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Response of Robusta Coffee Seedling Growth to The Application of Various Concentrations of Ecoenzymes to PMK Soil

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ABSTRACT

This study examined the growth of Robusta coffee seedlings treated with ecoenzymes derived from fruit peel and addressed the limitations of red-yellow podzolic soil, which is deficient in macronutrients and organic matter. The objective of this study was to determine whether the application of different concentrations of ecoenzymes could enhance the growth of Robusta coffee seedlings. This study employed a non-factorial completely randomized design (CRD) consisting of 5 treatments with 4 replicates. The treatments were as follows: K0 = application of 0 mL/L ecoenzyme concentration (Control), K1 = 25 mL/L ecoenzyme concentration, K2 = 50 mL/L ecoenzyme concentration, K3 = 75 mL/L ecoenzyme concentration, and K4 = 100 mL/L ecoenzyme concentration. The research data were analyzed using Analysis of Variance (ANOVA) and Duncan's Multiple Range Test (DMRT) at the 5% significance level using the DSAASTAT software. The results showed that the application of different ecoenzyme concentrations had a significant effect on improving the growth of Robusta coffee in terms of seedling height, stem diameter, leaf length, leaf width, root length, and dry weight. The optimal ecoenzyme treatment dose was K2 (a concentration of 50 mL/L), which increased seedling height by 6.91 cm, stem diameter by 1.88 mm, leaf length by 7.62 cm, leaf width by 3.35 cm, root length by 9.17 cm, and dry weight by 0.48 g.

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1. INTRODUCTION

Coffee is one of Indonesia's strategic plantation commodities, possessing high economic value and playing a crucial role in supporting community income, particularly that of smallholder farmers. According to preliminary figures from the Indonesian Plantation Statistics, sourced from the Directorate General of Plantations, Indonesia's coffee production in 2022 reached 789.97 thousand metric tons, derived from a plantation area of approximately 1.26 million hectares. Of this total area, approximately 99.40% is managed by smallholder plantations (PR), while state-owned large-scale plantations (PBN) and privately-owned large-scale plantations (PBS) account for only about 0.44% and 0.16%, respectively. By type, Indonesia's coffee production during the 2014–2023 period was dominated by Robusta coffee, which accounted for approximately 72.71% or an average of 517.41 thousand metric tons, while Arabica coffee contributed approximately 27.29% or 194.19 thousand metric tons. The main centers of Robusta coffee production are located in the provinces of South Sumatra, Lampung, Bengkulu, East Java, and Central Java (Ministry of Agriculture, 2023:1). This dominance indicates that increasing Robusta coffee productivity plays a crucial role in the development of the national coffee plantation subsector.

Robusta coffee productivity is influenced by various factors, ranging from the quality of planting material, the age of the plants, cultivation techniques, fertilization, to soil fertility conditions. Efforts to increase coffee production can be carried out through extensification and intensification. Extensification is achieved by expanding plantation areas, while intensification focuses on optimizing crop productivity on existing land. According to the Department of Horticulture and Food Crops (2021), coffee crop intensification can support improvements in plant quality, added value of the harvest, and the adoption of better cultivation techniques. One of the critical stages in intensification is the provision of coffee seedlings with optimal vegetative growth, as seedling quality determines the plants' ability to adapt after being transplanted to the field and influences crop productivity in subsequent stages. Therefore, nutrient management during the seedling phase is a critical component in fostering the development of healthy and vigorous Robusta coffee plants.

One of the challenges in coffee development is low soil fertility, particularly on lands dominated by red-yellow podzolic soils. Such soils generally have low organic matter content, high acidity, and relatively low availability of macronutrients such as phosphorus, potassium, calcium, and magnesium. These conditions limit the soil's ability to supply nutrients to plants and can hinder plant growth if not accompanied by proper management [1]. During the seedling stage, limited nutrient availability can affect root development, plant height, the number of leaves, stem diameter, and biomass accumulation. Therefore, improving the fertility of the growing medium through fertilization and the addition of organic matter is a necessary approach to support plant growth in low-fertility soils [2].

The use of organic materials capable of improving growing medium conditions while simultaneously providing nutrients is one alternative in coffee seedling management, such as through the use of ecoenzymes. Ecoenzymes are products resulting from the fermentation of organic waste, molasses, and water through a fermentation process involving the activity of various microorganisms (Rochyani et al., 2020). The use of ecoenzymes in agriculture holds great potential because the solution contains organic compounds and microorganisms that can improve the physical, chemical, and biological properties of the soil. Pakki et al. [3] explain that ecoenzymes can be used as soil conditioners and have the potential to serve as botanical pesticides. These characteristics make ecoenzymes relevant for study as a source of organic matter that can support nutrient availability and create growing conditions more suitable for the growth of Robusta coffee seedlings.

