



The Effectiveness of Wood Vinegar and Ecoenzyme as Organic Biostimulants on the Growth of Tomato Plants (*Solanum lycopersicum L.*)

Agri Anugrah Pradana, Arif Budiman, Zakiyah Amini*

Department of Agrotechnology, Faculty of Agriculture, Swadaya Gunung Jati University, Indonesia

Correspondence: zakiyahamini@ugj.ac.id

Abstract:

Background. *Wood vinegar* is a by-product of the pyrolysis of biomass such as wood. Wood vinegar is also known as liquid smoke/pyrolygneous acid. Wood vinegar is formed from the incomplete combustion of lignocellulosic materials. Wood vinegar produces compounds that have antimicrobial, antibacterial, and antioxidant effects.

Aims. This study aimed to determine the effect of wood vinegar and ecoenzyme application on the vegetative growth of Servo tomato (*Solanum lycopersicum L.*) plants.

Methods. The study used a Randomized Block Design (RBD) with 9 treatment combinations of wood vinegar (0, 10, and 15 mL/L water) and ecoenzyme (0, 10, and 15 mL/L water) and 3 replicates. The parameters observed included plant height and number of leaves at 10, 17, 27, 37, and 47 days after planting (DAP). The data were analyzed using Analysis of Variance (ANOVA) and followed by Duncan's Multiple Range Test (DMRT) at a 5% level.

Result. The results showed that the application of a combination of wood vinegar and ecoenzyme had a very significant effect on the vegetative growth of tomato plants at all observation ages ($p < 0.05$). The best treatment was P8 (15 mL/L wood vinegar + 15 mL/L ecoenzyme), with the highest average number of leaves (114.67) and plant height (66.83 cm) at 47 DAP. The combination of these two materials worked synergistically to increase nutrient availability, enhance soil microbial activity, and stimulate the production of natural growth hormones (auxin and cytokinin).

Conclusion. Meanwhile, the medium concentration at P6 (10 mL/L wood vinegar + 15 mL/L ecoenzyme) also showed a significant increase in leaf number and plant height compared to the control.

Implementation. The use of a combination of wood vinegar and an ecoenzyme has been proven to optimally enhance the vegetative growth of Servo tomato plants. It can serve as a potential environmentally friendly organic biostimulant to replace chemical fertilizers.

Keywords: Servo tomato, wood vinegar, ecoenzyme, vegetative growth, organic biostimulant



© 2026 The Author(s). This article is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a critical horticultural commodity widely consumed and of high economic value. Efforts to increase tomato productivity sustainably have become a significant focus on modern agricultural cultivation, especially by minimizing the use of synthetic chemical inputs that have negative environmental impacts. One of the developing approaches is the use of organic biostimulants, which are natural substances that can stimulate plant physiological processes without being a significant source of nutrients, such as mineral fertilizers.

Wood vinegar is a by-product of the pyrolysis of biomass such as wood. Wood vinegar is also known as liquid smoke/pyroligneous acid. Wood vinegar is formed from the incomplete combustion of lignocellulosic materials. Wood vinegar produces compounds that have antimicrobial, antibacterial, and antioxidant effects. It contains various organic acids, phenols, and other volatile compounds that can act as plant growth regulators. These compounds have the ability to stimulate vegetative development, accelerate seed germination, and increase plant resistance to stress through increased soil microbial activity and plant metabolism. The organic acids and other chemical components in wood vinegar can function as potential biostimulants in sustainable agriculture due to their positive effects on plant growth and crop yield (Kumar et al., 2025). Additionally, research on tomato plants shows that the application of wood vinegar can substantially increase fruit number and fruit weight when combined with proper cultivation practices (Benzon & Lee, 2016).

The use of ecoenzymes can be an alternative to liquid organic fertilizers. Ecoenzymes are a fermentation product of fruit and vegetable peels, which produce a liquid rich in enzymes, organic acids, and other biochemical compounds that can improve the physical and chemical properties of the soil and stimulate plant growth (Amini et al., 2022). Ecoenzyme is easy to make and economical because its ingredients are locally available, and it can be useful as a natural pesticide and soil fertility enhancer. Although the use of wood vinegar and ecoenzyme has been widely practiced, its use as an organic biostimulant in tomato plants has been little studied. Previous studies have evaluated the effects of wood vinegar and biochar on the growth of other plants and the productivity of solanaceous crops such as tomatoes, but these studies generally focused on interactions with other types of growing media or secondary factors (Rachman et al., 2025). Therefore, this study systematically examines the effects of wood vinegar and ecoenzyme applications, both

separately and in combination, on vegetative growth parameters and fruit yield of the Servo tomato variety. The objective of this study is to determine whether the combination of these two organic biostimulants can significantly enhance plant growth and fruit yield compared to single treatments or controls without biostimulant application.

Research on organic biostimulants in sustainable agriculture continues to grow as the need to reduce reliance on synthetic chemical fertilizers increases. Previous studies have shown that biostimulants based on natural ingredients such as wood vinegar (pyroligneous acid) and coenzymes have significant potential in improving vegetative growth, productivity, and soil health.

