



# Application of ecoenzymes for the growth of pak choi (*Brassica rapa* L.) growth in a wick hydroponic system toward sustainable agriculture

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## ABSTRACT

**Background:** Pak choi (*Brassica rapa* L.) is an important leafy vegetable in Indonesia, and sustainable nutrient management remains essential for improving its production. The use of eco-enzymes as an environmentally friendly alternative to liquid organic fertilizers for pak choi nutrition shows promising potential, whether grown in soil or hydroponically, to support sustainable agriculture. This study aims to identify the optimal ecoenzyme formulation as an alternative nutrient source for pak choi (*Brassica rapa* L.) grown in a wick-type hydroponic system (without water flow). **Methods:** This study used six treatments, including E0 (hydroponics without nutrients/using water only as the negative control), E1 (1% ecoenzyme), E2 (1.5% ecoenzyme), E3 (2% ecoenzyme), E4 (2.5% ecoenzyme), and E5 (0.5% AB mix). Observations were conducted over eight weeks, with water and nutrient changes performed once a week. The vegetative parameters measured included the number of leaves, plant height, leaf area, leaf color and shape, fresh weight, and dry weight. **Findings:** The results showed that a 2.5% concentration was the most optimal among the other ecoenzyme treatments for vegetative parameters, including the number of leaves, plant height and the percentage of yellowing leaves. The results indicate an upward trend with increasing concentration until the pH tolerance threshold was reached, revealing the potential of ecoenzymes as an alternative nutrient for pak choi in wick-system hydroponics. **Conclusion:** This study concluded that a 2.5 % ecoenzyme concentration was suggested for additional nutrition to support pak choi growth in hydroponic wick system, since the result shown still differ significantly from ab mix treatment. **Novelty/Originality of this article:** This study evaluated ecoenzyme as a standalone nutrient source rather than a fertilizer additive and identified its optimal concentration for supporting vegetative growth of pak choi in a wick hydroponic system.

**KEYWORDS:** ecoenzymes; pak choi; wick-system hydroponics.

## 1. Introduction

Provide Indonesia has historically been known as an agricultural nation with a thriving farming sector. Indonesia's agricultural sector not only contributes significantly to the national economy but also plays a vital role in ensuring the well-being of its citizens and strengthening national food security. With a total land area of 1.9 million square kilometers, and geographical factors and soil types that support agricultural activities, it is no surprise that many citizens rely on the agricultural sector as their primary source of livelihood (Anggreani et al., 2023).

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In this era of accelerating globalization, a concrete response is needed to address the complexity of the various challenges facing the agricultural sector. Land scarcity, population growth, and urbanization are exacerbating the impacts of environmental degradation and climate change on the agricultural sector, particularly conventional agriculture (Budiana, 2022). The transition from conventional agriculture to modern agriculture which demands innovation, technological expertise, and high precision is essential to maintaining the agricultural sector's role in ensuring sustainable food security (Balasundram et al., 2023).

The Sustainable Development Goals (SDGs) are a global call to action for all nations to protect the environment, combat climate change, eradicate poverty, and ensure access to a high quality of life and prosperity for current and future generations through development grounded in the principles of sustainability (Mishra et al., 2023). Modern agriculture's links to the SDGs are manifested in several specific targets, notably SDG 2, SDG 12, and SDG 13 on climate action. Taken together, these points show that three SDG programs are supported by the empowerment of sustainable modern agricultural practices.

Sustainable Development Goal 2 (zero hunger) states that modern agriculture founded on sustainability principles has increased global food supply. Chen et al. (2022) demonstrate the linkage between modern agriculture and this SDG by showing stability in wheat supply concurrent with rising wheat demand ratios in Asia and Africa during 1981–2018. SDG 12, on responsible consumption and production, is supported by Castillo-Díaz et al. (2024), who report that modern agricultural practices increase the percentage of waste recycling and improve energy efficiency through more renewable production processes. Modern agriculture also contributes to SDG 13 on climate action: agricultural intensification associated with modern practices supports the global uptake of greenhouse gas emissions. Together, these three SDG alignments indicate the importance of implementing modern, sustainable agricultural practices at a global scale.

Modern agriculture is characterized by the use of tools and machinery in farming, emphasizing agricultural mechanization as a key component in achieving sustainable food security. This concept of modern agriculture is closely linked to efforts to optimize agricultural land resources and to enhance sectoral competitiveness (Rosalina, 2022). One of the solution is trough soilless cultivation. Soilless cultivation systems allow for precise control of the growing environment, efficient use of water and nutrients, and minimal risk of soil-borne diseases, making them highly suitable for horticultural crops (Bihari et al., 2023).

Hydroponics is a modern farming method because of its practicality; crops can be grown in a variety of locations, including spaces with limited land, such as homes and apartments. This system can address issues such as land scarcity, poor soil conditions, uncontrolled pests and diseases, limited access to irrigation, and unpredictable climate change (Radinka et al., 2023). Wick-system hydroponics is a type of hydroponics that delivers nutrient solution to the growing medium via a wick. Typically, the wick used is made of string, a candle wick, or cotton thread. Wick hydroponics is known as a passive system, meaning there is no inflow or outflow into the growing medium.

Pak choi, with the scientific name *Brassica rapa* L., belongs to the Brassicaceae family and is one of the plants that can be grown hydroponically. This plant, whose leaves or flowers are used as food, contains seven beneficial nutrients, including carbohydrates, protein, calories, fat, fiber, Vitamin A, Vitamin B, and Vitamin C, Ca, P, and F. (Ernanda et al., 2022). In addition to its benefits, pak choi was selected because it can grow optimally in soilless cultivation or using a hydroponic system. While planting trough wick-system hydroponics the nutrition comes in a form of chemical solution (mostly ab mix). The problem with chemical fertilizers of this type is the potential for environmental pollution. One innovation in modern agriculture is the exploration of more environmentally friendly alternative nutrients, such as the use of eco-enzymes as liquid organic fertilizers.