The potential of ecoenzymes to support plant growth is related to their content of enzymes, organic acids, nutrients, and microorganisms. Larasati et al. [4] note that ecoenzymes may contain enzymes such as amylase, which plays a role in breaking down complex carbohydrates into simpler compounds; acetic acid, which possesses antibacterial activity; and nutrients such as nitrogen, phosphorus, and potassium. Ecoenzymes are also reported to contain microorganisms such as Aspergillus niger, Trichoderma harzianum, Penicillium chrysogenum, and Bacillus subtilis, which have the potential to act as organic matter decomposers, growth promoters, and agents for controlling plant pests. Findings by Tong and Liu (2020) indicate that the use of ecoenzymes has the potential to increase total nitrogen and soil organic matter content through the presence of active enzymes, organic matter, and microorganisms in the solution. These findings suggest a biological and agronomic basis for the use of ecoenzymes in supporting plant growth.

Although ecoenzymes have the potential to improve soil fertility and plant growth, their effectiveness is likely to be influenced by the concentration applied. Concentrations that are too low may result in insufficient availability of active compounds and nutrients to meet plant needs, while concentrations that are too high may create chemical conditions in the growing medium that are unsuitable for seedling development. Empirical evidence regarding the growth response of Robusta coffee seedlings to ecoenzyme application at various concentration levels also needs to be strengthened, particularly to determine whether its application can indeed enhance plant growth during the seedling stage. Given these conditions, this study aims to analyze the effect of applying various concentrations of ecoenzymes on the growth of Robusta coffee seedlings (Coffea canephora). This study is expected to provide empirical evidence regarding the effectiveness of ecoenzymes as an organic growth-promoting agent for seedlings and to serve as a basis for determining more appropriate nutrient management in Robusta coffee seedling propagation.

2. LITERATURE REVIEW

2.1 General Overview of Robusta Coffee

Robusta coffee is a coffee variety known for its relatively high resistance to various diseases and its ability to adapt to fluctuating environmental conditions. These characteristics give Robusta coffee superior adaptability and growth potential, making it widely cultivated in Indonesia. According to Froehner (1897:237–238), Robusta coffee is classified under the Kingdom Plantae, Subkingdom Angiospermae, Class Dicotyledoneae, Subclass Sympetalae, Order Rubiales, Family Rubiaceae, Genus Coffea, Subgenus Eucoffea, and species Coffea canephora. Morphologically, Robusta coffee berries are elliptical in shape with an average length of about 12 mm and can be harvested after about 10–11 months. The bean size ranges from 20–40% of the fruit's size, while in terms of flavor profile, Robusta coffee is often categorized as a second-grade coffee bean with a relatively low acidity level [5]. From an agroecological perspective, Robusta coffee grows best in areas at elevations of approximately 400–1,000 meters above sea level and with air temperatures ranging from 21–24 °C [6].

2.2 Red-Yellow Podzolic Soil

Red-yellow podzolic soil (PMK) is an old mineral soil formed in regions with high rainfall and is generally red to yellow in color due to the accumulation of oxidized iron and aluminum; it exhibits relatively low fertility due to nutrient leaching [7]. This soil is generally acidic with a pH of approximately 5.0–5.5; it has low base saturation and cation exchange capacity, low organic matter content, and relatively high levels of Al, Fe, and Mn. These conditions limit nutrient availability, water-holding capacity, infiltration, and soil permeability, which can hinder plant growth. The fertility of PMK soil is highly dependent on the organic matter content in the topsoil layer; therefore, fertilization and the addition of organic matter are necessary to increase crop productivity [8].

Despite its limitations as a growing medium, PMK soil still has the advantage of relatively high iron and aluminum mineral content (Foller & Silvina, 2017:2).

2.3 *Ecoenzymes*

Ecoenzymes are organic solutions produced by the fermentation of fruit or vegetable waste, molasses, and water, containing various compounds and nutrients beneficial to plants. Fruit waste such as pineapple peels and orange peels contains vitamins, flavonoids, polyphenols, phenols, and other bioactive compounds that have the potential to support biological processes and the activity of soil microorganisms [9]. Successfully fermented ecoenzymes are generally brown in color and have a fresh, sour aroma, while their color and aroma are influenced by the type of sugar used in the fermentation process [4]. In agriculture, ecoenzymes can be used as liquid organic fertilizers because they help improve the physical, chemical, and biological properties of the soil and support plant growth [10]. Ecoenzymes also help break down complex organic compounds, making nutrients more readily available and easier for plant roots to absorb [11].

