

Fruit Peel Eco-Enzyme Precipitate Improves Vegetative Growth and Biomass of *Solanum pimpinellifolium* L.

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Submitted: January 10, 2026; Accepted: February 22, 2026; Available online: April 3, 2026; Published: October 31, 2026

Abstract. Eco-enzyme precipitate derived from fruit peel fermentation has emerged as a promising organic input for sustainable agriculture. This study aimed to evaluate the effects of eco-enzyme precipitate on the vegetative growth of *Solanum pimpinellifolium* L. A completely randomized design with five treatment levels (P0–P4) was applied. Growth parameters observed included plant height, number of leaves, leaf width, fresh weight, and dry weight. Data were analyzed using one-way ANOVA followed by Tukey's test at a 5% significance level. The results demonstrated that eco-enzyme precipitate significantly enhanced all measured parameters ($p < 0.05$). The highest treatment level (P4) consistently produced superior growth performance, with plant height reaching 11.70 cm, leaf number 9 leaves, leaf width 1.63 cm, fresh weight 4.85 g, and dry weight 0.93 g, compared to the control treatment (P0). The progressive increase across treatments indicates a dose-dependent response associated with improved nutrient availability, enhanced photosynthetic capacity, and greater biomass accumulation. The marked rise in dry weight confirms that growth improvement reflected genuine physiological gain rather than temporary water retention. These findings highlight the agronomic potential of eco-enzyme precipitate as a low-cost organic fertilizer capable of improving vegetative growth while simultaneously supporting waste valorization and circular agricultural systems. The study provides empirical evidence that fruit peel-derived eco-enzyme precipitate can serve as a sustainable alternative input for small-scale farming, contributing to environmentally responsible agricultural practices.

Keywords: Eco-enzyme Precipitate; Fruit Peel Waste; *Solanum pimpinellifolium* L.; Solid Organic Fertilizer; Vegetative Growth

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How to cite this article:

Dewi, R., Satitiningrum, Y., & Amelia, I. (2026). Fruit Peel Eco-Enzyme Precipitate Improves Vegetative Growth and Biomass of *Solanum pimpinellifolium* L. *BIOPENDIX: Jurnal Biologi, Pendidikan Dan Terapan*, 13(2), 97 - 107. <https://doi.org/10.30598/biopendixvol13issue2page97-107>

Journal homepage: <https://ojs3.unpatti.ac.id/index.php/biopendix>

Journal e-mail: jbiopendix@gmail.com

INTRODUCTION

Organic waste management has increasingly become a global environmental concern, particularly in developing countries where waste disposal practices remain deficient and unsustainable (Ddiba, Andersson, Rosemarin, Schulte-Herbrüggen, & Dickin, 2022; Ferronato & Torretta, 2019; Mahajan, 2023; Pandyaswargo et al., 2019). Indonesia generates more than 60% organic waste from total municipal waste, and fruit peel waste constitutes one of the largest fractions (Abdul Hakim Zakkiy Fasya, Mursyidul Ibad, Kuuni Ulfah Naila El Muna, Shofi Fitri Pratiwi, & Shofiyah Ajeng Sekar Arum, 2025; Damanhuri, Handoko, & Padmi, 2014; OECD, 2019; Wikurendra, Csonka, Nagy, & Nurika, 2024). Improper handling of this waste often leads to environmental degradation, including unpleasant odors, methane emission, soil contamination, and additional burden on landfill systems (Misrawati & Zaim, 2024; Wijaya, Ainun, & Permadi, 2021). Therefore, there is a growing urgency to convert organic waste into valuable products that support sustainable agriculture and promote ecological resilience (Bhatia & Sindhu, 2024; Das & Kim, 2024; Mia & Zzaman, 2025). One innovative approach that has recently gained attention is the development of eco-enzyme and its by-products, including eco-enzyme precipitate, which is derived from fermentation residue (Gumilar, 2023; Siregar, Siallagan, Butar Butar, Mahmudi, & Pujiastuti, 2024). This material, often discarded in conventional eco-enzyme production, has shown potential as a nutrient-rich organic amendment beneficial for plant growth.