Ecoenzymes are a type of organic compound produced by the fermentation of organic waste. The benefits of using ecoenzymes in hydroponic systems include serving as a source of organic nutrients; furthermore, in a study conducted by Salsabila & Winarsih (2023), ecoenzymes were found to accelerate plant growth, increase plant height, and boost leaf

yield. Another study, conducted by Nurfadilah et al. (2024), examined the effect of ecoenzyme application on the growth of Japanese spinach (*Spinacia oleracea* L.) grown in soil. In their study, it was noted that although the growth of Japanese spinach treated with ecoenzymes was still below that of the positive control (treatment with mixed fertilizer), ecoenzymes at a concentration of 1.5% (15 ml of ecoenzymes in 1 L of water) showed the best growth compared to other concentrations. The last study conducted by Salsabila & Winarsih (2023) utilized liquid organic fertilizer based on ecoenzymes derived from fruit peel waste in the cultivation of pak choi in soil. Although optimal results have not yet been achieved from the use of ecoenzymes in soil, ecoenzyme formulations offer an alternative source of nutrients for pak choi growth in modern agriculture. Therefore, this study was conducted with the aim of determining the most optimal concentration of ecoenzymes for pak choi plant growth in a wick hydroponic system to support modern farming and also helps in supporting food security and Sustainable development goals globally.

## 2. Methods

The research period was carried out for 3 months, roughly from February 2026 to April 2026 at the Botanical garden Universitas Pendidikan Indonesia, Setiabudi, Bandung City. This research consists of four stages, namely preparation of ecoenzymes and hidroponics, analysis of AB mix and ecoenzyme content, observation and data analysis. Preparation includes making ecoenzymes (3 months fermentation) providing tools, materials and planting media. The main ingredient in this research is curly pak choi seeds obtained from local garden store in Bandung. Ecoenzyme were made from fresh organic waste (225 grams of pineapple peel; 225 grams of watermelon rind; 225 grams of orange peel; 225 grams of Chinese cabbage) with a ratio of water: organic waste: molase (ratio 10:3:1). The composition of the AB mix was analyzed based on literature, and the ecoenzyme solution was tested at an Indonesian National Standards/*Standar Nasional Indonesia* (SNI) ISO/IEC 17025:2017-accredited agrochemical laboratory using spectrophotometry and Atomic Absorption Spectrophotometry (AAS).

The mixture is stored in a closed container and fermented for 3 months. The plants were grown using a wick-type hydroponic system consisting of a plastic tray measuring 40 cm x 30 cm x 20 cm, equipped with a hydroponic cover featuring 9 holes, each with a diameter of 5 cm. At the research stage, pak choi (8 weeks) were treated with negative control, positive control and different concentrations of ecoenzymes using the wick hydroponic system. These treatments are E0 for 1 liter of well water without added nutrients; E1 for concentration of 1% (10 ml of ecoenzyme/1 liter of water); E2 for concentration of 1.5% (15 ml of ecoenzyme/1 liter of water); E3 for concentration of 2% (20 ml of ecoenzyme/1 liter of water); E4 for concentration of 2.5% (25 ml of ecoenzyme/1 liter of water); E5 for concentration of 0.5% (5 ml of AB mix per 1 liter of water).

The observation includes changing of water and nutrition once a week, and while doing the vegetative growth observations. Observations on vegetative growth is as follows: plant height is measured from the ground surface to the tip of the top leaf; the number of leaves is calculated. The average number of all leaves that appear on the samplings of each clump; Leaf surface area measured from the calculation; leaf length and leaf width times by error coefficient; qualitative conditions of leaf color and shape; fresh weight measured after harvested using analytical scales; dry weight measured using analytical scales after the pak choi has been dried for 2 days inside oven at 70°. Data analysis was carried out using IBM SPSS software. Testing begins with a normality test and a homogeneity test. The data was normally distributed and homogeneous so it was continued with testing using the One Way Anova test and the Tukey test. However if the data result is not normally distribute the significant effect will be continued Kruskal wallis test and the Duncan's/bonferonni correction at the 5% level.

### 3. Results and Discussion

#### 3.1 Analysis of material content

The analysis of material that used in treatment which include both ecoenzymes and AB mix solution were performed using different approach. For the AB mix solution, the analysis performed through literature searching from trusted article journal. Ecoenzymes on the other hand, were analyze after being fermented for 3 months. The result of fermented ecoenzymess is shown at Figure 1.



Fig. 1. 3 months Fermented ecoenzyme inside a gallon container

The ecoenzyme that were produce has characteristics that define a good ecoenzyme, which are nautral brown-blackish collor and natural fragrance of fermentation. Change in color and fragrance were proof that indicate fermentation were done successfully. This result align with research by Hasanah & Wahid (2025), it's stated that they identified lactic acid bacteria (LAB) that included *Staphylococcus aureus* and *Lactobacillus reuteri*. These Lactic acid bacteria (LAB) help lower the pH and create an acidic environment that inhibits the growth of harmful pathogens, thereby improving the quality and safety of the enzyme product. For the analysis of ecoenzyme, was tested at an SNI ISO/IEC 17025:2017-accredited agrochemical laboratory using spectrophotometry and AAS. The result of comparison between AB mix and Ecoenzyme content shown in Table 1.