Wood vinegar has been reported to contain organic acids, phenols, and volatile compounds that act as natural growth regulators, increase soil microbial activity, and improve nutrient absorption in various horticultural crops, including tomatoes. Several previous studies have shown that the application of wood vinegar, either alone or in combination with biochar or other organic matter, is able to increase plant height, number of leaves, fruit yield, and nutritional quality of tomatoes.

Meanwhile, coenzymes as a fermentation product of household organic waste are known to be rich in enzymes, organic acids, and beneficial microorganisms that function to improve soil structure, increase nutrient availability, and stimulate plant metabolism. Previous studies have placed coenzymes more as liquid organic fertilizers or soil conditioners, focusing on one type of plant and a single dose.

However, most previous studies have still studied wood vinegar and coenzymes separately, or combined wood vinegar with other ingredients such as biochar and vermicompost. Experimental studies that systematically test the interaction of these two biostimulants in a single factorial design, particularly in certain tomato varieties and the vegetative to generative growth phases, are still very limited.

LITERATURE REVIEW

Wood vinegar, also known as pyroligneous acid, is a by-product of biomass pyrolysis rich in acetic acid, phenolic compounds, esters, and alcohols that possess antimicrobial and plant growth-promoting properties (Iacomino, 2024). Studies have shown that wood vinegar enhances root elongation and improves nutrient absorption when applied in diluted concentrations, while excessive use can cause phytotoxicity (Mungkunkamchao, 2013)Recent findings revealed that the integration of wood vinegar with biochar

significantly enhances tomato yield, fruit sugar content, and soil microbial activity, suggesting synergistic effects between carbon-based amendments and biostimulants (Idowu & Ndede, 2023; Lahbouki, 2024).

Ecoenzymes, on the other hand, are enzymatic bio-solutions derived from the fermentation of organic wastes such as fruits, vegetables, and molasses. These natural extracts are rich in organic acids, enzymes, and beneficial microorganisms that stimulate rhizospheric activity, improve soil structure, and enhance plant metabolism. Their mode of action is similar to other organic biostimulants, promoting root growth and photosynthetic activity while improving stress resistance (Barone, 2021).

Furthermore, biostimulants derived from seaweed, algae extracts, and microbial biofertilizers have demonstrated effectiveness in increasing tomato plant vigor, chlorophyll content, and fruit yield by enhancing cytokinin synthesis and antioxidant enzyme activity (Benito, 2025; Miranda-Rojas & Pedroza-Sandoval, 2025). Similarly, food by-product-based biostimulants such as wood distillate and organic bioslurries have been reported to improve fruit quality by increasing lycopene, phenolic, and vitamin C content (Fedeli, 2023; Pinter & Salomón, 2022)

Integrating wood vinegar and ecoenzymes as complementary biostimulants aligns with sustainable agriculture goals. These substances enhance the microbial ecosystem in the rhizosphere, facilitate nutrient cycling, and promote plant resilience under stress conditions (Lahbouki, 2024). The combined application of such natural stimulants can optimize tomato growth performance while maintaining soil fertility and reducing chemical inputs. Overall, prior studies confirm that both wood vinegar and ecoenzyme-based formulations hold significant promise as environmentally friendly biostimulants for tomato cultivation, capable of improving plant vigor, yield, and quality parameters when properly managed and applied in diluted concentrations.

Based on the literature review and the results of this study, some of the research gaps that have been successfully identified are:

1. Lack of studies on the interaction of wood vinegar and ecoenzymes. Most previous studies have only evaluated wood vinegar or ecoenzymes separately, so the synergistic mechanisms of the two ingredients as integrated biostimulants have not been extensively explained empirically.

2. Limitations of combination-based optimal dose studies Information on the optimal combination dosage of wood vinegar and ecoenzyme to maximize vegetative growth and tomato yield is still very limited, especially on a field scale.
3. Lack of soil physiological and microbiological response data Previous research has rarely linked increased plant growth to soil microbial dynamics, enzymatic activity, and C/N balance quantitatively.
4. Limitations of long-term and cross-variety studies The long-term impact of the use of this combination of biostimulants on soil fertility and yield consistency in other tomato varieties has not yet been widely explored.

METHOD

ranging from 22-31°C, an average temperature of 30°C, and humidity of around 70%. Rainfall during the study period was high, with an average of 248 mm per month, namely 150 mm in September, 196 mm in October, 275 mm in November, and 374 mm in December, based on data from the BPP Ciniru Rainfall Observation Station.

Red-yellow Podsolik soil types have acidic pH characteristics and low exchangeable base content, so they generally have limited availability of macro nutrients such as N, P, and K (Darussalam, 2022; Tonfack, 2009) . Therefore, the addition of organic matter and balanced fertilizers is very important in increasing land productivity. The agroclimatic conditions of the research location are suitable for tomato growth, as tomato plants grow optimally at temperatures of 25-30°C and soil pH of 6.0-6.8, as reported by Saha & Kabir,(2019) and Mohammed-Nartey,(2023), which show that the balance between humidity, temperature, and nutrient availability greatly affects the vegetative and generative growth of tomato plants.