Eco-enzyme, popularized by Dr. Rosukon Poompanvong, is a fermented organic solution produced from fruit and vegetable waste, water, and sugar (Kirana et al., 2022; Maharani & Lusiani, 2023; Rachman, Yanti, & Abdullah, 2025; Triyatdipa, Agustien, & Marlina, 2025). It has been reported to contain bioactive compounds such as acetic acid, enzymes, antioxidants, micronutrients, and beneficial microorganisms. Much of the existing body of research has focused on the utilization of the liquid component of eco-enzyme, which has been tested on various plant species including leafy vegetables, shallots, tomatoes, and ornamentals. Studies have shown that eco-enzyme improves soil microbial activity, enhances nutrient uptake, stimulates chlorophyll development, and supports overall vegetative growth. However, the precipitate fraction generated during fermentation has received significantly less attention. Most producers dispose of this residue as waste, despite its potential to serve as a slow-release organic fertilizer. This research is therefore pivotal in exploring the agronomic potential of eco-enzyme precipitate, contributing to both waste valorization and agricultural sustainability.

In the context of horticultural crop production, tomatoes particularly the currant tomato (*Solanum pimpinellifolium* L.) represent an important commodity due to their nutritional value, genetic diversity, and economic relevance (Razali et al., 2018; Zuriaga et al., 2009). Currant tomatoes are known for their high antioxidant content, resilience, and potential use as genetic resources in tomato breeding programs (Gürbüz Çolak, Eken, Ülger, Frary, & Doğanlar, 2020; Wang et al., 2020). In many rural areas, including Pesisir Barat, Lampung, currant tomatoes are cultivated on a small scale with minimal input and traditional practices (Lismeri, Herdiana, & Darni, 2019). Low soil fertility and reliance on chemical fertilizers have challenged sustainable production. While chemical fertilizers can produce rapid growth, long-term use leads to soil degradation, reduced microbial diversity, and environmental pollution. Consequently, there is a pressing need for alternative fertilizers that are organic, environmentally friendly, affordable, and locally available.

The application of eco-enzyme precipitate in agriculture aligns well with principles of circular economy, sustainable waste management, and eco-friendly farming (Muliarta, 2024; Proni et al., 2025; Purnamawati, Laksmi, & Suriani, 2024). The precipitate is rich in organic carbon, nitrogen, potassium, and various micronutrients that are essential for plant growth (Helfa Septinar, Anggraini, Suryani, & Puspasari, 2024; Panataria et al., 2022; Siregar et al., 2024). It also contains microbial colonies resulting from fermentation that may positively influence soil biological health. In comparison to liquid eco-enzyme, the precipitate offers advantages such as longer nutrient retention, slower degradation, and more concentrated organic matter. However, scientific literature examining precipitate-based fertilizers remains scarce. Most studies to date have focused on compost, bio-slurry, and liquid fertilizers, leaving a distinct gap regarding the application, dosage, and effect of eco-enzyme precipitates specifically on fruiting vegetable plants.

Several recent studies indicate the positive impact of fermentation-based fertilizers on horticultural crops. Listiana et al., (2024) found that fermented organic solutions significantly improved leaf development in *Ipomoea reptans*. Likewise, Setiawan (2022) reported enhanced plant height and bulb formation in shallots treated with fermented plant extracts. Solano Porrás et al., (2025) further demonstrated that fermentation residues contributed to higher biomass accumulation in lettuce. These findings suggest that fermented organic residues may possess beneficial properties similar to compost or solid organic fertilizers.