Table 1. Comparison of nutritional content from AB mix and ecoenzyme

| Nutrients contained           | AB mix (%) | Ecoenzyme (%) |
|-------------------------------|------------|---------------|
| C organic                     | -          | 1.49          |
| N total                       | 9.90       | 0.03          |
| P <sub>2</sub> O <sub>5</sub> | 4.83       | 0.02          |
| K <sub>2</sub> O              | 16.50      | 0.30          |
| MgO                           | 2.83       | 0.02          |
| Ca                            | 8.30       | 0.08          |
| Mn                            | 0.01       | 0.000269      |
| Zn                            | 0.01       | 0.00001       |
| Fe                            | 0.04       | 0.001322      |

The analysis of nutritional content between AB mix and ecoenzyme revealed substantial differences across all measured parameters, as shown in Table 1. AB mix demonstrated markedly higher concentrations of macronutrients, with N total at 9.90%, P<sub>2</sub>O<sub>5</sub> at 4.83%, K<sub>2</sub>O at 16.50%, MgO at 2.83%, and Ca at 8.30%. In contrast, ecoenzyme showed considerably lower values for the same nutrients, with N total at only 0.03%, P<sub>2</sub>O<sub>5</sub> at 0.02%, K<sub>2</sub>O at 0.30%, MgO at 0.02%, and Ca at 0.08%. Notably, ecoenzyme contained organic carbon (C organic) at 1.49%, a parameter absent in AB mix, while micronutrients such as Mn, Zn, and Fe were present in trace amounts in both solutions, albeit at slightly higher concentrations in AB mix.

The different that were displayed between the 2 nutritional solution, were highlight amongst macronutrient (especially Nitrogen) and the absent of C organic in AB mix. Fang et al. (2023) stated that in hydroponic systems, nitrogen supplied through AB mix is rapidly available for root uptake. Nitrogen nutrients contained in the combination of AB Mix nutrition play a role in supporting the growth and development of plants, particularly contributing to fresh weight accumulation. That statement align with the founding from Wahyuningsih et al. (2024) which stated that Plants need the nitrogen for the formation of leaf blades and areas with high chlorophyll content. With the large gap between the two solutions, it's expected the result of vegetative growth will differ significantly.

The next macronutrient that might indicate deficiency in ecoenzymes is phosphorus. This macronutrient supports plant life and is required in relatively large amounts. Phosphorus plays a central role in plant growth and participates in various vital processes, including energy production, photosynthesis, glycolysis, respiration, and the biosynthesis of nucleic acids and membrane lipids (Ren et al., 2023).

According to Mishra et al. (2023), phosphorus deficiency directly inhibits genetic replication and transcription. When phosphorus is present at inadequate levels, genetic processes such as cell division and plant growth are disrupted; consequently, phosphorus-deficient plants may mature more slowly than plants with sufficient phosphorus supply. In addition, Choi et al. (2026) report that phosphorus deficiency directly damages root system architecture. Symptoms of cytosolic phosphate deficiency include reduced photosynthetic activity, stunted growth, increased branching, weakened stems and leaves, and impaired root formation. This impaired root development exacerbates plant stress because the area available for nutrient uptake depends on the roots' ability to absorb nutrient solutions.

Other macronutrients that's also shown deficiency in ecoenzymes are kalium. Kalium is an essential macronutrient that regulates osmotic balance, enzyme activation, stomatal function, and phloem transport in plants. Ortel et al. (2024) report that impaired stomatal function caused by potassium deficiency indicates a loss of plant control over transpiration rate and water-use efficiency, which directly suppresses photosynthesis and growth. Furthermore, Fang et al. (2024) explain that potassium availability disrupts carbohydrate metabolism systemically. Potassium plays a critical role in regulating enzymes that metabolize carbohydrates to promote sucrose accumulation and translocation; low K levels substantially reduce plant resilience and hinder K uptake itself. This inhibition of carbohydrate metabolism creates a paradoxical condition in which leaves accumulate sugars while other organs are deprived of energy substrates, resulting in uncoordinated and suboptimal growth.

On the other hand, AB mix lacked measurable organic carbon than ecoenzyme. Ecoenzyme contained 1.49% C organic. Though this value is modest, organic carbon plays an important indirect role in plant nutrition. C organic matter provides insufficient energy and carbon sources for soil microbial activities, which can accelerate the reproduction and growth of microorganisms, and improve soil physicochemical properties. This suggests that ecoenzyme, despite its lower macro-nutrient concentrations, offers a biologically active supplement that can improve nutrient cycling and microbial support functions unavailable in purely inorganic AB mix formulations (Zhou et al., 2022).

### *3.2 The effects of ecoenzyme application on the vegetative growth of pak choi*

The vegetative development of pak choi represents a key indicator in evaluating the efficacy of nutrient treatments within hydroponic cultivation systems. In the present study, the influence of ecoenzyme application on pak choi's vegetative growth was examined through six parameters: plant height, leaf count, leaf area, leaf color, and fresh and dry plant weight. Each parameter reflects the plant's physiological response to nutrient availability and the environmental conditions established by the applied treatment. After all vegetative data were collected, it were being analyze using ibm spss software to obtain statistic conclusion for each vegetative data. The result of statistic analyze are shown in Table 2.