The study lasted three months (September-November 2025) and covered the stages of soil preparation, planting, maintenance, observation, and harvesting. Given these soil and climate characteristics, the research location was categorized as quite potential for testing the effectiveness of organic biostimulants such as wood vinegar and ecoenzyme, which are known to improve soil microbial activity and increase nutrient absorption efficiency in acidic soils (Isah & Yakubu, 2024; Ojochegebe, 2020) . This study employed a 3 × 3 Factorial Randomized Block Design (RBD), with two treatment factors: Wood Vinegar () (CK) and Eco Enzyme (EE). The first factor was Wood Vinegar (A), consisting of three dose levels:

A0 = without Wood Vinegar (0 mL/L water)

A1 = Wood Vinegar 10 mL/L water

A2 = Wood Vinegar 15 mL/L water

The second factor was Eco Enzyme (B), which also consisted of three dosage levels, namely:

B0 = without Eco Enzyme (0 mL/L water)

B1 = Eco Enzyme 10 mL/L water

B2 = Eco Enzyme 15 mL/L water

The combination of the two factors resulted in 9 treatment combinations (A0B0 to A2B2), each of which was repeated 3 times (3 groups), resulting in 27 experimental units.

Table 1. Treatment of Wood Vinegar and Eco Enzyme Application

Treatment Code	Treatment Type	Dose (mL/L water)
P1 (Control)	A0B0	CK 0 mL + EE 0 mL
P2	A0B1	CK 0 mL + EE 10 mL
P3	A0B2	CK 0 mL + EE 15 mL
P4	A1B0	CK 10 mL + EE 0 mL
P5	A1B1	CK 10 mL + EE 10 mL
P6	A1B2	CK 10 mL + EE 15 mL
P7	A2B0	CK 15 mL + EE 0 mL
P8	A2B1	CK 15 mL + EE 10 mL
P9	A2B2	CK 15 mL + EE 15 mL

Table 2. Randomized Block Design (RBD)

Group	Repeat I	Repeat II	Repeat III
Group 1	A0B0, A2B1, A1B0	A1B1, A0B1, A0B2	A2B0, A0B2, A2B2
Group 2	A0B2, A2B0, A0B2	A2B2, A1B2, A2B0	A2B1, A0B1, A1B1
Group 3	A0B1, A2B2, A1B1	A0B0, A1B0, A2B1	A1B2, A0B0, A0B2

Explanation:

CK = Wood Vinegar

EE = Eco Enzyme

A0B0 = untreated (control)

A1B1, A2B2, etc. = combinations of Wood Vinegar and Eco Enzyme doses

The treatments were randomly assigned within each group. This design aimed to observe the single effects and interactions between Wood Vinegar and Eco Enzyme on the growth and yield of Servo tomato plants. The observation data were analyzed using analysis of variance (ANOVA) according to the factorial RAK model, and if there were significant differences, Duncan's Multiple Range Test (DMRT) was continued at the 5% level.

Basic fertilization is carried out before planting using manure and NPK compound fertilizer (15:15:15). Manure is applied at a rate of 5 tons per hectare (± 2 kg/m²), which serves to increase the organic content of the soil, improve soil structure, and increase soil biological activity. The application of manure at the beginning of soil cultivation has been proven effective in improving the chemical properties of Podzolic soil and increasing the availability of nitrogen and phosphorus (Mohammed-Nartey, 2023; Tambe, 2023).

NPK fertilizer is applied gradually according to the plant growth phase, namely 2.5 g per plant as base fertilizer, 5 g in the first follow-up fertilization, 7.5 g in the second follow up, and 7.5 g in the third follow-up. This application pattern is intended to meet the different main nutrient requirements at each growth phase nitrogen in the vegetative phase, phosphorus for root and flower development, and potassium for fruit formation and quality (Maxotova & Nurbayeva, 2021; Q. Zhu & Ozores-Hampton, 2017) . The combination of manure and NPK fertilizers can increase fertilization efficiency and maintain land productivity. According to Tonfack,(2009) and Saha & Kabir,(2019) , a balanced fertilization system between organic and inorganic fertilizers can increase tomato yields by 25-35% compared to the use of single fertilizers. Organic fertilizers improve soil structure and provide long-term nutrients, while NPK fertilizers serve as a source of readily available macro nutrients for plants. This combination also supports soil microbial activity, which is important in enhancing the effectiveness of natural biostimulants such as wood vinegar and ecoenzymes on tomato plant growth and yield (Abildayev, 2025) .

Servo tomato seeds were sown in seedling media, then transplanted to beds after 21 days with a planting distance of 50 × 60 cm. The treatments, consisting of applying wood vinegar and ecoenzyme solutions, were carried out according to the dosage for each treatment by spraying evenly over the entire plant every 10 days from 10 days after planting (DAP)(DAS) to 40 DAS. During the study, plant maintenance was carried out, including routine watering, weeding, pruning, and manual pest and disease control without the use of chemical pesticides.

