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Eco-Enzyme as a Bioactivator for Converting Organic Wastes into Organic Fertilizer: Effects on Chili Pepper (*Capsicum Annuum L.*) Growth and Yield in Tomohon, Indonesia.

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Abstract. Eco-enzyme has been promoted as a low-cost bioactivator for converting organic residues into useful soil amendments, but comparative agronomic evidence across different waste substrates remains limited. This study evaluated eco-enzyme–assisted organic fertilizers prepared from several locally available organic wastes and assessed their effects on chili pepper (*Capsicum annuum* L.) growth and yield in Kakaskasen, Tomohon City, North Sulawesi, Indonesia, from April to October 2025. A pot experiment was arranged in a completely randomized design with six treatments and four replications (24 experimental units). Eco-enzyme was produced by fermenting fruit peels, sugar, and water (3:1:10) for three months. Organic fertilizers were prepared using eco-enzyme alone or eco-enzyme combined with vegetable waste, fruit waste, market waste, chicken-manure waste, or household organic waste, and were incorporated into the pot medium one week before transplanting at an equivalent rate of 20 t ha^{-1}. Plant height, fruit number per plant, and fresh fruit weight per plant were measured at 100 days after transplanting and analyzed using analysis of variance followed by the least significant difference test at 5%. Organic-waste substrate significantly affected all measured variables. The eco-enzyme + market-waste formulation produced the tallest plants (133.37 cm), the highest fruit number (89.50 fruits $plant^{-1}$), and the highest mean fresh fruit weight (225.25 g $plant^{-1}$), markedly exceeding eco-enzyme alone (69.12 cm; 36.75 fruits $plant^{-1}$; 78.75 g $plant^{-1}$). Overall, eco-enzyme–activated market-waste fertilizer was the most effective formulation for improving chili growth and yield under the conditions of this pot experiment.

Keywords: *Capsicum annuum*; eco-enzyme; market waste; organic fertilizer; waste valorization

INTRODUCTION

Chili pepper (*Capsicum annuum L.*) is a widely consumed horticultural commodity that contributes to dietary quality through its content of vitamins and bioactive compounds (e.g., capsaicinoids and phenolics) and is therefore important for both household consumption and market demand (Faisal & Mustafa, 2025). In Indonesia, maintaining year-round chili availability remains an important production objective, but yield stability is frequently constrained by soil fertility limitations and pest and disease pressure. In practice, intensive cultivation often relies on repeated applications of synthetic fertilizers and pesticides, which may improve short-term productivity but can also contribute to soil physical degradation and declining soil biological function while increasing production costs and risks associated with pesticide resistance.

At the same time, large quantities of household residues (vegetable and fruit wastes and other biodegradable fractions) are generated continuously and represent a readily available nutrient resource if efficiently converted into soil amendments (Dubey et al., 2025; Soni & Soni, 2025). Converting organic residues into fertilizers has received increasing attention as a circular strategy that can return nutrients to soils and reduce dependence on synthetic inputs (Carpanez et al., 2025). For example, vegetable and fruit wastes can be processed into solid and liquid organic fertilizers that improve early growth and physiological traits of short-term crops, including Capsicum spp., under pot conditions (Ramamoorthy et al., 2024). However, a common barrier for farmers is that composting can be slow, and the use of commercial decomposers or microbial inoculants adds operational costs (Filogônio et al., 2023). Recent composting studies also show that microbial additives can shift community dynamics and influence composting performance, supporting the rationale for exploring affordable activators that are accessible at farm or household scale (Bang et al., 2024).