Table 2. Result of statistic analysis for each vegetative parameters

| Vegetative parameters | Negative Control (E0)    | 1.0% Ecoenzyme (E1)      | 1.5% Ecoenzyme (E2)       | 2.0% Ecoenzyme (E3)      | 2.5% Ecoenzyme (E4)        | Positive control (E5)     |
|-----------------------|--------------------------|--------------------------|---------------------------|--------------------------|----------------------------|---------------------------|
| Leaf surface area     | 9.61 ± 1.95 <sup>b</sup> | 9.91 ± 2.32 <sup>b</sup> | 11.22 ± 2.90 <sup>b</sup> | 9.39 ± 2.55 <sup>b</sup> | 10.25 ± 2.25 <sup>b</sup>  | 20.15 ± 8.83 <sup>a</sup> |
| Plant height          | 9.22 ± 1.50 <sup>b</sup> | 9.33 ± 1.55 <sup>b</sup> | 9.49 ± 1.87 <sup>b</sup>  | 9.34 ± 1.78 <sup>b</sup> | 9.74 ± 1.82 <sup>b</sup>   | 13.41 ± 3.07 <sup>a</sup> |
| Number of leaves      | 4.62 ± 0.88 <sup>b</sup> | 4.60 ± 1.15 <sup>b</sup> | 4.97 ± 1.30 <sup>b</sup>  | 4.92 ± 1.21 <sup>b</sup> | 10.25 ± 1.33 <sup>ab</sup> | 7.35 ± 2.80 <sup>a</sup>  |
| Wet weight            | 9.5 <sup>a</sup>         | 12.6 <sup>a</sup>        | 15.9 <sup>a</sup>         | 14.7 <sup>a</sup>        | 5.02 ± 1.33 <sup>ab</sup>  | 58.6 <sup>a</sup>         |
| Dry weight            | 1 <sup>a</sup>           | 1.4 <sup>a</sup>         | 2.3 <sup>a</sup>          | 1.8 <sup>a</sup>         | 2 <sup>a</sup>             | 4.5 <sup>b</sup>          |

Other than the table above, the result of vegetative measurement was also shown for each week during observation. The discussion for each parameter will cover the result and significance from each treatment after anova and representative post hoc test (Bonferonni, Tukey, and Duncann). There is also data about qualitative conditions of leaf color and shape shown below to highlight the difference of leaf morphological state between each treatment. Based on observations of the colour of the pak choi leaves, there were differences in colour for each treatment.

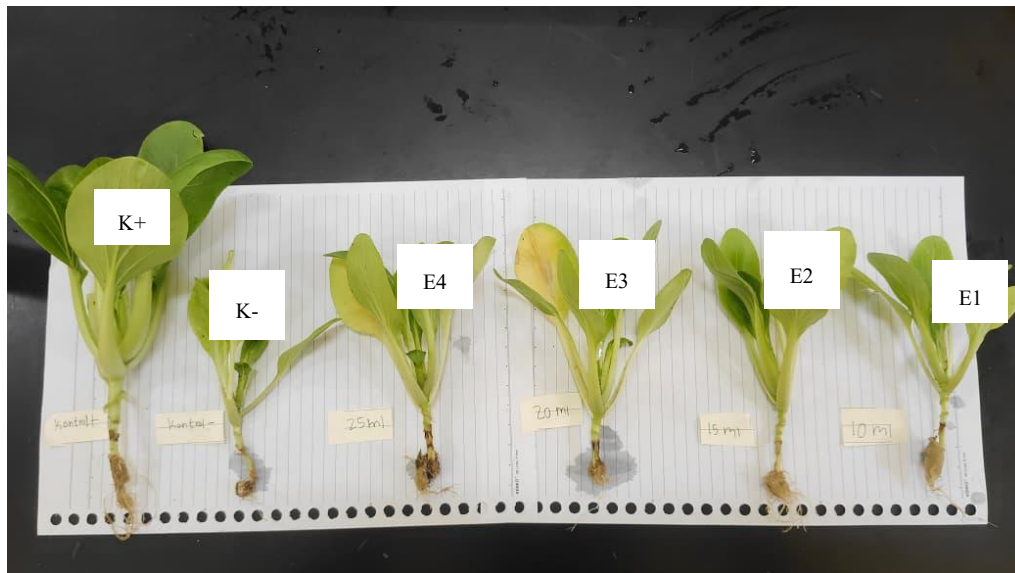


Fig. 2. The colour of the leaves in the control and ecoenzyme treatments

The positive control (K+) showed green leaves, while the negative control (K-) and the ecoenzim treatment showed leaves that were greenish-yellow. The leaves of the positive control treatment appeared a darker shade of green, indicating a healthy and optimal condition of the plant. In contrast, the leaves of the negative control and ekoenzim treatments appeared paler, ranging from light green to yellowish, indicating differences in the plants' physiological conditions (Figure 2). The appearance of pale yellow colouring in K-E4 indicates a deficiency of nutrients in this treatment. The colour of the pak choi leaves is a very important visual indicator of physiological disorders or nutritional deficiencies. Changes in colour, such as a shift from normal green to yellow, may indicate that the plant is experiencing environmental stress or an underlying health issue. Healthy pak choi leaves are generally a dark green colour, which indicates optimal levels of chlorophyll, as well as macronutrients and micronutrients. The conditions shown in Table 3. indicate a disruption to the plant's physiological mechanisms due to a lack of nutrients.