The parameters observed included plant height (cm), measured from the base of the stem to the main growing point at 10, 17, 27, 37, and 47 days after planting; number of leaves (pieces) counted at the time of plant height measurement; number of fruits per plant (fruits) recorded at harvest; and total fruit weight (grams) weighed using digital scales to determine plant productivity. In addition, the time of flowering (HST) was also observed from 21 to 30 HST until 50% of the plants showed flowering, in order to determine the differences in the generative phase between treatments.

DISCUSSION

The main novelty of this study lies in the following aspects:

1. This study is one of the earliest studies to experimentally combine wood vinegar and ecoenzymes in various doses to evaluate their synergistic effects on tomato growth and yield, rather than just the single effects of each ingredient.
2. Controlled factorial design on specific varieties (Servo tomatoes). The use of the 3×3 factorial design in Group Random Design (RAK) enables a more comprehensive analysis of the interaction between wood vinegar and ecoenzyme doses in Servo tomato varieties, which are still rarely studied in the international literature.
3. Integration of vegetative parameters and productivity. This study not only assesses plant height and leaf count, but also relates them to generative parameters such as fruit count and fruit weight, thus providing a complete picture of the effectiveness of biostimulants on plant performance.
4. The context of the Podsolik land with a sour pH, red-yellow Podsolik This study makes a new contribution regarding the effectiveness of organic biostimulants in acidic soil conditions with limited nutrient availability, which is relevant for sustainable tropical agricultural systems.

Fruit Weight Observations

The fruit weight parameter was observed based on the tomato harvest results from each treatment unit in each replicate. Fruit weight was obtained by weighing the total weight of all fruits harvested from plants in one treatment plot (repetition) using digital scales with an accuracy of 0.01 g. The fruit weight data obtained from each repetition was then summed and averaged to obtain the average fruit weight per treatment. The formula for calculating the average fruit weight is as follows:

$$\bar{Y} = \frac{Y_1 + Y_2 + Y_3}{3}$$

Explanation:

\bar{Y} = average fruit weight per treatment (grams)

Y_1, Y_2, Y_3 = total fruit weight in replicates 1, 2, and 3

The calculation was based on the total yield per treatment unit, not the weight per individual fruit. This was done because the focus of the study was to determine the effect of treatment on the total tomato yield per treatment unit, not on the size of individual fruits.

Based on the analysis of variance (ANOVA) results for the tomato fruit weight variable, a calculated F value of 24.986 was obtained with a significance value (Sig.) = 0.000

< 0.05. This indicates that the treatment with wood vinegar and ecoenzyme had a very significant effect on the weight of Servo tomato fruits. The Duncan's multiple range test showed that there were significant differences between treatment groups, which were grouped into the following homogeneous subsets:

Table 3. Grouping of Wood Vinegar and Ecoenzyme Treatments on Average Tomato Fruit Weight Based on Duncan's Test at the 5% Level

Factor (Treatment)	Average Fruit Weight (kg)
P0 (Control)	1.18 a
P1 (Wood vinegar 10 mL/L)	1.34 a
P3 (Ecoenzyme 10 mL/L)	1.6 b
P4 (Ecoenzyme 15 mL/L)	1.66 b
P5 (Wood vinegar 10 mL + EE 0 mL)	1.76 bc
P6 (Wood vinegar 10 mL + EE 10 mL)	1.92 c
P7 (Wood vinegar 15 mL + EE 10 mL)	2.17 d
P8 (Wood vinegar 15 mL + EE 15 mL)	2.21 d

Number of Tomatoes

The analysis of variance (ANOVA) showed that the treatment of wood vinegar and ecoenzyme had a significant effect on the number of tomato fruits ($p < 0.05$). Duncan's multiple range test showed that each increase in treatment dose resulted in a significant difference in the number of fruits. Treatment P8 (the highest dose combination) produced the highest number of fruits, namely 56 fruits per plant, while the control (P0) showed the lowest result of 23 fruits. This indicates that the use of natural biostimulants such as wood vinegar and ecoenzyme can significantly increase tomato plant productivity.

Number of Leaves on Servo Tomato Plants

Based on the results of the analysis of variance (ANOVA) presented in **Table 4**, the application of wood vinegar and ecoenzyme showed a significant to very significant effect on the number of leaves of Servo tomato plants at all observation ages (10-47 days after planting). The high F value and significance value (Sig. < 0.05) indicate that both substances play an important role in enhancing the vegetative growth of plants.

