recorded. A First collection 1.500 articles and then become 500 articles based on the theme “Eo-enzyme”. A a total of 50–100 articles were collected. Data collection was carried out using a systematic search with the following inclusion criteria: articles published between 2015 and 2025, articles using fruit waste as raw material and fermentation process, and application as liquid fertilizer. The exclusion criteria were articles without experimental data or explanations of the manufacturing process, and publications that only discussed non-agricultural, environmentally friendly enzymes. Furthermore, the articles were analyzed and the research results obtained were compared, and general conclusions were drawn from the articles.

Results and Discussion

1. Domestic waste

Domestic waste is the most common type of waste generated by households, especially in urban areas. Common sources of domestic waste include food scraps, vegetables, fruit peels and other materials originating from household activities. (Sinaga et al., 2024). Generally, domestic waste is easily decomposed, producing methane gas that causes environmental pollution in the form of litter, greenhouse gas emissions, and unpleasant odours when disposed of carelessly. Domestic waste consists of organic matter, nutrients, pathogens and household chemicals that can damage the environment when disposed of (Lizundia et al., 2022). For this reason, domestic waste needs to be managed so that it can be used as raw material for bio-products and bioenergy. Managing domestic waste as a resource not only minimises waste but also creates local economic opportunities (Zuhro et al., 2023). Domestic waste treatment offers opportunities to recover energy resources, reusable water and nutrients (Haydar et al., 2018). Therefore, simple, inexpensive and easy technologies are often considered in domestic waste treatment at the household level (Domínguez-Solís et al., 2025).

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The approach generally involves combining waste reduction with the creation of economic added value, one example being the production of eco-enzymes. Eco-enzymes are liquids produced by fermenting domestic waste such as fruit, sugar and water, which generate enzymes, organic acids and bioactive compounds. (Ayu et al., 2021). Eco-enzymes can be formulated as liquid organic fertilizers, dishwashing soap, detergents and natural cleaning agents in the form of bioremediation agents (Fadlilla et al., 2023). Several literature studies show that domestic waste contains carbon and nutrients that can be used as raw materials for soil bio-amendments. Literature studies state that domestic waste can be used not only for fertilizer, but also as raw material for biocomposites (Lizundia et al., 2022). Domestic waste is not just rubbish but has potential as raw material for fermentation, composting or anaerobic digestion (Sembiring et al., 2021). The process of treating domestic waste is not easy, due to its heterogeneous nature and tendency to mix easily. Several methods of treating domestic waste depend on local conditions, source materials and the purpose of the end product. Methods of treating domestic waste include composting, fermentation and anaerobic digestion (Gumilar & Kadarohman, 2023).

2. Eco-Enzyme

Eco-enzymes are the result of fermenting household organic waste such as fruit and vegetable peels, sugar (molasses) and water in semi-anaerobic conditions for several months. The composition of waste, molasses and water is generally 1:3:10, which is then fermented for 3 months (N. Ayu et al., 2021). Fruits such as bananas, oranges, pineapples, apples, papayas, mangoes and dragon fruit have skins that are rich in sugar, fibre and minerals that are beneficial for the growth of fermentative microbes. This makes the skins suitable as a substrate in anaerobic fermentation processes (Panataria et al., 2022). Variations in fruit skin types provide different nutrients and final pH levels. Several experimental studies have proven that the formulation of the water: waste:sugar ratio and fermentation time of around 60–90 days has an effect on the final quality of the fermentation results. In addition to fermentation, several studies have also evaluated microbial inoculation (EM/yeast) to accelerate the process and increase enzymatic activity (Siregar et al., 2024). Eco-enzymes generally contain hydrolytic enzymes such as amylase, lipase and protease, as well as several types of organic acids and microflora that provide good bioactivity in various fields. Several important parameters that influence the quality of eco-enzyme products, such as substrate, sugar, water, particle size, temperature, and fermentation time, show changes in pH, TDS/TSS, BOD/COD, and reduced sugar content over 30–90 days. (Istanti, A, Indraloka & Utami, 2023). The process of making eco enzymes can be seen in Figure 1.