Table 3. Percentage of physiological leaf disorders based on observations

| Element        | Symptoms + References                                                                                                    | Treatments | Percentage of deficiency (%) |
|----------------|--------------------------------------------------------------------------------------------------------------------------|------------|------------------------------|
| Nitrogen (N)   | Leaves turn yellow (Silva et al., 2021)                                                                                  | K-         | 50                           |
| Nitrogen (N)   | Leaves turn yellow (Silva et al., 2021).                                                                                 | E1         | 25                           |
|                |                                                                                                                          | E2         | 17.52                        |
|                |                                                                                                                          | E3         | 15.24                        |
|                |                                                                                                                          | E4         | 6.67                         |
|                |                                                                                                                          | K+         | 0                            |
| Phosphorus (P) | Leaves turn purplish-gray, starting with older leaves (Hernita et al., 2021).                                            | 0          |                              |
|                | Leaf margins turn brown (Hernita et al., 2021).                                                                          | 0          |                              |
|                | Veins of young leaves turn dark green (Hernita et al., 2021).                                                            | 0          |                              |
| Potassium (K)  | Burn-like spots appear (Liu et al., 2021).                                                                               | K-         | 34.05                        |
|                |                                                                                                                          | E1         | 25                           |
|                |                                                                                                                          | E2         | 18                           |
|                |                                                                                                                          | E3         | 9.52                         |
|                |                                                                                                                          | E4         | 3.33                         |
| Calcium (Ca)   | The leaf margins dry out (Liu et al., 2021).<br>Leaves dry out, curl, become small, and fall off (Sumiati et al., 2024). | K+         | 0                            |
|                |                                                                                                                          | 0          |                              |
|                |                                                                                                                          | K-         | 41.9                         |
|                |                                                                                                                          | E1         | 24.46                        |
|                |                                                                                                                          | E2         | 14.76                        |
| Magnesium (Mg) | Yellow spots appear on the surface of older leaves (Ishfaq et al., 2022).                                                | E3         | 12.38                        |
|                |                                                                                                                          | E4         | 6.6                          |
|                |                                                                                                                          | K+         | 0                            |
|                |                                                                                                                          | K-         | 22.38                        |
|                |                                                                                                                          | E1         | 11.43                        |
|                |                                                                                                                          | E2         | 8.57                         |
|                |                                                                                                                          | E3         | 0                            |
|                |                                                                                                                          | E4         | 0                            |
|                |                                                                                                                          | K+         | 0                            |

### 3.2.1 Effect on leaf surface area

From graph shown in Figure 3, all treatments showed a general trend of increasing leaf area from W1 to W8, reflecting natural vegetative development over time. However, notable differences between treatments became more pronounced in the later stages (W6–W8). The Control+ (AB mix) demonstrated consistently the highest leaf area across all seed ages, reaching approximately 30.5 cm<sup>2</sup> by W8. The ecoenzyme treatments (1.00%–2.50%) produced relatively similar and moderate leaf areas throughout, ranging between approximately 10–15 cm<sup>2</sup> at W8, while Control– recorded the lowest values, particularly in the later stages.

A distinct pattern emerged from M3 onwards, the gap between Control+ and all other treatments widened progressively. Among ecoenzyme treatments, no single concentration showed consistently superior performance across all time points, with values remaining relatively clustered between 10–13 cm<sup>2</sup> from W4 to W8. The clearly dominant leaf area

values of the Control+ (AB mix) treatment across all growth stages are attributable to its complete and highly available macro- and micronutrient profile. The success of a hydroponic system relies on the composition of the nutrient solution, which contains all the essential mineral elements necessary for optimal plant growth and high yield (Fathidarehnijeh et al., 2023).

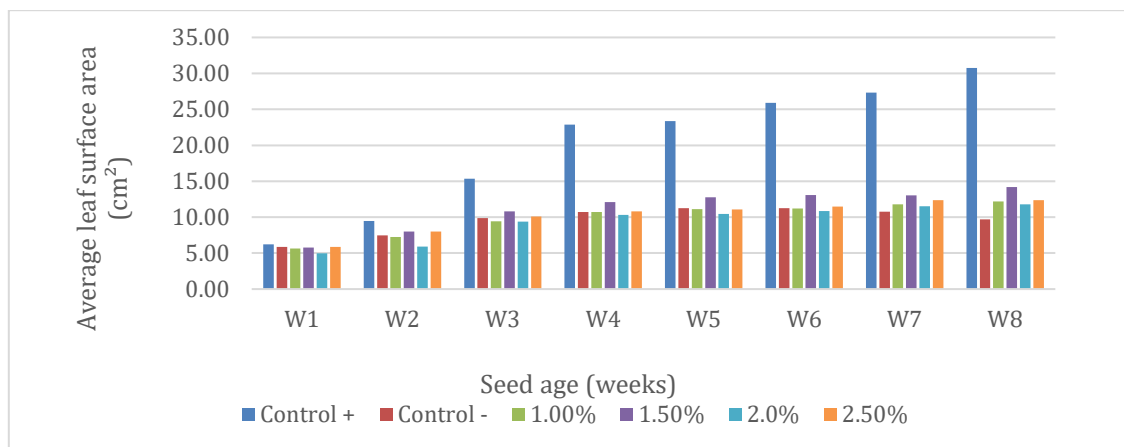


Fig. 3. Average leaf surface area pak choi from week 1 to week 8 for each treatment

Ecoenzyme treatments on the other hand, shown the result of all concentration produced moderate leaf areas that were notably lower than Control+ but higher than Control- from the mid-growth stages onward. This pattern suggests that ecoenzyme does contribute positively to leaf development, even though its macro-nutrient concentrations are considerably lower than AB mix. Even when nutrient levels in eco-enzyme are relatively low, the biologically active enzymes present can enhance plant development by improving soil microbial activity and nutrient availability (Fadlilla et al., 2023). The inability of ecoenzyme at any tested concentration to match the leaf area achieved by AB mix can be explained by the fundamental differences in nutrient delivery mechanisms and amount of nutrition contained. This align with the founding from, when they used as a sole nutrient source, liquid organic fertilizers often fail to meet plant nutrient requirements due to the slower release and lower availability of essential elements.

### 3.2.2 Effect on number of leaves

The bar chart shown in Figure 4. presents the average number of leaves of pak choi plants across eight seed age stages (W1–W8) under six treatment groups: Control+ (AB mix), Control - (no nutrient), and four ecoenzyme concentrations (1.00%, 1.50%, 2.00%, and 2.50%). All treatments began at relatively similar leaf counts of approximately 3 leaves at W1, reflecting the uniform early seedling stage. From W3 onwards, however, clear divergence between treatments emerged, becoming especially pronounced from W6 to W8. Control+ (AB mix) showed the most dramatic increase, reaching approximately 11.5 leaves by W8, whereas all ecoenzyme treatments remained clustered between 6–7 leaves at the same stage. Control- remained the lowest throughout, ending at approximately 5 leaves at W8. Among the ecoenzyme treatments, no single concentration consistently outperformed the others; the 2.00% and 2.50% concentrations showed marginally higher values at later stages compared to 1.00% and 1.50%, though differences remained modest. The contrasting performance between Control+ and all other treatments can be directly linked to the nitrogen (N) content each treatment supplies. AB mix contains 9.90% N total the highest among all treatments while ecoenzyme at all concentrations supplies only 0.03% N total. Control- provides no nutrients whatsoever.