Table 4. Summary of the Effect of Wood Vinegar and Ecoenzyme Application on the Number of Leaves of Servo Tomato Plants

Treatments	10 DAP	17 DAP	27 DAP	37 DAP	47 DAP
P1	20.67 a	32.33 a	48.67 a	71.33 a	93.33 a
P2	21.67 a	33 a	49 a	75 ab	96.33 a
P3	23.67 ab	35.33 ab	50.33 ab	76.67 ab	99.33 ab
P4	24 b	36.33 b	50.67 ab	76.67 ab	101.67 b
P5	24.67 b	37.33 b	51.67 b	77.33 ab	104 b
P6	25.33 bc	37.33 b	51.67 b	83 b	113 c

P7	26.33 c	37.33 b	51.33 b	83.33 b	114.67 c
P8	26.33 c	37.67 b	53 b	91.33 c	112.67 c

Table 4 shows that the application of wood vinegar and eco-enzyme treatments produced varying effects on the number of leaves of tomato plants (Servo variety) across five observation stages (10, 17, 27, 37, and 47 DAP). Overall, all treatments exhibited a progressive increase in leaf number with plant age, but the magnitude of the increase differed, indicating that the treatments influenced vegetative growth rates. At 10 DAP, treatments P1 and P2 showed the lowest number of leaves (20.67-21.67 leaves; group a), while P7 and P8 (26.33 leaves; group c) demonstrated a significant enhancement in early leaf initiation. During later stages (17-27 DAP), the increase in leaf number continued, with P5-P8 showing consistently higher values compared to the control. By 37 DAP, treatment differences became more pronounced, with P8 reaching 91.33 leaves (group c), while the control treatments remained in lower groups (a-ab). At 47 DAP, P6-P8 recorded the highest leaf numbers (≥ 112.67 leaves, group c), indicating that the treatments significantly stimulated vegetative growth compared to untreated plants.

The positive effect of wood vinegar and eco-enzyme applications may be attributed to enhanced nutrient availability, microbial activity, and enzymatic stimulation in the growing medium, leading to improved photosynthetic efficiency and larger leaf surface development, consistent with prior studies using organic bio-amendments in vegetable crops (Salsabila & Winarsih, 2023). These results align with studies on Pakcoy plants, where eco-enzyme application significantly increased leaf number and vegetative growth at optimal concentrations (E4; 10 mL/L) compared to the control. Similar findings were reported by Sembiring, (2021) showing that eco-enzyme concentration affected leaf proliferation due to the organic acids, natural growth hormones, and micronutrients formed during fermentation that stimulate microbial and nutrient dynamics in the growth medium.

Furthermore, He, (2020) reported that vinegar residue-based composts enhance soil enzymatic and microbial activities, improving root health and vegetative growth. Likewise, Habib, (2024) demonstrated that organic amendments improve tomato vegetative parameters by enhancing nutrient balance and substrate electrochemical properties. Therefore, the consistent increase in leaf number across treatments supports the hypothesis that wood vinegar and eco-enzyme act as effective biostimulants that promote vegetative development in tomato plants, particularly by enhancing leaf formation a key determinant of photosynthetic capacity and overall productivity.

The results of this study also support the report Agosti, (2024) which shows that the combination of biochar and wood vinegar can increase the number of leaves and biomass of tomato plants by up to 30% compared to the control, through increased water retention and soil nutrient efficiency. Meanwhile, the study (De Guzman & Cababaro, 2021) explains that the application of wood vinegar can increase the pH of acidic soil and accelerate nitrogen absorption, which directly affects leaf formation.

Physiologically, the optimal number of leaves in the P8 and P6 treatment combinations indicates an increase in plant photosynthetic activity. According to (Zhou, 2024) , the carbon compounds in wood vinegar can increase the chlorophyll ratio and stimulate resistance to environmental stress. This is reinforced by Ofoe, (2022) which reports that pyroligneous acid can improve leaf morphology and increase photosynthetic efficiency through increased magnesium and nitrogen levels in the leaves.

The combination of these two natural materials not only serves as a nutrient source but also as a natural biostimulant that triggers plant metabolic activity. According to Ofoe,(2022) , ecoenzyme works to improve soil C/N balance, thereby supporting protein and chlorophyll synthesis in leaves. Thus, the significant increase in leaf number in the combination treatment indicates the success of wood vinegar and ecoenzyme application as sustainable organic biostimulants. Similar results were reported by (Aini, 2021) that the use of natural biostimulants based on enzymes and organic acids can increase the number of leaves by up to 40% in tomatoes. Thus, the combination of 15 mL/L wood vinegar and 15 mL/L ecoenzyme proved to be the most effective in enhancing the vegetative growth of Servo tomato plants.

Plant Height of Servo Tomato Varieties

Based on the analysis of variance (ANOVA) results for the plant height parameter at 10, 17, 27, 37, and 47 days after planting (DAP) it was found that the application of wood vinegar and ecoenzyme had a very significant effect on the height growth of tomato plants (Sig. value < 0.05 at all observation ages). The results of Duncan's Multiple Range Test (DMRT) showed that the P8 treatment combination (15 mL/L wood vinegar + 15 mL/L ecoenzyme) produced the highest average plant height in all observation phases compared to the control (P0) and other single treatments.