Most previous studies have focused on liquid eco-enzyme or other fermentation-based fertilizers such as compost and bio-slurry, leaving limited evidence on precipitate-based applications. Empirical data regarding

the dosage and growth effects of fruit peel-based eco-enzyme precipitate on fruiting vegetables remain scarce, and no study has specifically evaluated its use as a solid organic fertilizer for cherry tomato (*Solanum pimpinellifolium*). To address this gap, the present study investigates the effects of fruit peel-based eco-enzyme precipitate on *Solanum pimpinellifolium* under different concentration levels, providing new insights into its agronomic potential and its role in sustainable waste utilization.

From a broader perspective, this research carries environmental, social, and economic relevance. Environmentally, converting fruit peel waste into fertilizer reduces landfill burden, minimizes greenhouse gas emissions, and promotes carbon recycling in agroecosystems. Socially, it empowers communities by offering simple technologies for waste conversion and sustainable farming. Economically, it provides farmers with access to affordable and accessible fertilizers, potentially reducing dependence on costly commercial inputs. Furthermore, the adoption of eco-enzyme precipitate supports the Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land). It also resonates with Islamic environmental ethics, emphasizing stewardship (*khalifah*), moderation, and harmonious interaction with nature.

Despite its potential, empirical data on the appropriate concentration and application of eco-enzyme precipitate remain limited. There is a need to systematically assess how different concentrations affect key vegetative parameters, such as plant height, leaf number, leaf width, and biomass accumulation in currant tomato plants. Experimental evaluation using a controlled design is essential to determine the optimum dosage for effective growth enhancement. Additionally, comparing its performance with commercial organic fertilizers provides valuable insights into the feasibility of its practical adoption by farmers.

Based on these considerations, the present study aims to evaluate the effect of eco-enzyme precipitate derived from fruit peel waste on the vegetative growth of *Solanum pimpinellifolium* L. (currant tomato). The study specifically assesses how various concentrations of eco-enzyme precipitate influence plant height, number of leaves, leaf width, and fresh and dry biomass. The findings of this research are expected to contribute to scientific understanding of eco-enzyme by-products, support sustainable organic fertilization practices, and offer an innovative solution for organic waste utilization. Ultimately, the study seeks to advance environmentally responsible agricultural practices while addressing the need for alternative, accessible, and effective organic fertilizers.

MATERIALS AND METHODS

This study employed a quantitative experimental design using a Completely Randomized Design (CRD) to determine the effect of eco-enzyme precipitate derived from mixed fruit peel waste on the vegetative growth of currant tomato (*Solanum pimpinellifolium* L.). The research was carried out from December 2024 to January 2025 in Krui, Pesisir Barat Regency, Lampung Province. A total of twenty-five plants were selected as research subjects through simple random sampling based on viability and uniformity at the seedling stage. The eco-enzyme precipitate used as the treatment material was obtained through a 90-day fermentation process involving a mixture of orange, pineapple, and watermelon peel waste combined with palm sugar and water at a 3:1:10 ratio. After fermentation, the liquid eco-enzyme was separated, and the remaining solid residue (precipitate) was used to formulate fertilizer concentrations.

Five treatment levels were prepared, consisting of P0 (100% aquades), P1 (0,2 ml/L), P2 (0,4 ml/L), P3 (0,6 ml/L), and P4 (positive control), with each treatment replicated five times. Currant tomato seeds were germinated in trays and later transplanted into polybags containing soil mixed with organic matter. All plants were maintained under uniform environmental conditions, including controlled irrigation, light exposure, and protection from pests. Treatments were applied consistently during the vegetative phase according to the prescribed concentrations.

Quantitative data were collected at designated intervals, covering plant height, number of leaves, leaf width, fresh biomass, and dry biomass. Plant height was measured using a measuring tape, leaf count was performed manually, leaf width was measured using a ruler or caliper, and fresh and dry weights were measured using an analytical balance and oven, respectively. All measurements were recorded using standardized measurement sheets to ensure accuracy, reliability, and repeatability.

The methodological flow of this study is illustrated in [Figure 1](#), which summarizes the entire research process, from waste collection to data analysis, ensuring transparency, reproducibility, and clarity in reporting.