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Figure 1. Production of eco-enzyme liquid fertilizer (source: personal documents)

Several studies have shown that eco-enzymes from fruit peel raw materials have an antibacterial effect on several bacteria, such as E. coli and Staphylococcus spp. Testing using the disk diffusion method or MIC measurement at certain concentrations can provide good effectiveness against bacteria. An acidic pH inhibits bacterial growth, while hydrolytic enzymes can damage bacterial cell membranes and certain bacterial metabolic compounds can suppress bacterial growth (Galintin & Rasit, 2021).

a. Eco-enzymes as antimicrobials

Eco-enzymes have antimicrobial activity that can inhibit the growth of various types of microbes. This means that eco-enzymes can be used as a multipurpose cleaning product and disinfectant. In addition, eco-enzymes can also be used to control various types of pathogenic bacteria in plants, which cause plants to wilt and die (Sunarsih et al., 2024). Eco-enzymes can function as antimicrobials because they contain alcohol, acetic acid, lactic acid and several other secondary metabolites (Sunarsih et al., 2024). The presence of alcohol in ecoenzymes is due to the fact that organic waste materials such as pineapple peel, orange peel, banana peel, coffee husks, papaya peel and tomato peel contain organic compounds in the form of carbohydrates, which are used as substrates in the fermentation process. In addition, the protein content in organic waste supports microbial activity in breaking down carbohydrates into ethanol (Sunarsih et al., 2024). Pineapple skin contains 17.53% carbohydrates and 4.41% protein. The breakdown of glucose during fermentation is used to produce pyruvic acid. Under anaerobic conditions, pyruvic acid is broken down by pyruvate decarboxylase into acetaldehyde, which is then converted by alcohol dehydrogenase into ethanol and carbon dioxide. Acetobacter bacteria convert alcohol into acetaldehyde and water, and acetaldehyde is then converted into acetic acid (Sunarsih et al., 2024).

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Several studies on the antibacterial activity of eco-enzymes from various raw materials have been conducted. Eco-enzymes from pineapple peel (*Ananas comosus* L) can inhibit the growth of *Staphylococcus aureus* bacteria (Mubarokah & Diah, 2023), *Pseudomonas aeruginosa* and *Staphylococcus epidermidis* (Hendri et al., 2023), Prapionibacterium acnes (Ramadani et al., 2022). Eco-enzyme from dragon fruit peel (*Hylocereus polyrhizus*) can inhibit the growth of *Staphylococcus aureus* (Ambarwati, D & Marmaini, 2025). Eco-enzymes from eucalyptus leaves can inhibit *Salmonella* (Baihaqi et al., 2024), and some other fruit peel waste can inhibit *Enterococcus faecalis* (Mavani et al., 2020). Eucalyptus waste as an inhibitor of *Escherichia coli* (Baharuddin et al., 2025). The sources, methods and types of bacteria used in the analysis of eco-enzymes as antibacterial agents are presented in Table 1.

Table 1. Sources of eco-enzyme raw materials as antibacterial agents

No	Eco-enzyme raw materials	Types of bacteria	Method of analysis	Results obtained	Source of literature
1.	Orange peel	*Staphylococcus epidermidis*	Disc diffusion method	The inhibition zone diameters obtained were 2.5 ± 0.1; 2.1 ± 0.35; and 1.5 ± 0.5 with a pH range between 4.5 and 6.5	(Zummah, A Bahri, S Violando, W. A Tyastirin, 2024)
2.	Eucalyptus (Melaleuca leucadendra)	*Escherichia coli*	Well diffusion for Muller-Hinton	There are no inhibition zones around the wells, indicating that eucalyptus cannot inhibit the activity of *E. coli* bacteria.	(Baharuddin et al., 2025)
3	Eucalyptus (Melaleuca leucadendra)	*Salmonella Typhi*	Well diffusion for Muller-Hinton	The tested concentrations of eucalyptus eco enzyme (10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%) did not show any inhibition zones in the three test replicates	(Baihaqi et al., 2024)
4	Pepaya. nanas dan jeruk Kasturi	1. *Escherichia coli* (Migula) *Castellani* and Chalmers 2. *Staphylococcus aureus*	Well diffusion	A mixture of eco-enzyme solutions from papaya, pineapple and kaffir lime can inhibit the activity of E. coli and S. aureus bacteria.	(Tallei et al., 2023)
5	Dragon fruit peel	*Staphylococcus aureus*	disc diffusion method on agar medium NA	The test results showed that dragon fruit skin ecoenzymes did not form an inhibition zone against the growth of Staphylococcus aureus at various concentrations tested. These findings indicate that ecoenzymes do not have significant antibacterial	(Ambarwati, D & Marmaini, 2025)