2.4 *Uses of Ecoenzymes*

The use of ecoenzymes has been shown to have the potential to enhance plant growth and yield because they can improve the physical, chemical, and biological properties of soil and help increase nutrient availability. Enzymes derived from pineapple peel have been reported to enhance the growth and yield of pak choi [12], though a balanced nutrient supply remains essential, as both nutrient deficiencies and excesses can inhibit photosynthesis and reduce crop yields (Rochyani et al., 2020:136). In Liberica coffee, a 50 mL/L concentration of ecoenzyme combined with 50% inorganic fertilizer produced the best growth and was comparable to the use of 100% inorganic fertilizer [13]. Meanwhile, a 10 mL/L concentration of ecoenzyme was shown to yield the best results for plant height, number of leaves, root length, and fresh biomass of pak choi [14], with an application of 75 mL per polybag weekly from 0 to 6 MST [14].

3. METHODS

This study was conducted at the Experimental Garden, Gang Lobak, Jalan Karya Tani, Delta Pawan Subdistrict, Ketapang Regency, West Kalimantan, from February to May 2025. The study used a non-factorial completely randomized design (CRD) consisting of five ecoenzyme concentration treatments and four replicates, with each replicate comprising five samples, resulting in a total of 100 plants. The treatments applied were K0 = 0 mL/L (control), K1 = 25 mL/L, K2 = 50 mL/L, K3 = 75 mL/L, and K4 = 100 mL/L. The main materials used were Robusta coffee seeds of the BP 42 clone, red-yellow podzolic soil, sand, pineapple peels, orange peels, molasses, and rainwater, while the equipment included polybags, growth measurement tools, an analytical balance, an oven, measuring cups, and other supporting equipment.

The ecoenzyme was produced by fermenting fruit peels, molasses, and water in a 3:1:10 ratio for three months under anaerobic conditions, as described by Rochyani et al. (2020:138). The growing medium—a 2:1 mixture of red-yellow podzolic soil and sand—was placed into 15 × 15 cm polybags. Robusta coffee seeds were selected based on uniformity and freedom from pests and diseases, then one seed was planted in each polybag. Ecoenzyme application began two weeks after planting at a volume of 200 mL per polybag once a week, according to the treatment concentration. Maintenance involved watering in the morning at a rate of 200 mL per polybag and weeding to prevent competition for nutrients.

The parameters observed included plant height, stem diameter, leaf length, leaf width, root length, and seedling dry weight. Plant height and stem diameter were measured at 4, 6, 8, 10, and 12 weeks after planting (WAP), while leaf length and width were measured at 20 WAP. Root length was measured from the base to the tip of the longest root, and seedling dry weight was determined after samples were dried in an oven at 80 °C for 48 hours.

The observation data were analyzed using analysis of variance (ANOVA) with the DSAASTAT software. If a treatment showed a significant effect, the analysis was continued using the Duncan Multiple Range Test (DMRT) at the 5% level.

The research stages are as follows:

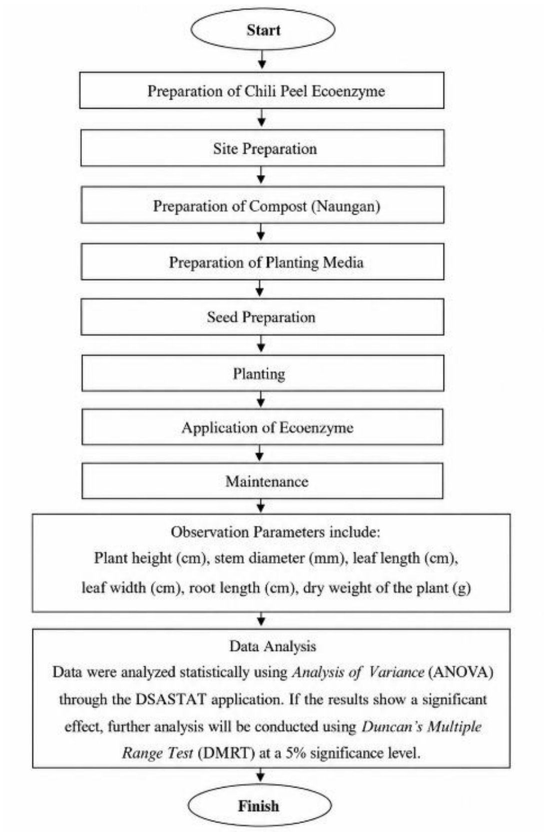

Figure 1. Research Phases

4. RESULT AND DISCUSSION

4.1 Respondent Characteristics

The results of the analysis of variance indicate that the application of different concentrations of ecoenzymes had a significant effect on the parameters of seedling height, stem diameter, leaf length, leaf width, root length, and seedling dry weight. The seedling height parameter showed a significant effect at 8, 10, and 12 weeks after planting (WAP). Stem diameter showed a significant effect at 4, 6, 8, 10, and 12 weeks after planting. Leaf length and leaf width showed a significant effect at 20 weeks after planting. Root length and seedling dry weight showed a significant effect at 12 weeks after planting.