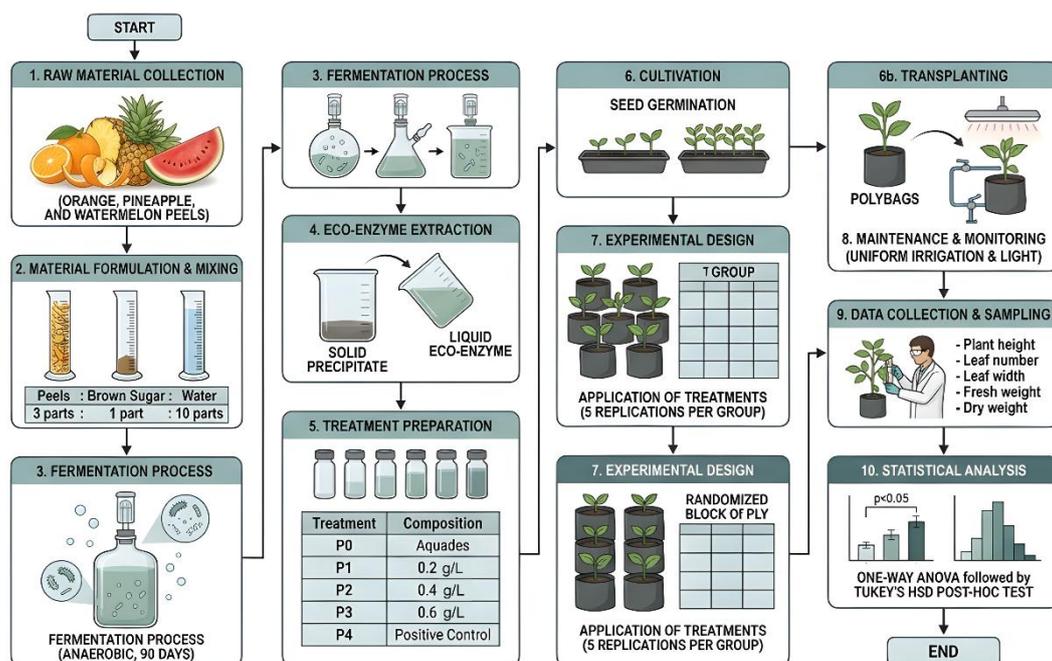


Figure 1. Systematic Flowchart of Eco-enzyme Production and Application in Plant Cultivation

Data were analyzed using one-way Analysis of Variance (ANOVA) at a significance level of $\alpha = 0.05$. When significant differences occurred, Tukey's Honestly Significant Difference (HSD) test was performed to compare pairwise treatment means. The interpretation of the data was conducted by associating experimental outcomes with the research objectives and linking them with relevant literature on organic fertilizers and eco-enzyme applications.

RESULTS AND DISCUSSION

The physicochemical analysis of eco-enzyme precipitate showed that the material contains substantial macro- and micronutrients essential for plant growth, including nitrogen (16.2%), phosphorus (15.5%), and organic carbon (25.4%). Additional micronutrients such as Fe (518.7 mg/kg), Cu (8.7 mg/kg), Zn (12 mg/kg), and Ca (6740.9 mg/kg) were also detected, indicating that the precipitate has the potential to support vegetative development despite its acidic pH (1.89). The laboratory profile of nutrient availability is described in Table 1.