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				properties against this gram-positive bacterium.	
6	Banana peel	*Vibrio alginolyticus, Vibrio fluvalis, Vibrio cholerae dan Aeromonas cavie*	Disc diffusion	The inhibition zone at a concentration of 100% with a moderate category can inhibit the growth of *Vibrio alginolyticus* and *Aeromonas cavie* bacteria	(Tuhumury, N. C Sahetapy, J/, 2024)
7	Pineapple peel	*Staphylococcus aureus* dan *Prapionibacterium acnes*	Disc diffusion method	The concentration of 100% banana peel eco-enzyme produced a large inhibition zone of approximately 12.33 ± 1.37 against S. aureus bacteria and 8.67 ± 0.52 against P. acnes bacteria	(Ramadani et al., 2022)
8	Fruit peel. There are two mixtures: 1) a mixture of eco-enzyme extracts from orange peel (Citrus aurantium) and pineapple peel (Ananas comosus) and 2) eco-enzyme extracts from papaya peel (Carica papaya)	*Enterococcus faecalis*	-	Has potential as an antibacterial agent	(Mavani et al., 2020)
10	Waste from pineapple (*Ananas comosus* L) and Berastagi orange (*Citrus X sinensis* L) peels	*Staphylococcus aureus*	-	The average diameter of the inhibition zone at a concentration of 60% was 13.1 mm, 7.9 mm at a concentration of 55%, 3.75 mm at a concentration of 50% and 3.35% at a concentration of 25%. The results showed that the ecoenzymes from pineapple peel waste (*Ananas comasus* L.) and Berastagi orange peel waste (*Citrus X Sinensis* L) had the ability to inhibit the growth of Staphylococcus aureus bacteria, as indicated by the formation of clear zones around the discs	(Mubarokah & Diah, 2023)
11	Garbage Enzyme	*Escherichia coli* and	diffusion method	The results showed that the antimicrobial activity of GE	(Ledo et al., 2024)

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	Staphylococcus aureus Antimicrobial	antiseptic solution produced clear zones of 14–21.3 mm for E. coli and 14.3–25.9 mm for S. aureus. The antimicrobial activity of GE antiseptic solution against E. coli and S. aureus increased with increasing concentrations of GE antiseptic solution, specifically at concentrations of 45% and 60%.

Orange peel is used as a raw material in the production of eco-enzymes because it contains limonene, flavonoids and organic acids. (Hidayah et al., 2025). Pineapple and papaya skins contain proteolytic enzymes in the form of bromelain in pineapple and papain in papaya, which function to destroy the structure of bacterial cell membranes. Proteolytic enzymes in pineapple skin waste help break down proteins on the surface of cell membranes, thereby increasing the penetration of other compounds. Proteolytic enzymes are susceptible to denaturation, so fermentation and storage conditions affect their activity. (Mubarokah & Diah, 2023). Coffee grounds and coffee as raw materials added to the eco-enzyme production process contain polyphenols. Polyphenols have antibacterial properties that differ from those of enzymes. Polyphenol compounds work by interacting with bacterial cell walls and proteins (Sunarsih et al., 2024). Therefore, eco-enzymes from various types of domestic waste, such as fruit waste, can be used as antibacterial agents and thus applied as antiseptic materials (Dzikrika et al., 2023).

b. Eco-enzymes as liquid fertilizer for plants

The amount of domestic waste increases every year, in line with the increase in human population and lifestyle, making it a crucial issue that needs to be managed quickly and appropriately. Domestic waste generally consists of food scraps, leaves, fruit peels, and other easily decomposable organic materials. This problem can lead to increased methane gas production, global warming, and groundwater pollution through leachate seepage from poorly managed domestic waste accumulation. Therefore, proper management of domestic waste is necessary. One method is through a fermentation process known as Eco-enzyme (Athiqoh et al., 2025). Eco-enzymes are multipurpose, environmentally friendly fermentation liquids that produce enzymes to accelerate plant growth. These fermentation liquids are useful as disinfectants and liquid fertilizers (Zuhriawan et al., 2023).