4.2 Seedling Height (cm)

The results of the analysis of variance indicate that the application of different concentrations of ecoenzyme had a significant effect on seedling height at 8, 10, and 12 weeks after planting. The results of the 5% DMRT test are shown in Table 1.

Table 1. Results of the 5% DMRT Test: Mean Height of Robusta Coffee Seedlings in Response to Different Concentrations of Ecoenzyme

Treatment	Concentration	Seedling				
		Height at 4 WAP	Height at 6 WAP	Height at 8 WAP	Height at 10 WAP	Height at 12 WAP
K0	Without Eco-Enzyme Application	3.53	4.17	4.72a	5.57b	5.89a
K1	Eco-Enzyme Concentration 25 mL/L	3.74	4.23	5.27b	6.07ab	6.63b
K2	Eco-Enzyme Concentration 50 mL/L	3.63	4.14	5.11b	6.45a	6.91b
K3	Eco-Enzyme Concentration 75 mL/L	3.78	4.20	5.17b	5.89ab	6.74b
K4	Eco-Enzyme Concentration 100 mL/L	3.44	4.14	5.09b	5.58b	6.30ab

Note: Numbers followed by the same letter in the same column indicate no significant difference in the 5% DMRT test

Based on Table 1, the results of the 5% DMRT test show that at the 8 MST observation, treatment K0 differed significantly from all other treatments, namely K1, K2, K3, and K4. At the 10 MST observation, treatment K0 differed significantly from K2, but treatment K0 did not differ significantly from K1, K3, and K4. At the 12 MST observation, treatment K0 differed significantly from treatments K1, K2, and K3, but treatment K0 did not differ significantly from treatment K4. Plant height growth can be seen in Figure 2.

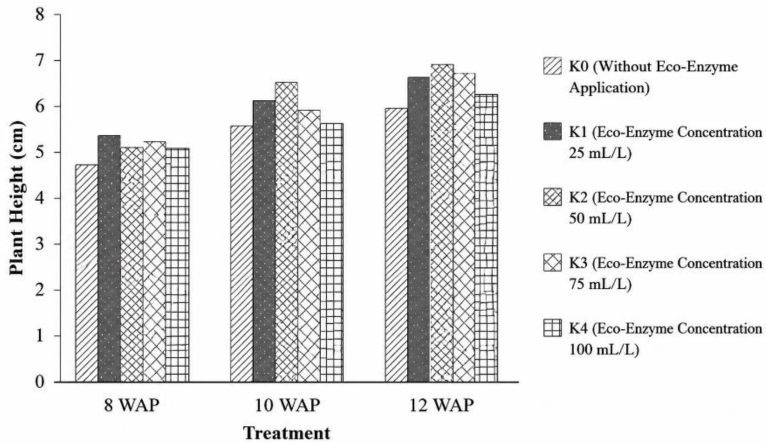

Figure 2. Graph of the Average Effect of Different Ecoenzyme Concentrations on the Height Growth of Robusta Coffee Seedlings

Based on Figure 2, treatment K1 with an ecoenzyme concentration of 25 mL/L showed the highest plant height at 8 MST, while treatment K2 with a concentration of 50 mL/L yielded the highest results at 10 and 12 MST. These differences in growth are believed to be related to the ability of ecoenzymes to support nitrogen availability and soil microorganism activity, thereby making nutrients more readily available to the plants. Although laboratory test results showed that the nitrogen content of the ecoenzymes was relatively low, at 0.09%, application at an appropriate concentration can still support plant height growth. Nitrogen plays a crucial role in the formation of vegetative tissue, while the organic acid content in the ecoenzyme can also support the activity of growth hormones such as auxin, cytokinin, and gibberellin. This is consistent with the findings of Salsabila and Winarsih [14], who reported that a 10 mL/L ecoenzyme solution produced the tallest pak choi plants compared to other treatments. Stem elongation is related to the processes of cell division, elongation, and enlargement in the apical meristem and stem nodes (Widiastuti, 2014:235).

Plant growth responses to ecoenzymes have also been reported in several studies. Simanullang et al. [15] found that the application of ecoenzyme plus at a 5% concentration, combined with 50% of the inorganic fertilizer dose, resulted in the best growth of Tungkal Komposit variety Liberica coffee seedlings, which was attributed to the activity of enzymes such as amylase and lipase acting as biocatalysts. Hastuti and Titiaryanti [16] also reported that a 15% ecoenzyme solution tended to yield the best results in terms of seedling height, number of leaves, chlorophyll content, stem diameter, as well as fresh and dry plant weight. However, plant response to fertilizer concentration has an optimum limit because increasing the concentration can enhance nutrient availability and root development, whereas excessively high concentrations can actually inhibit plant growth [17].