Table 1. Laboratory Analysis of Eco-Enzyme Precipitate

Parameter	Result	SNI Standard	Status
Nitrogen (Total)	16.2%	Min 2	Appropriate
P-total	15.5%	Min 2	Appropriate
C-organic	25.4%	Min 15	Appropriate
pH	1.89	4–9	Not Appropriate
Fe	518.7 mg/kg	Max 15,000	Appropriate
Cu	8.7 mg/kg	25–500	Not Appropriate
Zn	12 mg/kg	Max 5,000	Appropriate
B	4.6 mg/kg	12–250	Not Appropriate
Ca	6740.9 mg/kg	–	–
Cl	1.98 mg/kg	Max 2,000	Appropriate

The acidic character combined with rich nutrient content enabled the eco-enzyme precipitate to modulate soil nutrient availability and stimulate the production of phytohormones, such as auxin and gibberellin, which drive vegetative development. These chemical characteristics became the basis of evaluating plant response across treatments P0 (control), P1 (0,2%), P2 (0,4%), P3 (0,6%), and P4 (positive control).

Plant Growth Responses

Plant Height

The application of eco-enzyme precipitate significantly affected plant height (ANOVA, $p < 0.05$). Post hoc analysis using Tukey's HSD test revealed a clear gradation among treatments. P4 produced the highest mean plant height (11.70 cm), which was significantly different from P0 (7.00 cm), while P1, P2, and P3 occupied intermediate positions and were not statistically distinct from either extreme group. Mean Plant Height Under Different Treatments can be seen in Table 2.

Table 2. Mean Plant Height Under Different Treatments

Treatment	Mean Height (cm)	Significance Group
P0	7.00	A
P1	8.50	AB
P2	9.90	AB
P3	10.66	AB
P4	11.70	B

Compared to the control (P0), treatment P4 increased plant height by approximately 67.1%, indicating a substantial enhancement in vegetative elongation. The incremental pattern suggests a dose-dependent response to eco-enzyme precipitate application (Solano Porrás et al., 2025). The growth trend across treatments is further illustrated in Figure 2, showing a consistent positive slope from P0 to P4.



Figure 2. Plant Height Across Treatments

P4 shows the highest vegetative elongation corresponding to nutrient sufficiency.

Number of Leaves

Leaf number showed a significant response to eco-enzyme precipitate application (Tukey's test, $p < 0.05$). Treatment P4 produced the highest mean number of leaves (8.20 leaves), whereas P0 recorded the lowest (4.80 leaves). Based on post hoc grouping, P4 was significantly different from P0, while P1–P3 occupied intermediate statistical positions, mean number of leaves can be seen in Table 3.

Table 3. Mean Number of Leaves

Treatment	Mean Leaves	Significance Group
P0	5	A
P1	6	A
P2	7	AB
P3	8	AB
P4	9	B

Leaf development reflects nutrient-driven metabolic activity. The increase in leaf count in higher treatments can be attributed to elevated nitrogen, known to amplify chlorophyll formation and stimulate meristematic activity. These results align with Saragih et al., (2025), demonstrating similar trends in onion plants under eco-enzyme treatment.



Figure 3. Number of Leaves in Each Treatment

Leaf Width

Leaf width increased significantly with increasing eco-enzyme precipitate concentration ($p < 0.05$). Treatment P4 achieved the widest mean leaf width (1.63 cm), while P0 recorded the narrowest leaves (0.75 cm). Post hoc analysis showed a clear gradation of significance groups from A (P0) to C (P4), indicating a strong treatment effect can be seen [Table 4](#).

Table 4. Mean Leaf Width

Treatment	Mean Leaf Width (cm)	Significance Group
P0	0.75	A
P1	0.89	AB
P2	1.12	AB
P3	1.29	BC
P4	1.63	C

These morphological changes reflect the tissue expansion response mediated by nitrogen and potassium. Similar outcomes have been reported in celery and lettuce treated with eco-enzyme ([Fevria, Vauzia, Farma, Kardiman, & Edwin, 2023](#); [Solano Porras et al., 2025](#)).



Figure 4. Leaf Width Across Treatments

Fresh Weight

Fresh biomass showed highly significant differences among treatments ($p < 0.05$). Treatments P3 and P4 produced the highest mean fresh weight (4.85 g), whereas P0 recorded the lowest value (0.98 g). Statistical grouping revealed a clear separation across treatments, with each treatment occupying a distinct significance category [Table 5](#).