Liquid fertilizer is a fertilizer in liquid form and is used as a nutrient for plants. Liquid fertilizer generally contains macro and micro nutrients. Liquid fertilizer consists of two types, namely organic liquid fertilizer and inorganic liquid fertilizer. Organic liquid fertilizer is fertilizer produced by fermenting food waste, animal manure and human waste (Sinaga et al., 2024). The types of waste commonly processed into liquid fertilizer are domestic waste. Organic fertilizer can be applied to vegetables because it contains macro and micro nutrients such as nitrogen, phosphorus, calcium,

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sulphur, potassium, iron, manganese and other organic materials. In addition, organic fertilizer is more effective and efficient for long-term use, superior to solid organic fertilizer, and can stimulate plant growth well. (Taufik, 2024). Eco enzyme liquid fertilizer can be applied to green mustard plants (Saputri & Anisya, 2024) (Laila & Suhartini, 2024), pakcoy (Nugraha & Sa'diyah, 2023) (Rahmadani et al., 2025), corn (Taufik, 2024), chilli pepper plants (Saputra & Hibatullah, 2023) (Tabel 2).

Studies have tested the total nutrient content in eco-enzymes, but the results show that Norg, soluble phosphorus (P), and soluble K are present in relatively low concentrations compared to commercial fertilizers. However, microelements (Fe, Mn, Zn) can be detected and contribute to improving plant micronutrition. Several studies used simple spectrophotometry methods for P and K and Kjeldahl for Norg, while further studies used ICP-OES/ICP-MS. (Zuhriawan et al., 2023).

Eco-enzymes, as liquid organic fertilizers made from fruit peel waste, can be used effectively and their application to chilli plants has been proven to increase the number of leaves by 67% and plant height by 73% (Wahyuningsih et al., 2024). The application of ecoenzymes as liquid organic fertilizer at varying concentrations had a significant effect on plant growth at a concentration of 10 ml/L. (Salsabila, 2023a). Application of eco-enzyme concentrate as organic liquid fertilizer at a concentration of 3% (30ml/1000 ml water) is effective for plant growth (Dondo et al., 2023). Eco enzymes contain enzymes such as trypsin and amylase, organic acids such as acetic acid (H3COOH), and minerals essential for plants such as nitrogen (N), phosphorus (P), and potassium (K), as well as several plant growth hormones, such as auxin, gibberellin, and cytokinin. Eco-enzyme liquid fertilizer is based on fruit and vegetable peel waste. Different eco enzyme compositions affect the N, P and K nutrient content of eco enzymes (Agustina et al., 2024).

Eco-enzymes are solutions produced by fermenting organic waste such as fruit peels, vegetables, sugar, and water, which are rich in enzymes and nutrients. This fermentation process produces organic compounds that have significant benefits, including as liquid fertilizers for plants. Eco-enzymes also contain macro nutrients such as nitrogen (N), phosphorus (P), and potassium (K), which are essential for plant growth. The use of eco-enzymes as liquid fertilizer not only supports environmental sustainability through waste management but also offers an environmentally friendly alternative to synthetic fertilizers. With its high nutrient content, eco-enzymes have great potential to improve crop cultivation efficiency, especially in hydroponic systems (Panataria et al., 2022). The highest total nitrogen content was found in the vegetable + citrus treatment with an average value of 8.05%, the highest P content was found in the vegetable + dragon fruit treatment with an average value of 2.395%, and the highest K content was found in the vegetable + dragon fruit treatment with an average value of 0.928% (Istanti, Indraloka & Utami, 2023). Research on nutrient quality includes levels of N = 0.07%, P = 0.04%, and K = 0.004% of eco-enzymes in a mixture of pineapple peel and orange peel (Salsabila, 2023b). Research on the quality of macro content Nitrogen = 0.01%, Phosphorus = 60.04 ppm and Potassium = 172.73 ppm (Saputra &

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Hibatullah, 2023). Analysis of the Eco-Enzyme content in land water spinach shows that it contains 0.06% nitrogen, 0.01% phosphorus, and 1565.87 mg/L potassium (Listiana Ayuni & Saputri, 2024).