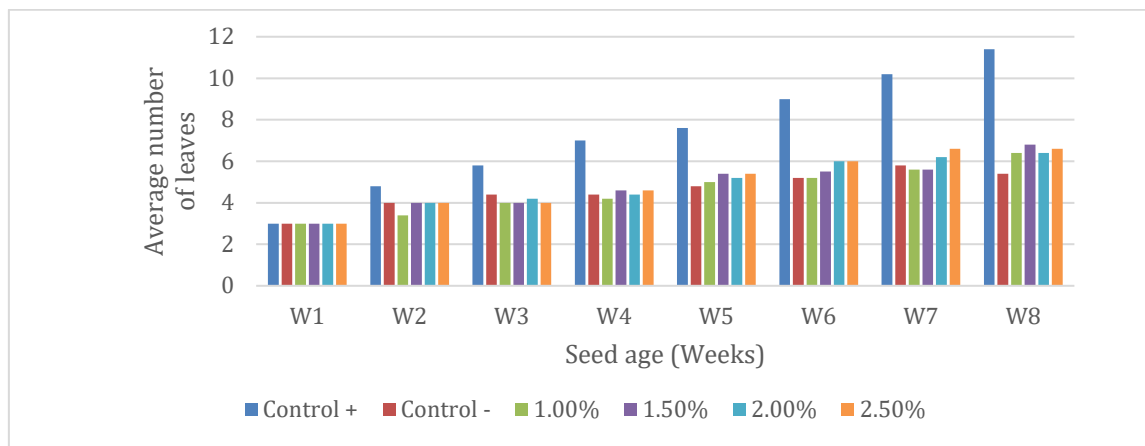


Fig. 4. Average number of leaves pak choi from week 1 to week 8 for each treatment

This theory aligns as research by Ali et al. (2025) which says nitrogen gradient closely mirrors the leaf count hierarchy observed across the growth stages. Nitrogen is a fundamental component of amino acids, proteins, chlorophyll, and nucleic acids, and is crucial for various physiological processes including cell division and tissue development, which directly supports leaf formation and vegetative growth. This is further confirmed by the graph on nitrogen levels and leaf number in hydroponic pak choi crops. Increasing nitrogen levels significantly increased leaf number, fresh and dry weights, leaf area, and nitrate accumulation in hydroponically grown lettuce plants, demonstrating a clear positive relationship between nitrogen supply and leaf developmental parameters (Razmjooei et al., 2022).

### 3.2.3 Effect on average height of pak choi

The bar below shown Figure 5. a chart presents the average plant height (cm) of pak choi (*Brassica rapa* L.) across eight seed age stages (W1–W8) under six treatment groups: Control+ (AB mix), Control- (no nutrient), and four ecoenzyme concentrations (1.00%, 1.50%, 2.00%, and 2.50%). At W1, all treatments began at similar heights of approximately 6 cm, reflecting relatively uniform seedling conditions. From W3 onwards, a clear divergence between Control+ and all other treatments became apparent, widening progressively through each subsequent week.

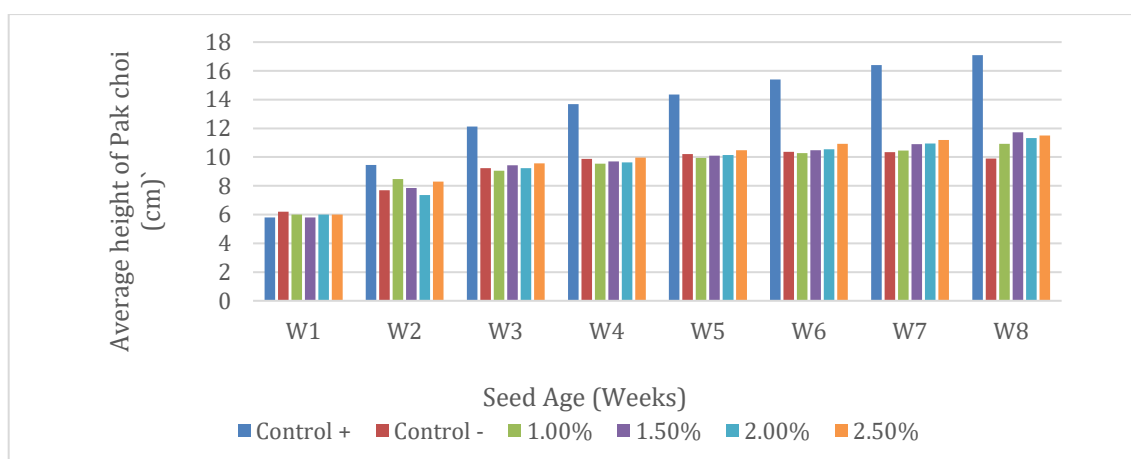


Fig. 5. Average height of pak choi from week 1 to week 8 for each treatment

By W8, Control+ reached the highest plant height at approximately 17.5 cm, while the four ecoenzyme concentrations converged at similar heights ranging between approximately 10.5–11.5 cm. Control- produced the lowest plant height, reaching only about 10 cm at W8, marginally lower than the ecoenzyme treatments at the same stage.