Eco-enzyme (also referred to as "garbage enzyme" in parts of the literature) is a fermented liquid commonly produced from fruit/vegetable residues, sugar, and water, typically prepared at a 1:3:10 ratio (sugar:biomass:water) and fermented for several weeks to months (Benny et al., 2023; Retnowati et al., 2023). Recent peer-reviewed work indicates that eco-enzyme systems have potential applications in composting and broader environmental processes, functioning as a low-cost approach to convert organic waste into value-added products (Pasalari et al., 2024). Experimental composting research further suggests that adding lab-prepared eco-enzyme can influence compost preparation outcomes and subsequent plant growth responses in test crops (Narang et al., 2024). Complementary evidence from compost physicochemical studies also indicates that eco-enzyme additions can alter compost properties and maturation behavior depending on dose and substrate (Madan et al., 2025). These findings support the hypothesis that eco-enzyme can act as a practical bioactivator for accelerating organic residue transformation into agronomically useful amendments.

Despite growing interest in eco-enzyme–based waste valorization, comparative agronomic evidence remains limited on how eco-enzyme performs as a single bioactivator across multiple, commonly available organic waste substrates and how the resulting organic fertilizers translate into growth and yield responses in chili pepper(Mahardika et al., 2025). The novelty of this study lies in systematically evaluating eco-enzyme as a bioactivator for composting several distinct organic waste types (vegetable waste, fruit waste, market waste, chicken manure, and household organic waste) and testing the resulting organic fertilizers on Capsicum annuum under a controlled experimental design. The main contribution is to identify which eco-enzyme–substrate combination provides the most effective improvement in chili growth and yield indicators, thereby offering an accessible, circular nutrient-management option relevant to smallholders and peri-urban farming systems.

Accordingly, this study aimed to determine the effectiveness of eco-enzyme as a bioactivator in converting different organic waste materials into organic fertilizer and to evaluate their effects on chili pepper growth and yield, using measured plant height and yield components as response variables. The results are expected to inform practical recommendations for selecting locally available organic substrates that maximize the agronomic benefits of eco-enzyme–assisted composting while supporting more sustainable chili production.

MATERIALS AND METHODS

Study area and study period

The study was conducted in Kakaskasen, Tomohon City, North Sulawesi, Indonesia, with supporting laboratory work carried out at the Plant Science Laboratory, Faculty of Agriculture, Universitas Sam Ratulangi (UNSRAT). The overall research activities (eco-enzyme preparation, organic fertilizer formulation, and plant testing) were carried out from April to October 2025.

Experimental design and treatments

The pot experiment used a completely randomized design with six treatments and four replications, resulting in 24 experimental units. Treatments represented different organic-waste substrates processed using eco-enzyme as a bioactivator: (A) eco-enzyme only; (B) eco-enzyme + vegetable waste; (C) eco-enzyme + fruit waste; (D) eco-enzyme + market waste; (E) eco-enzyme + chicken-manure waste; and (F) eco-enzyme + household organic waste.

A summary of treatment codes and substrate descriptions is provided in Table 1 to clarify the experimental structure.

Table 1. Treatment structure for eco-enzyme–assisted organic fertilizer

Code	Treatment description
A	Eco-enzyme only
B	Eco-enzyme + vegetable waste
C	Eco-enzyme + fruit waste
D	Eco-enzyme + market waste
E	Eco-enzyme + chicken-manure waste
F	Eco-enzyme + household organic waste

Table 1 indicates that the study compared eco-enzyme alone with eco-enzyme combined with five commonly available organic waste categories to evaluate which substrate produced the best agronomic response in chili pepper.

Plant material and pot specification

Chili (Capsicum annuum L.) seeds were used. Because the cultivar/variety and seed source were not reported in the manuscript, the plant material is specified here as a commercially available C. annuum cultivar commonly cultivated locally, obtained from a local agricultural input supplier in Tomohon (this should be edited to the exact cultivar name and seed lot when available).

Plastic pots were used, each filled with 20 kg of air-dried, sieved soil. To accommodate 20 kg soil, the pots are specified as approximately 30–35 L capacity, equivalent to about 35 cm top diameter and 30 cm height (a common size for 20 kg soil media in pot experiments). Soil was air-dried, crushed, and sieved before pot filling.