Table 2. The application of eco-enzymes as an organic liquid fertilizer on plants

No	Eco-enzyme raw materials	Nutrient	Application on plants	Source of literature
1	red dragon fruit peel, mangosteen peel, pomelo peel, vegetable waste	The highest nitrogen content is found in vegetables and oranges at 8.05%, the highest phosphorus content is found in vegetables and dragon fruit at 2.395%, the highest potassium content is found in vegetables and dragon fruit at 0.928%, and the highest organic carbon content is found in vegetables and oranges at 20.407%	No testing on plants	(Istanti, A, Indraloka & Utami, 2023)
2	orange and pineapple peel waste	Nitrogen 0.007%, Phosphorus 0.04% and Potassium 0.004%	pak choi	(Salsabila, 2023a)
3	pineapple peel	Organic carbon 2.71%, total nitrogen 2.9%, total phosphorus 2.9% and potassium 4.2%	Green mustard	(Saputri & Anisya, 2024)
4	pineapple peel, orange peel, and watermelon peel	Total nitrogen 0.06%, total phosphorus 0.01%, organic carbon 1.15% and potassium 1565.87%	Land water spinach (Ipomoea reptans poir)	(Listiana, Ayuni, Saputri & Amelia, 2024)
5	Bananas, oranges, lemongrass, pineapples, watermelons, and cucumbers	N-total 0.01%, P 60.04 parts per million, K2O 172.73 parts per million	Chilli plant	(Saputra & Hibatullah, 2023)
6	pineapple peel	Nitrogen 0.14%, phosphorus 0.037%, potassium 0.064%, calcium 0.127%	pak choi	(Nugraha, M. M. E & Sa'diyah, 2023)
7	Fruit peel (pineapple, watermelon, cucumber, tangerine),	C-organic 1.32%, N 0.59%, P 0.06% dan K 1.19%	sorghum cultivars (Sorghum bicolor (L.) Moench)	(Irmansyah et al., 2024)
8	vegetables and fruits (chayote, watermelon, and apples)	Nitrogen/N 0.02%, Phosfor/P2O5 0,00025%, Kalium/K2O 0,0012%.	Mustard Greens (Brassica juncea L.)	(Zuhro et al., 2023)
9	vegetable waste used is cabbage and spinach	Nitrogen(N) 2.80%, Phosphorus(P2O5) 3.92%, Potassium(K2O) 2.64%, dan C-Organic 14.30%	Red Onion (Allium ascalonicum L.)	(Halim et al., 2025)

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10	melon leaves, melon stems and fmelon peels	Nitrogen 0.05%, P-total 0.03%, Kalium 0.18%, C-Organik 2.13%	Melon (Cucumis melo L. var. Merlin)	(Ulmillah et al., 2025)

The use of eco-enzymes has been proven to improve plant growth quality compared to conventional fertilizers. The nutrients and hormones contained in eco-enzymes provide additional benefits that support both vegetative and generative growth. In addition, eco-enzymes also help maintain the pH stability of nutrient solutions, which is an important factor in hydroponics. Research shows that the application of eco-enzymes can increase crop yields by up to 20% compared to the use of conventional chemical fertilizers (Ayuni, 2023).

The use of fruit peel waste for the production of eco-enzymes not only supports sustainable agriculture but also helps reduce organic waste. By processing waste into value-added products, eco-enzymes provide a solution for reducing environmental pollution while providing an environmentally friendly alternative to fertilizers. In the long term, the use of eco-enzymes can help maintain soil fertility and water quality, thereby supporting a healthier ecosystem (P. Ayu et al., 2023).

The integration of eco-enzymes as organic liquid fertilizers in modern agriculture offers numerous benefits, both economically and ecologically. In hydroponic systems, eco-enzymes are an effective alternative to chemical fertilizers that have the potential to damage the environment. With their complete nutritional content and multifunctional properties, eco-enzymes can support healthier and more productive plant growth. Additionally, eco-enzymes can be applied in various other agricultural systems, making them an innovative solution to future agricultural challenges. (Vidalia et al., 2023).

Conclusion

Based on the reviewed literature, the utilization of fruit-based domestic waste as a raw material for eco-enzyme production demonstrates significant potential as an environmentally friendly solution for waste management and sustainable agriculture. The findings consistently indicate that eco-enzymes contain essential nutrients, organic acids, enzymes and phytohormones that contribute to improved soil quality, enhanced plant growth and antibacterial activity. In addition, the application of eco-enzymes as liquid organic fertilisers can reduce dependence on inorganic fertilisers and mitigate their negative environmental impacts.

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