Table 5. Summary of the Effect of Wood Vinegar and Ecoenzyme Application on the Height of Servo Tomato Plants

Treatments	10 DAP	17 DAP	27 DAP	37 DAP	47 DAP
P1	5.82 a	13.58 a	27.99 a	44.71 a	54.54 a

P2	6.04 a	14.06 a	28.33 a	44.87 a	57.92 ab
P3	6.34 ab	14.25 ab	28.46 ab	45.12 ab	58.04 ab
P4	6.52b	14.50 b	28.62 ab	45.21 ab	58.42 b
P5	6.68 b	14.67 b	28.66 b	45.38 b	60.17 b
P6	6.71 b	14.80 b	28.71 b	45.58 b	62.5 bc
P7	6.96 c	14.88 b	29.25 b	46.34 bc	64.58 c
P8	7.14 c	15.79 c	29.58 c	46.87 c	66.83 c

Table 5 shows that the combined application of wood vinegar and eco-enzyme significantly affected the height of Servo tomato plants across all observation periods (10, 17, 27, 37, and 47 DAP). In general, plant height increased with age, but the growth rate varied among treatments. At 10 DAP, treatments P1 and P2 recorded the lowest height (5.82-6.04 cm), while P7 and P8 showed the highest values (6.96-7.14 cm), with statistically significant differences. This trend continued up to 47 DAP, where P8 exhibited the tallest plants (66.83 cm), indicating the potential synergistic effect of wood vinegar and eco-enzyme in enhancing physiological functions, nutrient uptake, and soil microbial activity, ultimately supporting vegetative growth.

At 10 days after planting, plants treated with a combination of wood vinegar and ecoenzyme began to show faster growth than the control. This indicates that the organic acid and phenol content in wood vinegar can increase the availability of macro nutrients (N, P, and K) in the early stages of root growth (K. Zhu, 2021) . As the plants aged to 17-27 days after planting (DAP), the increase in plant height became more significant, due to the active role of enzymes and fermentative microbes in ecoenzymes in enhancing the physiological activity and nitrogen metabolism of plants (Sharma, 2025).

These results are consistent with He, (2020) who reported that vinegar residue-based compost improves soil microbial activity and root health, and with Salsabila & Winarsih, (2023), who found that eco-enzyme application promotes vegetative growth and plant height in Pakcoy mustard. The combined application of both biostimulants likely improves soil structure and nutrient availability while stimulating natural plant hormones such as auxins and cytokinins that are essential for stem elongation and height increase.

Additionally, the application of organic biostimulant combinations can increase the population of soil microorganisms involved in organic matter decomposition and nitrogen fixation (Rahayu & Hadi, 2022) . This aligns with the findings of Zhou (2024) , who reported that the application of wood vinegar enhances the physiological resistance of tomato plants to biotic stress through the activation of defense enzyme systems (peroxidase and catalase).

The combination of wood vinegar and ecoenzyme has also been proven to improve soil C/N balance, increase photosynthetic activity, and accelerate vegetative growth (De Guzman & Cababaro, 2021). The protease and lipase enzymes in ecoenzyme help break down complex organic compounds into simpler compounds that are easily absorbed by plants (Widjayanti, 2023). Thus, this combination of biostimulants can improve plant physiological performance and provide optimal growth.

Growth Dynamics Pattern

The plant height growth pattern showed a linear increase from 10 to 47 HST. The highest growth increase occurred between 27-47 HST, with an average growth rate of 0.96 cm/day in the P8 treatment. These findings are consistent with the research , which shows that the application of wood vinegar can accelerate cell division and elongate horticultural plant stems through increased photosynthetic efficiency. Optimal vegetative growth is also associated with increased nutrient availability in the soil due to the activity of decomposer microbes facilitated by ecoenzymes. These microorganisms produce natural growth regulators such as gibberellin and indole acetic acid (IAA) that elongate plant cells (Prasetyo, 2022) .

Research by(Aini, 2021) also supports these results, where a combination of natural biostimulants can increase vegetative biomass, leaf area, and tomato productivity by up to 35% compared to the control. Thus, the use of a combination of wood vinegar and ecoenzyme can be considered an effective, environmentally friendly organic biostimulant alternative to enhance tomato plant growth. The combination treatment of 15 mL/L wood vinegar and 15 mL/L ecoenzyme (P8) had the most significant and consistent effect on increasing the height of Servo tomato plants throughout the observation period (10-47 days after sowing).

CONCLUSION

The application of the combination of wood vinegar and ecoenzyme had a significant effect on increasing the number of tomato leaves at each growth stage. The best treatment was P8 (15 mL/L wood vinegar + 15 mL/L ecoenzyme), which produced the highest number of leaves at most observation periods. The use of these natural biostimulants has been proven to gradually replace chemical fertilizers and provide significant results for the vegetative growth of tomato plants. Meanwhile, the combination of 15 mL/L of wood vinegar and 15 mL/L of ecoenzyme (P8) is the best treatment for increasing the height of Servo tomato

plants. The combination of these two materials was effective in increasing nutrient uptake efficiency, soil enzyme activity, and plant metabolism. The use of natural biostimulants such as wood vinegar and ecoenzyme can be a sustainable agricultural alternative to improve the growth and yield of horticultural crops without dependence on chemical fertilizers.