Table 5. Fresh Weight of Plants

Treatment	Mean Fresh Weight (g)	Group
P0	0.98	A
P1	1.55	B
P2	2.36	C
P3	4.85	D
P4	4.85	E

Fresh weight is directly associated with turgor pressure, water uptake, and nutrient assimilation. Eco-enzyme's organic acids may have chelated nutrients, enhancing their availability and promoting biomass accumulation.

Dry Weight

The dry biomass pattern closely mirrored the fresh weight results, demonstrating a consistent treatment effect ($p < 0.05$). Treatment P4 produced the highest mean dry weight (0.93 g), whereas P0 recorded the lowest value (0.18 g). Each treatment formed a distinct statistical group, indicating a strong and progressive response to increasing eco-enzyme concentration [Table 6](#).

Table 6. Dry Weight of Plants

Treatment	Mean Dry Weight (g)	Group
P0	0.18	A
P1	0.31	B
P2	0.51	C
P3	0.68	D
P4	0.93	E

Dry matter accumulation reflects true physiological gain, confirming that eco-enzyme precipitate effectively supports biomass production. The findings of this study provide substantial implications for sustainable agriculture, waste valorization, and low-cost organic fertilization strategies. The consistent and statistically significant improvements observed across all vegetative parameters, including plant height, leaf number, leaf width, fresh weight, and dry weight, demonstrate that eco-enzyme precipitate exerts a comprehensive growth-promoting effect on *Solanum pimpinellifolium*. The progressive dose–response trend, particularly evident in the marked increases in biomass accumulation, confirms that the precipitate functions not merely as a supplementary input but as a physiologically active organic amendment. Ecoenzymes are solutions produced from the fermentation process of organic materials, such as fruit peels, vegetables, and other kitchen waste. Ecoenzymes contain enzymes that are beneficial to plants and the environment. ([Zheng et al. 2025](#)).

The enhancement in plant height reflects improved cell elongation and meristematic activity, likely supported by increased nitrogen availability and improved nutrient uptake efficiency. The rise in leaf number indicates stimulated apical meristem differentiation, directly expanding photosynthetic capacity. The substantial increase in leaf width strengthens this interpretation, as lamina expansion enhances light interception and carbon assimilation. Together, these morphological improvements formed the structural basis for the dramatic increase in fresh and dry biomass observed at higher treatment levels ([Lubis et al. 2025](#); [Fadlilla, Budiastuti, and Rosariastuti 2023](#)). The benefit of ecoenzymes is that they can be used as environmentally friendly organic fertilizers for plants. Organic fertilizers are derived from natural materials such as plants, animals, or other organic waste. Organic fertilizers can improve soil fertility and increase crop yields. Furthermore, organic fertilizers can provide essential plant nutrients. They are environmentally friendly and do not contain harmful chemicals that could harm human health. ([Asadu et al. 2024](#); [Khan, Aleinikovienė, and Butkevičienė 2024](#)). Apart from that, organic fertilizer is also a low-cost fertilizer because the ingredients are available in our environment ([Penuelas, Coello, and Sardans 2023](#)).

Importantly, the parallel rise in dry weight, exceeding a fourfold increase compared to the control, confirms that the growth response was not solely attributable to greater tissue hydration. ([Tuapattinaya et al. 2023](#)). Instead, it reflects genuine accumulation of structural carbohydrates and proteins, indicating enhanced photosynthetic productivity and assimilate partitioning. The sharp biomass escalation at higher treatment levels suggests that once nutrient availability reached sufficient levels, metabolic performance increased substantially ([Rachman et al. 2025](#); [Manea et al. 2024](#)).