Notably, among the ecoenzyme treatments, the 2.00% and 2.50% concentrations appeared to produce marginally taller plants than 1.00% and 1.50% from W5 onwards, though the differences remained modest throughout all growth stages.

The highest plant heights recorded under Control+ throughout W1–W8 directly reflect the superior and complete macro and micronutrient availability supplied by AB mix particularly its high nitrogen content (9.90% N total). This Research align with the result from Wahyuningsih et al. (2024) tells that pak choi in hydroponic cultivation showed that AB Mix concentration had a significant effect on the parameters of plant height, number of leaves, and wet weight, confirming that the availability of complete nutrition from AB mix directly governs the vegetative height performance of pak choi plants in hydroponic systems. The contribution of ecoenzyme to plant height beyond what nitrogen alone would suggest is likely attributable to its organic acid content and enzymatic activity, which can enhance nutrient availability and uptake efficiency even from low-concentration sources. Research on pak choi using ecoenzyme as liquid organic fertilizer demonstrated that even though N, P, and K content in ecoenzyme was very low (N = 0.07%, P = 0.04%, K = 0.004%)

### *3.2.4 Effect on qualitative conditions of leaf color and shape*

Based on observations of the qualitative condition of pak choi leaves, a clear difference in color was found between the positive control, negative control, and ecoenzyme treatments. The K+ treatment showed fresh, dark green leaf color, which directly indicates healthy plant condition with adequate nutrition. In contrast, the negative control and all ecoenzyme treatments showed leaf colors that tended to be closer to light green to yellowish, indicating differences in physiological condition and nutritional adequacy among the treatments, as shown in Table 3.

In the positive control treatment (AB mix), nitrogen and magnesium levels were relatively high and available in easily absorbed ionic forms, resulting in optimal chlorophyll formation and fresh, dark green leaves. In the negative control and ecoenzyme treatments, the paler and yellowish color indicated nutrient deficiencies. According to Tiljuir et al. (2023), the dark green and fresh leaf color in the positive control was due to higher chlorophyll levels optimal for growth compared to the negative control and ecoenzyme treatments, owing to sufficient nitrogen as a constituent element. This is because, in the AB mix treatment, nutrients were available in sufficient quantities and in a chemical form that is more easily absorbed than the ecoenzyme nutrient formulation. A difference in leaf color was observed, with the leaves appearing lighter and less fresh compared to the positive ecoenzyme control in the negative control and ecoenzyme treatment groups, the paler, yellowish color indicated a nutrient deficiency. According to Tiljuir et al. (2023), the dark green and fresh color of the leaves in the positive control group was due to higher chlorophyll levels optimal for growth compared to the negative control and ecoenzyme groups, owing to sufficient nitrogen as a constituent element. This is because, in the AB mix treatment, nutrients are available in sufficient quantities and in a chemical form that is more easily absorbed compared to the ecoenzyme nutrient formulation. A difference in leaf color was observed, with leaves appearing lighter and less fresh compared to the positive ecoenzyme control in the other treatments. This is consistent with the statement.

Leaves that turn yellow indicate that, in addition to nitrogen deficiency, plants may be deficient in sulfur. Sulfur deficiency can inhibit protein synthesis and the accumulation of amino acids that do not contain sulfur, resulting in chlorosis in plants similar to nitrogen deficiency. Other characteristics of sulfur deficient plants, according to Narayan et al. (2022), include yellowing of young leaves and stunted growth, as shown in Table 3. Yellowing leaves can indicate a deficiency in either nitrogen or sulfur. A sulfur deficiency reduces the synthesis of proteins and sulfur containing amino acids, leading to the accumulation of free amino acids that do not contain sulfur and a decrease in chlorophyll, resulting in chlorosis that visually resembles a nitrogen deficiency.

According to Narayan et al. (2022), other symptoms of sulfur deficiency in plants include yellowing of young leaves and stunted growth, as shown in Table 3. Yellowing leaves

can indicate a deficiency in either nitrogen (N) or sulfur (S). A sulfur deficiency reduces the synthesis of sulfur-containing proteins and amino acids, leading to an accumulation of sulfur-free amino acids and a decrease in chlorophyll, resulting in chlorosis that visually resembles nitrogen deficiency, with symptoms often more pronounced on young leaves. Symptoms of nitrogen (N) deficiency, in the form of leaf yellowing (chlorosis), showed a linear downward trend as ecoenzyme concentration increased, from 50% in the K- treatment to 6.67% in the E4 treatment, while the K+ treatment showed no symptoms at all (0%). This pattern illustrates a positive correlation between increasing ecoenzyme dosage and a reduction in deficiency symptoms. Nitrogen is an essential element that serves as a primary component in chlorophyll formation and is a constituent of fatty acids, proteins, and various other metabolites within plant tissues. According to Arzita et al. (2023), elements such as nitrogen play a role in chlorophyll formation and serve as key components in the synthesis of fats, proteins, and other compounds; thus, its availability is critical for leaf cell division and enlargement. Furthermore, Qi et al. (2023) add that in hydroponically grown plants, a decrease in nitrogen concentration has been shown to have a significant impact on physiological characteristics of plants under more vulnerable conditions showed a decrease in net photosynthesis rate and a lower dry weight compared to tolerant varieties when supplied with low nitrogen, confirming that nitrogen plays a crucial role in maintaining photosynthetic capacity and the plants' physiological resilience to nutrient stress. The high percentage of chlorosis in the K- treatment (50%) was confirmed by the absence of nitrogen supply from the well water used as the growing medium, while the gradual reduction in the ecoenzyme treatment indicated that the ecoenzyme's N content (0.03%), although very low, still made a partial contribution to mitigating nitrogen deficiency symptoms.