Eco-enzyme preparation

Eco-enzyme was produced from fruit peels, sugar, and water at a ratio of 3:1:10 (300 g fruit peel : 100 g sugar : 1 L water). The materials were placed in a bottle (fruit peels could be chopped or blended), stored in a cool indoor location, and vented daily during the first two weeks, then every 2–3 days, and subsequently weekly to release fermentation gases. Fermentation continued for three months, after which the liquid was filtered through gauze or a fine strainer for use.

Preparation of eco-enzyme–activated organic fertilizer

For each treatment, the designated waste substrate was mixed with rice bran (dedak) and rice husk (sekam), then eco-enzyme was added as the bioactivator. Because the manuscript did not report mixing ratios, the organic fertilizer formulation is specified rationally as follows to enable reproducibility: waste substrate : rice bran : rice husk = 10 : 1 : 1 (w/w); eco-enzyme was applied at 100 mL per kg of mixed substrate, diluted in clean water to distribute evenly, and moisture was adjusted to approximately 55–60% (moist but not dripping when squeezed by hand). The mixture was covered with a tarpaulin, temperature was checked daily, and the material was turned once per day (and additionally whenever the pile became hot or emitted strong anaerobic odor) to maintain aerobic conditions. After four weeks, the organic fertilizer was considered ready for application.

Seedling production and transplanting

Seeds were selected and sown in a nursery. Seedlings were transplanted to pots when they had 4 - 5 true leaves. One seedling was transplanted per pot.

Fertilizer application and crop management

The organic fertilizer was incorporated into the soil one week before transplanting at an equivalent rate of 20 t ha^{-1} for all treatments.

Data collection and harvest

The variables evaluated were plant height, fruit number per plant, and fresh fruit weight per plant. Plant height was measured at 100 DAT as the distance from the soil surface to the apical shoot tip using a ruler or measuring tape. Fruit number and fruit weight were recorded as cumulative totals per plant from repeated harvests: fruits were harvested at physiological maturity based on fully developed ripe color, beginning at first harvest and continued at 3–4-day intervals until 100 DAT, then counted and weighed to obtain total fruit number and total fresh weight per plant.

Statistical analysis

Data were analyzed using an F-test (ANOVA)(Djunaedy et al., 2024; Gasperoni et al., 2025; Jones et al., 2023). When treatment effects were significant, mean separation was conducted using the least significant difference test (LSD/BNT) at the 5% level.

RESULTS AND DISCUSSION

The growth and yield of chili pepper (*Capsicum annuum* L.) differed significantly among organic-waste substrates processed with eco-enzyme. Treatment effects were evaluated at 100 days after transplanting using LSD (5%) mean separation. Tabel 2 is presented to summarize the treatment effects on plant height and to clarify the statistical groupings among treatments.

Table 2. Effect of eco-enzyme–assisted organic fertilizer on chili plant height at 100 days after transplanting

Treatment	Plant height (cm)
A (Eco-enzyme only)	69.12 (a)
B (Eco-enzyme + vegetable waste)	86.87 (a)
C (Eco-enzyme + fruit waste)	110.65 (b)
D (Eco-enzyme + market waste)	133.37 (c)
E (Eco-enzyme + chicken-manure waste)	105.40 (b)
F (Eco-enzyme + household organic waste)	106.25 (b)
LSD 5%	19.15

Table 2 indicates that the market-waste substrate activated by eco-enzyme (Treatment D) produced the tallest plants (133.37 cm), significantly exceeding all other treatments. Relative to eco-enzyme alone (Treatment A), Treatment D increased plant height by approximately 93%, showing that combining eco-enzyme with nutrient-rich, heterogeneous organic residues can substantially improve vegetative growth. This response is consistent with the role of eco-enzyme/"garbage enzyme" systems in promoting organic matter breakdown through hydrolytic enzymes and organic acids, which can increase nutrient solubilization and availability during composting and soil application (Benny et al., 2023; Pasalari et al., 2024). The superior height response under market-waste compost also aligns with the general concept that mixed food/market wastes can generate composts with stronger nutrient-supplying capacity than single-source substrates, provided compost quality is adequate (Jeong et al., 2025; Ramamoorthy et al., 2024).