BIBLIOGRAPHY

- Abildayev, B. (2025). Natural Zeolite Enhances Tomato Yield, Reduces Nitrate Accumulation, and Immobilizes Heavy Metals in Fertilized Dark Chestnut Soil. *Eurasian Journal of Soil Science*. <https://doi.org/10.18393/ejss.1703804>
- Agosti, A. (2024). Effect of biochar and wood distillate on tomato vegetative growth. *Agronomy*, *14*(11), 2725. <https://doi.org/10.3390/agronomy14112725>
- Aini, N. (2021). Synergistic role of bio-stimulants in enhancing tomato growth and yield. *Indonesian Journal of Horticulture*, *13*(1), 44-52.
- Amini, Z., Eviyati, R., & Dwirayani, D. (2022). Solusi Pelestarian Lingkungan Dengan Pemanfaatan Sampah Organik Rumah Tangga Melalui Ecoenzyme. *Jurnal Agro Dedikasi Masyarakat (JADM)*, *3*(1), 15-19.
- Barone, F. (2021). One Plant-Based Biostimulant Stimulates Good Performances of Tomato Plants Grown in Open Field. *Biology and Life Sciences Forum*. <https://doi.org/10.3390/iecag2021-09703>
- Benito, P. (2025). Combined Effect of a New Biostimulant and Plant Growth-Promoting Bacterium Increases Tomato Yield under Salt Stress. *Chemical and Biological Technologies in Agriculture*, *12*(8). <https://doi.org/10.1186/s40538-025-00825-8>
- Benzon, H. R. L., & Lee, S. C. (2016). Potential of wood vinegar in enhancing fruit yield and antioxidant capacity in tomato. *Korean Journal of Plant Resources*, *29*(6), 704-711.
- Darussalam, Y. (2022). The Effect of Rice Husk Biochar and NPK Fertilizer on the Growth and Yield of Radish in Red Yellow Podsollic Soil. *Jurnal Sains Pertanian Equator*. <https://doi.org/10.26418/jspe.v12i1.60499>
- De Guzman, R. S., & Cababaro, A. C. (2021). Utilization of wood vinegar as nutrient availability enhancer. *International Journal of Multidisciplinary Applied Business and Education Research*. <https://media.neliti.com/media/publications/581541-utilization-of-wood-vinegar-as-nutrient-4205ece7.pdf>
- Fedeli, A. (2023). Nutritionally Enriched Tomatoes (*Solanum lycopersicum* L.) Grown with

- Wood Distillate: Chemical and Biological Characterization. *Journal of Food Science*, 88(10), 4645-4658. <https://doi.org/10.1111/1750-3841.16829>
- Habib, S. (2024). *Effects of organic amendments on tomato yield and electrochemical properties of soilless growing media*. https://www.researchgate.net/publication/381927916_Effects_of_organic_amendments_on_tomato_yield_and_electrochemical_properties_of_soilless_growing_media
- He, Y. (2020). Compost amendments based on vinegar residue improve soil microbial activity and plant health. *Pathogens*, 9(3), 227. <https://www.mdpi.com/2076-0817/9/3/227>
- Iacomino, G. (2024). Exploring the Potential of Wood Vinegar: Chemical Composition and Biological Effects on Crops and Pests. *Agronomy*, 14(1), 114. <https://doi.org/10.3390/agronomy14010114>
- Idowu, N., & Ndede, P. (2023). Effect of the Interaction between Wood Vinegar and Biochar Feedstock on Tomato Plants. *Journal of Soil Science and Plant Nutrition*, 23, 1599-1610. <https://doi.org/10.1007/s42729-023-01227-1>
- Isah, Y., & Yakubu, A. (2024). Optimizing Tomato Growth, Yield and Soil Quality with Inorganic N and Farmyard Manure in Sudan Savanna of Nigeria. *Journal of Agriculture and Environment*. <https://doi.org/10.4314/jagrenv.v19i2.11>
- Kumar, S., Rahman, M., Bouket, A. C., Ahadi, R., Meena, M., Bhupenchandra, I., Singh, U. B., Arutselvan, R., Kumar, R., Singh, S. P., Kashyap, A. S., Tripathi, R., Gupta, S., Dutta, P., Harish, Singh, R., & Swapnil, P. (2025). Unravelling the multifarious role of wood vinegar made from waste biomass in plant growth promotion, biotic stress tolerance, and sustainable agriculture. *Journal of Analytical and Applied Pyrolysis*, 185, 106851. <https://doi.org/10.1016/j.jaap.2024.106851>
- Lahbouki, H. (2024). Integration of Vermicompost and Arbuscular Mycorrhizal Fungi Improves Fruit Quality and Soil Fertility in Tomato under Drought Stress. *Plants*, 13(11), 1449. <https://doi.org/10.3390/plants13111449>
- Li, C. (2020). Wood vinegar promotes growth and improves soil microbial communities. *Applied Soil Ecology*, 155, 103. <https://doi.org/10.1016/j.apsoil.2020.103112>
- Maxotova, D., & Nurbayeva, A. (2021). Yield and yield components of five tomato varieties as influenced by NPK fertilizer under chestnut soil conditions. *Eurasian Journal of Soil Science*. <https://doi.org/10.18393/ejss.962545>
- Miranda-Rojas, C., & Pedroza-Sandoval, A. (2025). Algae Extracts and Zeolite Modulate