4.3 Stem Diameter (mm)

Analysis of variance (ANOVA) results indicate that the application of different ecoenzyme concentrations has a significant effect on stem diameter at 4, 6, 8, 10, and 12 MST. The results of the 5% DMRT test are presented in Table 2.

Table 2. Results of the 5% DMRT Test for the Mean Stem Diameter of Robusta Coffee in Response to Different Concentrations of Ecoenzyme

Treatment	Concentration	Stem Diameter				
		4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
K0	Without Eco-Enzyme Application	0.85c	1.04c	1.24c	1.45b	1.66d
K1	Eco-Enzyme Concentration 25 mL/L	1.06b	1.25b	1.37b	1.51b	1.68cd
K2	Eco-Enzyme Concentration 50 mL/L	1.25a	1.38a	1.53a	1.69a	1.88a
K3	Eco-Enzyme Concentration 75 mL/L	1.13ab	1.29ab	1.47ab	1.66a	1.87ab
K4	Eco-Enzyme Concentration 100 mL/L	1.08b	1.26ab	1.47ab	1.61a	1.77bc

Note: Numbers followed by the same letter in the same column indicate no significant difference among treatments in the DMRT test at the 5% level

Based on Table 2, the results of the 5% DMRT test show that at 4 weeks after planting, treatment K0 differed significantly from all other treatments—namely K1, K2, K3, and K4—but treatment K1 did not differ significantly from treatments K3 and K4. At 6 and 8 weeks after planting, treatment K0 differed significantly from all other treatments—namely K1, K2, K3, and K4—but treatment K1 did not differ significantly from K3 and K4, though it did differ significantly from K2. At 10 weeks after planting, treatment K0 was not significantly different from treatment K1 but was significantly different from treatments K2, K3, and K4. At 12 weeks after planting, treatment K0 was not significantly different from treatments K1 and K4 but was significantly different from treatments K2 and K3. Stem diameter growth is shown in Figure 3.

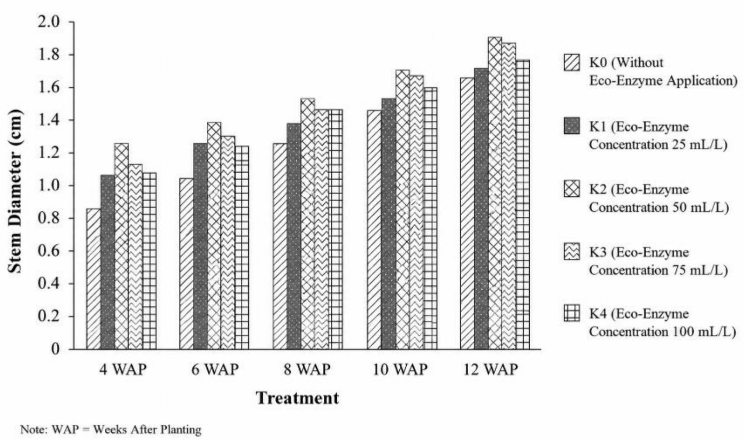

Figure 3. Graph of the Average Effect of Different Ecoenzyme Concentrations on the Stem Diameter Growth of Robusta Coffee Seedlings

Based on Figure 3, treatment K2 with an ecoenzyme concentration of 50 mL/L showed the highest stem diameter in Robusta coffee seedlings at 6, 8, 10, and 12 MST. These results are consistent with those of Nugroho et al. [18], who stated that the application of ecoenzymes to Robusta coffee seedlings can enhance vegetative growth—including stem diameter—as well as improve soil structure and nutrient availability. Based on laboratory test results, the ecoenzyme contains 1.91% organic carbon, 0.09% nitrogen, 224.13 ppm phosphorus, and 2,501.74 ppm potassium, which can support plant growth. Potassium plays a role in vegetative growth, the transport of assimilates, stomatal regulation, and enhancing plant resistance to pests and diseases [19]. Ecoenzyme also contains active enzymes such as protease, amylase, and lipase, which can support the mineralization of nutrients and the activity of soil microorganisms, thereby optimizing nutrient uptake by the roots and contributing to an increase in the stem diameter of Robusta coffee.

4.4 Leaf Length (cm)

Analysis of variance results indicate that the application of different ecoenzyme concentrations had a significant effect on leaf length at 20 weeks after planting (MST). The results of the DMRT test at the 5% significance level are presented in Table 3.

Table 3. Results of the 5% Significance Level DMRT Test for Average Robusta Coffee Leaf Length in Response to Different Concentrations of Ecoenzyme

Treatment	Concentration	Leaf Length at 20 WAP
K0	Without Eco-Enzyme Application	5.37 c
K1	Eco-Enzyme Concentration 25 mL/L	5.70 c
K2	Eco-Enzyme Concentration 50 mL/L	7.62 a
K3	Eco-Enzyme Concentration 75 mL/L	7.20 b
K4	Eco-Enzyme Concentration 100 mL/L	6.92 b

Note: Numbers followed by the same letter in the same column indicate no significant difference among treatments in the DMRT test at the 5% level

Based on Table 4.3, the results of the 5% DMRT test show that at the 20-week post-planting observation, treatment K0 differed significantly from all other treatments—namely K2, K3, and K4—but treatment K0 did not differ significantly from treatment K1. Leaf length growth can be seen in Figure 4.