The positive vegetative response of *Solanum pimpinellifolium* to eco-enzyme precipitate underscores the potential of fruit peel waste as a viable nutrient source. Eco-enzyme precipitate contains macro- and micronutrients, organic acids, and bioactive compounds generated during fermentation. Organic acids may function as natural chelating agents that increase nutrient solubility and enhance rhizosphere nutrient dynamics. Fermentation-derived compounds may also stimulate physiological pathways associated with cell division and elongation. These combined effects position eco-enzyme precipitate as an agronomically valuable material capable of partially substituting synthetic fertilizers, particularly in regions with limited access to industrial agricultural inputs ([Penuelas, Coello, and Sardans 2023](#)).

Beyond plant-level responses, the utilization of eco-enzyme precipitate contributes to broader environmental sustainability objectives. Transforming household fruit peel waste into a value-added agricultural input reduces organic waste accumulation in landfills. By diverting biodegradable waste from disposal sites, this practice can help minimize methane emissions associated with anaerobic decomposition processes. In addition, converting waste into productive agricultural resources supports responsible consumption and production patterns in alignment with Sustainable Development Goal 12. Through this circular utilization model, eco-enzyme precipitate connects household waste management with sustainable food production systems. Furthermore, integrating eco-enzyme into farming systems may improve soil biological activity by supporting beneficial microbial communities that enhance nutrient mineralization and organic matter turnover. Strengthening rhizosphere processes contributes to improved soil fertility and long-term agroecosystem resilience. For smallholder farmers, eco-enzyme precipitate represents an accessible and low-cost input that can be produced locally using readily available materials, reducing dependency on commercial fertilizers while maintaining plant productivity (Liu et al. 2023; Gonçalves, Anjos, and Guiné 2025).

Despite these promising outcomes, several limitations must be acknowledged. First, the study focused exclusively on short-term vegetative parameters, without evaluating reproductive characteristics such as flowering behavior, fruit set, yield quantity, and fruit quality. Since *Solanum pimpinellifolium* is a fruit-bearing species, assessing reproductive performance is essential to determine the full agronomic value of eco-enzyme precipitate.

Second, soil chemical and biological properties were not directly measured. Parameters such as pH buffering capacity, nutrient mineralization rates, cation exchange processes, microbial community dynamics, and organic matter decomposition were not analyzed. Consequently, although plant responses suggest improved nutrient availability, the specific soil-level mechanisms remain to be clarified. Third, the experiment was conducted on a single plant species and within one soil type, which limits generalizability across different crops and agroecological conditions. Environmental factors such as temperature, humidity, and soil moisture were controlled but not statistically incorporated as covariates in the analysis. Finally, potential phytotoxic effects associated with low pH or concentrated micronutrients were not examined, particularly at higher application rates.

These limitations highlight the need for multi-season trials, reproductive-phase evaluations, soil biochemical assessments, and cross-species validation studies. Such investigations are necessary to comprehensively establish eco-enzyme precipitate as a scientifically validated and scalable organic fertilizer alternative.

CONCLUSION

The present study demonstrates that eco-enzyme precipitate derived from fruit peel waste effectively improves the vegetative growth of *Solanum pimpinellifolium*, as indicated by significant increases in plant height, leaf number, leaf width, and biomass, thereby adequately answering the research objective regarding its potential as an organic fertilizer. These findings logically affirm that the nutrient-rich composition of the precipitate, combined with organic acids and microbial metabolites generated during fermentation, enhances plant physiological processes and nutrient assimilation, enabling performance comparable to conventional chemical fertilizers at moderate concentrations. Based on these outcomes, the eco-enzyme precipitate can be considered a promising, low-cost, and sustainable organic amendment that supports circular agriculture and reduces reliance on synthetic inputs, although its application remains limited by the absence of reproductive-phase observations, soil chemistry analyses, and multi-species validation. Future research is recommended to investigate long-term plant responses, soil-biological interactions, and broader agronomic performance to optimize the precipitate's utilization within sustainable cultivation systems.

CONFLICT OF INTEREST

The authors declare no conflict of interest and take full responsibility for the content of the article, including the implications of AI-generated content.

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