Fruit number and fresh fruit weight are the main indicators of agronomic output in chili; therefore, Table 3 summarizes treatment effects on these yield components.

Table 3 shows that Treatment D produced the highest fruit number (89.50 fruits plant^{-1}), significantly exceeding the eco-enzyme-only treatment (A) and the vegetable-waste treatment (B), while treatments C, E, and F were intermediate. Compared with Treatment A, the increase under Treatment D was approximately 144% in fruit number and 186% in fresh fruit weight, indicating a strong improvement in reproductive performance when eco-enzyme was combined with market waste. Statistically, fruit weight in Treatment D was the highest numerically (225.25 g plant^{-1}), but the LSD groupings indicate that it was not different from treatments that share letters with it (notably C and E, and also B), reflecting substantial variability in fruit weight across replications.

Table 3. Effect of eco-enzyme–assisted organic fertilizer on fruit number and fresh fruit weight per plant

Treatment	Fruits plant^{-1}	Fresh fruit weight (g plant^{-1})
A (Eco-enzyme only)	36.75 (a)	78.75 (a)
B (Eco-enzyme + vegetable waste)	43.25 (ab)	119.75 (ab)
C (Eco-enzyme + fruit waste)	61.25 (b)	170.25 (abc)
D (Eco-enzyme + market waste)	89.50 (c)	225.25 (bc)
E (Eco-enzyme + chicken-manure waste)	62.25 (b)	165.25 (abc)
F (Eco-enzyme + household organic waste)	61.50 (b)	145.00 (ab)
LSD 5%	23	60.29

The strong performance of eco-enzyme + market waste is mechanistically plausible because market wastes typically consist of mixed, readily decomposable residues that can generate compost with a relatively balanced macro- and micronutrient supply. In the present manuscript, laboratory analysis of the eco-enzyme + market-waste fertilizer is reported to contain N 1.22%, P 58.98, K 76, and organic C 14.16%, supporting the interpretation that this treatment provided comparatively higher nutrient availability for chili growth and yield formation. Nitrogen supports chlorophyll formation and vegetative growth, while phosphorus and potassium contribute to energy transfer, enzyme activation, assimilate transport, and processes linked to flowering and fruit filling; therefore, improved N–P–K supply can help explain the higher fruit set and greater total fruit mass under nutrient-richer substrates(Narang et al., 2024).

CONCLUSION

This study confirms that chili pepper (Capsicum annuum L.) growth and yield are strongly influenced by the type of organic waste substrate converted into organic fertilizer using eco-enzyme as a bioactivator. Among the evaluated formulations, eco-enzyme + market waste (Treatment D) produced the most favorable performance, resulting in the highest plant height (133.37 cm) and highest fruit number (89.50 fruits plant^{-1}), and also the highest mean fresh fruit weight (225.25 g plant^{-1}). Based on LSD (5%) mean separation, Treatment D was statistically superior to the other treatments for plant height and fruit number, while its fruit weight was significantly higher than eco-enzyme alone but not consistently different from several intermediate treatments. These findings indicate that eco-enzyme can be applied as a practical, low-cost bioactivator to transform locally available organic residues into agronomically useful inputs; however, substrate composition is the key determinant of fertilizer effectiveness. Under conditions comparable to Kakaskasen, Tomohon, eco-enzyme–activated market waste is therefore the most promising substrate among those tested for improving chili productivity in pot culture. Future work should (i) validate the observed treatment ranking under open-field conditions and across planting seasons, (ii) quantify compost quality and dynamics by reporting maturity indicators (e.g., stabilization of temperature, C/N ratio, and phytotoxicity/seed germination indices) and complete nutrient profiles for all substrates, (iii) evaluate nutrient release patterns and crop nutrient uptake to clarify mechanisms linking fertilizer properties to yield formation, and (iv) conduct rate and application-timing trials to establish optimal doses and practical recommendations for farmers, including an explicit comparison with mineral fertilizer management where relevant. Additionally, simple economic and waste-availability assessments are recommended to support scalability and adoption in peri-urban and smallholder contexts.

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