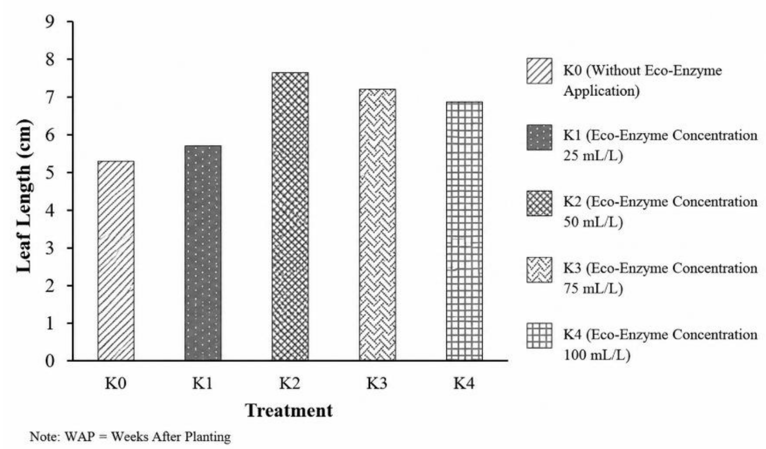

Figure 4. Graph of the Average Effect of Different Ecoenzyme Concentrations on Leaf Length Growth of Robusta Coffee Seedlings

Based on Figure 4, treatment K2—with an ecoenzyme concentration of 50 mL/L—showed the greatest leaf length in Robusta coffee seedlings at 20 weeks after planting. These results are consistent with Sapitri et al. [13], who stated that the application of ecoenzymes and NPK fertilizer has a significant effect on leaf number and area, with an ecoenzyme concentration of 50 mL/L combined with 50% inorganic fertilizer yielding the best growth in Liberica coffee and matching the results of using 100% inorganic fertilizer. The increase in leaf length is believed to be related to the availability of nitrogen in the ecoenzyme, which supports the formation and development of leaf tissue. Nitrogen plays a role in increasing the number and size of leaves, thereby expanding the leaf surface area to capture light and perform photosynthesis [20]. Well-developed leaves increase photosynthetic capacity and produce photosynthates, which are subsequently translocated to support the growth of other plant organs. This is also related to the role of chlorophyll in the assimilation of carbon dioxide to produce photosynthates that support the development of leaf meristems (Ginting & Mirwandhono, 2021). Leaf elongation is also influenced by the processes of cell formation, division, and elongation in meristematic tissues. According to Pramushinta and Yulian [21], these processes require proteins and carbohydrates as building blocks for cells and as sources of metabolic energy. Based on chemical analysis results, ecoenzymes contain 0.09% nitrogen, which plays a role in the formation of amino acids, proteins, and chlorophyll. Sufficient nitrogen availability can enhance chlorophyll formation, thereby improving the plant's ability to capture light energy and perform photosynthesis. Increased photosynthesis produces the energy and photosynthates needed for new tissue formation, including leaf growth and elongation, whereas nitrogen deficiency can cause chlorosis and inhibit leaf development.

4.5 Leaf Width (cm)

Analysis of variance (ANOVA) results indicate that the concentration of ecoenzyme applied had a significant effect on stem diameter at 20 weeks after planting. The results of the 5% DMRT test can be seen in Table 4.

Table 4. Results of the 5% DMRT Test: Mean Leaf Width of Robusta Coffee in Response to Different Concentrations of Ecoenzyme

Treatment	Concentration	Leaf Width at 20 WAP
K0	Without Eco-Enzyme Application	2.20 c
K1	Eco-Enzyme Concentration 25 mL/L	2.35 bc
K2	Eco-Enzyme Concentration 50 mL/L	3.35 a
K3	Eco-Enzyme Concentration 75 mL/L	3.17 a

K4	Eco-Enzyme Concentration 100 mL/L	2.65 c

Note: Numbers followed by the same letter in the same column indicate no significant difference between treatments in the DMRT test at the 5% level

Based on Table 4, the results of the 5% DMRT test show that at 20 weeks after planting, treatment K0 differed significantly from treatments K2 and K3, but treatment K0 did not differ significantly from treatments K1 and K4. The increase in leaf width can be seen in Figure 6.