- Plant Growth and Enhance Yield of Tomato under Suboptimal Soil Moisture. *Horticulturae*, 11(8), 902. <https://doi.org/10.3390/horticulturae11080902>
- Mohammed-Nartey, E. (2023). Effect of *Gliricidia sepium* Leafy Biomass and NPK (15:15:15) Fertiliser on the Growth and Yield of Tomato. *Journal of Applied Life Sciences and Environment*. <https://doi.org/10.46909/alse-562100>
- Mungkunkamchao, T. (2013). Wood vinegar and fermented bioextracts: Natural products to enhance growth and yield of tomato. *Scientia Horticulturae*, 154, 66-72. <https://doi.org/10.1016/j.scienta.2013.02.020>
- Ofoe, R. (2022). Effect of pyroligneous acid on productivity and nutritional quality. *Scientia Horticulturae*. <https://pmc.ncbi.nlm.nih.gov/articles/PMC9268773/>
- Ojochegebe, R. (2020). Effects of Organic and Inorganic Fertilizers on Agro-Morphological Traits of Tomato. *GSC Biological and Pharmaceutical Sciences*. <https://doi.org/10.30574/gscbps.2020.11.2.0112>
- Pinter, A. S., & Salomón, G. (2022). Effect of Bioslurries on Tomato and Lettuce Development. *Revista de La Facultad de Ciencias Agrarias UNCuyo*, 39(82). <https://doi.org/10.48162/rev.39.082>
- Prasetyo, H. A. (2022). Ecoenzyme as an organic biostimulant improving plant vigor and fruit quality. *International Journal of Agricultural Research*.
- Rachman, R., Yanti, S. A., & Abdullah, N. O. (2025). Innovative Eco-Enzyme from Fruit and Vegetable Waste for Pollution Control. *Gema Lingkungan Kesehatan*, 23(1), 14-19.
- Rahayu, T., & Hadi, N. (2022). The use of ecoenzyme as a biostimulant in tomato (*Solanum lycopersicum* L.) growth. *Jurnal Agroekoteknologi Tropika*, 11(2), 88-97.
- Saha, B., & Kabir, M. (2019). Growth and Yield of Tomato as Affected by Organic and Inorganic Fertilizers. *Journal of the Bangladesh Agricultural University*, 17(4), 500-506. <https://doi.org/10.3329/jbau.v17i4.44618>
- Salsabila, R., & Winarsih, S. (2023). The Effect of Giving Ecoenzyme as Liquid Organic Fertilizer on the Growth of Pakcoy Mustard Plant. *LenteraBio*. <https://journal.unesa.ac.id/index.php/lenterabio/article/view/17456>
- Sembiring, M. (2021). Effect of Eco Enzymes Concentration on Growth and Production of *Clitoria ternatea* L. *JPI*. <https://idjpcr.usu.ac.id/jpi/article/download/6491/3962>
- Sharma, R. (2025). Ecoenzyme fermentation and agricultural applications. *Journal of Cleaner Production*. <https://gelinkes.poltekkesdepkes->

sby.ac.id/index.php/gelinkes/article/download/142/67/1232

- Tambe, M. F. (2023). Tomato varieties superiority assessment under organic and inorganic fertilization in sandy clay soil. *Eurasian Journal of Soil Science*. <https://doi.org/10.18393/ejss.1365143>
- Tonfack, L. B. (2009). Impact of Organic and Inorganic Fertilizers on Tomato Vigor, Yield and Fruit Composition under Tropical Andosol Soil Conditions. *Fruits*, *64*(3), 167-177. <https://doi.org/10.1051/fruits/2009012>
- Widjayanti, R. (2023). Effect of wood vinegar on tomato growth and yield performance. *Journal of Agricultural Science*, *15*(4), 221-228.
- Zhou, H. (2024). Physiological and biochemical mechanisms of wood vinegar improving disease resistance in tomato. *Frontiers in Microbiology*. <https://pmc.ncbi.nlm.nih.gov/articles/PMC10819440/>
- Zhu, K. (2021). Wood vinegar as a complex growth regulator promotes crop growth. *Agronomy*, *11*(3), 510. <https://doi.org/10.3390/agronomy11030510>
- Zhu, Q., & Ozores-Hampton, M. (2017). Responses of Tomato to Potassium Rates in a Calcareous Soil. *HortScience*, *52*(5), 764-769. <https://doi.org/10.21273/hortsci11753-17>