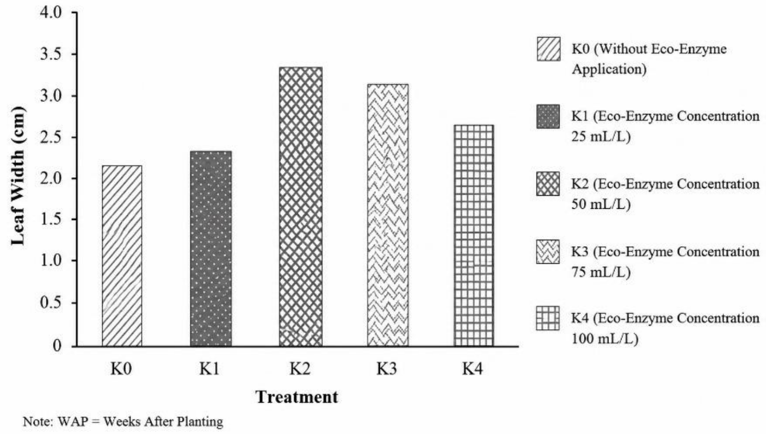

Figure 5. Graph of the Average Effect of Different Ecoenzyme Concentrations on Leaf Width Growth of Robusta Coffee Seedlings

Based on Figure 5, treatment K2—with an ecoenzyme concentration of 50 mL/L—showed the greatest leaf width in Robusta coffee seedlings at 20 weeks after planting. These results are consistent with those reported by Nugroho et al. [18], who found that the application of 60 mL/polybag of ecoenzyme was able to enhance the growth of Robusta coffee seedlings, including leaf area. Leaf growth and development are related to the processes of cell formation, division, and elongation, which require proteins and carbohydrates as tissue components and energy sources [21]. Nitrogen also plays a crucial role in the formation of proteins and chlorophyll, which support the process of photosynthesis.

Ecoenzymes can help increase the availability of nutrients and organic compounds that support plant vegetative growth. Microorganisms and enzymes produced during fermentation play a role in breaking down organic matter, making nitrogen more readily available in a form that plants can absorb. Sufficient nitrogen availability can enhance chlorophyll and photosynthate formation, thereby supporting leaf tissue development. In addition, compounds produced by fermentation also have the potential to support plant physiological activities; thus, the application of ecoenzymes at the appropriate concentration can increase the growth and leaf width of Robusta coffee.

4.6 Root Length (cm)

Analysis of variance (ANOVA) results indicate that the concentration of ecoenzymes applied has a significant effect on root length at 12 weeks after planting. The results of the 5% DMRT test are shown in Table 5.

Table 5. Results of the 5% DMRT Test: Mean Root Length of Robusta Coffee in Response to Different Concentrations of Ecoenzyme

Treatment	Concentration	Root Length at 12 WAP
K0	Without Eco-Enzyme Application	5.27 b
K1	Eco-Enzyme Concentration 25 mL/L	9.95 a

K2	Eco-Enzyme Concentration 50 mL/L	9.17 a
K3	Eco-Enzyme Concentration 75 mL/L	8.97 a
K4	Eco-Enzyme Concentration 100 mL/L	8.20 a

Note: Numbers followed by the same letter in the same column indicate no significant difference among treatments in the DMRT test at the 5% level

Based on Table 5, the results of the 5% DMRT test show that at 12 weeks after planting, treatment K0 differed significantly from treatments K1, K2, K3, and K4. Root length growth is shown in Figure 6.

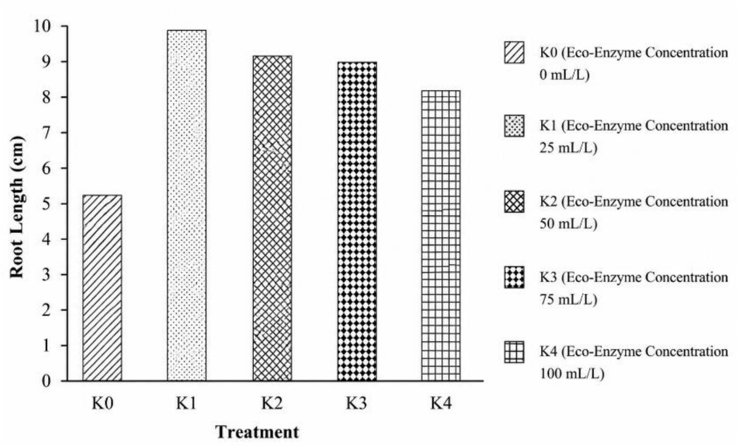

Figure 6. Graph of the Average Effect of Different Ecoenzyme Concentrations on Root Length Growth of Robusta Coffee Seedlings

Based on Figure 6, the application of ecoenzymes had a significant effect on the root length of 12-day-old Robusta coffee seedlings. These results are consistent with those of Salsabila et al. [14], who found that an ecoenzyme concentration of 10 mL/L produced the best root length, as well as Agustin et al. (2021:139), who reported that a concentration of 30 mL/L yielded the highest total root length. Differences in ecoenzyme concentration affect the availability of nutrients and organic matter that support root system development. Based on the test results, the ecoenzyme contained 0.09% nitrogen, 224.23 ppm phosphorus, and 2,501.74 ppm potassium, which play a role in supporting root division, elongation, and enlargement. Adequate nutrient availability can expand the root zone, thereby enhancing the plant's ability to absorb water and nutrients (Gunawan et al., 2019).

4.7 Seedling Dry Weight (grams)

Analysis of variance (ANOVA) results indicate that the application of different ecoenzyme concentrations had a significant effect on the dry weight of seedlings 12 weeks after planting. The results of the DMRT test at the 5% significance level are presented in Table 6.

Table 6. Results of the DMRT Test at the 5% Significance Level: Mean Dry Weight of Robusta Coffee Seedlings in Response to Ecoenzyme Application

Treatment	Concentration	Dry Weight at 12 WAP
K0	Without Eco-Enzyme Application	0.43 ab
K1	Eco-Enzyme Concentration 25 mL/L	0.44 ab
K2	Eco-Enzyme Concentration 50 mL/L	0.48 a
K3	Eco-Enzyme Concentration 75 mL/L	0.40 b
K4	Eco-Enzyme Concentration 100 mL/L	0.39 b

Note: Numbers followed by the same letter in the same column indicate no significant difference between treatments in the DMRT test at the 5% level

Based on Table 6, the results of the 5% DMRT test show that at 20 weeks after planting, treatment K2 differed significantly from treatments K3 and K4, but treatment K2 did not differ significantly from treatments K0 and K1. The increase in seedling dry weight can be seen in Figure 7.

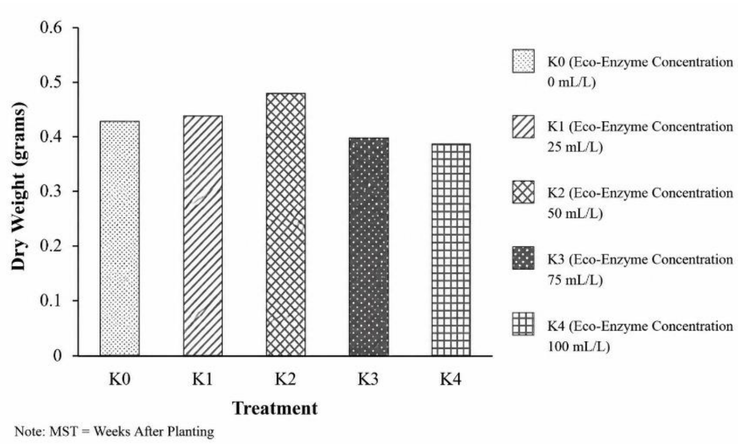

Figure 7. Graph of the Average Effect of Different Ecoenzyme Concentrations on the Dry Weight Growth of Robusta Coffee Seedlings

Based on Figure 7, treatment K2—with an ecoenzyme concentration of 50 mL/L—showed the highest dry weight of Robusta coffee plants at 12 MST. This increase in dry weight is believed to be related to the ability of ecoenzymes to supply nutrients and support the vegetative growth of plants. Ecoenzymes contain macro- and micronutrients required for plant tissue formation, thereby increasing biomass accumulation (Nugroho et al., 2023:101). Based on the test results, the ecoenzyme contains 1.91% organic carbon, 0.09% nitrogen, 224.13 ppm phosphorus, and 2,501.74 ppm potassium. The content of organic matter and enzymes such as amylase, protease, and lipase can also help break down organic matter into forms that are more easily absorbed by the roots, thereby increasing nutrient availability and supporting plant growth (Sapitri et al., 2024:1041). Dry weight reflects the accumulation of photosynthetic products stored in plant tissues; therefore, an increase in dry weight indicates better growth and biomass formation.

5. CONCLUSION

The application of ecoenzymes had a significant effect on the growth of Robusta coffee seedlings, as evidenced by increases in seedling height, stem diameter, leaf length, leaf width, root length, and seedling dry weight. A concentration of 50 mL/L of ecoenzyme yielded the best results, with seedling height of 6.91 cm, stem diameter of 1.88 mm, leaf length of 7.62 cm, leaf width of 3.35 cm, root length of 9.17 cm, and dry weight of 0.48 grams; thus, this concentration was deemed the most effective in supporting the vegetative growth of Robusta coffee seedlings. Further research is recommended to be conducted directly in the field or on coffee plantations to evaluate the long-term effects of ecoenzymes on the growth of mature plants, coffee bean production and quality, as well as resistance to pests and diseases. The effectiveness of ecoenzymes can also be further studied through combination with other organic materials such as compost, manure, or biofertilizers to enhance nutrient availability and soil microorganism activity.

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