In all treatments, including the negative control, no symptoms of phosphorus (P) deficiency were observed. In hydroponic systems, plants are highly dependent on nutrient concentrations in the nutrient solution because there are no nutrient reserves from the soil, as in conventional cultivation; thus, if the solution concentration is insufficient, physiological symptoms such as chlorosis, necrosis, and even reduced crop yield can appear more rapidly compared to soil-based systems (Suharjo et al., 2023). The absence of phosphorus deficiency symptoms in this study was most likely due to the fact that pak choi's basal nutrient requirements during the early growth phase could still be met by food reserves in the seeds and cotyledons; at this stage, the role of the growing medium or external nutrient solution was not yet significant because the plants still rely on internal reserves derived from the breakdown of the endosperm and cotyledons (Wardhani et al., 2025). In addition, phosphorus deficiency in plants is generally difficult to detect visually in the early stages, as characteristic symptoms such as a purplish discoloration caused by anthocyanin accumulation only become clearly visible at more advanced stages of deficiency.

Based on the observation results presented in Table 3, symptoms of potassium (K) deficiency characterized by the appearance of scorch-like spots on the leaves were observed in all treatments except the positive control (K+) treatment using AB Mix nutrients, where the percentage of symptom occurrence was 0%. Conversely, the negative control treatment (K-) without nutrient application showed the highest percentage of symptoms, at 34.05%. In treatments with eco-enzyme application, the percentage of symptom occurrence decreased consistently as the concentration of the applied eco-enzyme increased, namely 25% in E1 (1%), 18% in E2 (1.5%), 9.52% in E3 (2%), and 3.33% in E4 (2.5%). Symptoms characterized by burn-like spots on the leaf margins and tips are a hallmark of potassium deficiency, which has been widely reported in various plant species. According to Liu et al. (2021), these symptoms generally begin with chlorosis at the leaf margins, which then develops into yellowish-brown necrotic spots, starting from older leaves due to potassium's mobility and ease of translocation to younger tissues.

An increase in the concentration of ecoenzymes from 1% to 2.5% was shown to reduce the incidence of potassium deficiency symptoms in hydroponic plants, as indicated by burn-like spots on the leaves. The consistent reduction in symptoms observed from E1 to E4

indicates that the higher the concentration of eco-enzymes applied, the lower the severity of the resulting K deficiency. According to Ladikou et al. (2025), this pattern is physiologically relevant because potassium is an essential element that plays a role in photosynthesis, osmoregulation, enzyme activation, and plant nutrient balance.

The results of the observations show that symptoms of calcium deficiency—characterized by leaves drying out, curling, shrinking, and falling off—appeared in all treatments except K+, with a consistent decrease in the percentage of symptoms as the concentration of eco-enzymes increased: 41.9% (K-), 24.46% (E1), 14.76% (E2), 12.38% (E3), 6.6% (E4), and 0% (K+), with an overall average symptom rate of 16.68%. The percentage value for the calcium parameter was the highest among the other nutrient parameters observed, indicating that the plants' need for calcium during the observation period was relatively high and that a deficiency was most easily visualized. Calcium plays a crucial role as a component in cell wall formation and also strengthens intercellular adhesion through calcium-pectate/pectin bonds in the cell walls and intercellular layers, thereby increasing tissue strength, which makes this element crucial to the strength and structural integrity of plant tissues. Furthermore, calcium can be "immobile" within the plant because it is translocated through the xylem along with the transpiration stream and cannot be redistributed via the phloem; thus, when its supply is limited, actively dividing young tissues (growth points, root tips, young leaves) will be the first to show symptoms of damage, such as curling, reduced size, and leaf drop. This condition occurs because, without sufficient calcium, cell division and elongation are disrupted, causing the tissues to become brittle and prone to necrosis at their edges and tips. The reduction in the percentage of symptoms in treatments with higher eco-enzyme concentrations is believed to be related to the calcium content in the eco-enzyme solution, which, according to some reports, can reach tens of mg/L depending on the fermentation raw materials used. Nevertheless, the high percentage of symptoms in treatments E1–E3 compared to other nutrient parameters indicates that calcium supply from eco-enzymes at low to moderate concentrations is insufficient to meet plant needs; thus, only at the highest concentration (E4) were symptoms significantly reduced, approaching optimal conditions for K+.

For magnesium, symptoms in the form of yellow spots on the surface of older leaves were observed at rates of 22.38% (K-), 11.43% (E1), 8.57% (E2), and 0% in E3, E4, and K+, with an average total symptom score of 7.06%. Unlike the pattern observed for calcium, symptoms of magnesium deficiency were no longer detectable at an eco-enzyme concentration of 2% (E3), indicating that plants' magnesium requirements are relatively easier to meet than those for calcium or potassium within the tested concentration range. Magnesium ( $Mg^{2+}$ ) is a major component of chlorophyll and plays a crucial role in photosynthesis; thus, its availability directly affects a plant's capacity to absorb light and convert it into chemical energy for growth. According to Saputra et al. (2025), chlorophyll levels which are positively correlated with the rate of photosynthesis indicate that magnesium deficiency reduces a plant's efficiency in absorbing light energy, thereby inhibiting the formation of organic compounds necessary for growth. Unlike calcium, magnesium is "mobile" and can easily be translocated from older leaves to younger tissues when a deficiency occurs; consequently, chlorosis symptoms such as yellow spots first appear on older leaves, as reported in the symptoms observed in this study (Ishfaq et al., 2022). When magnesium is insufficient, chlorophyll synthesis is inhibited, causing a decrease in light energy capture capacity and affecting the rate of photosynthesis as well as overall plant growth. The rapid onset of Mg deficiency symptoms at relatively low coenzyme concentrations (E2–E3) indicates that the magnesium content in the ecoenzyme solution is sufficient to meet the plants' needs even when administered at moderate doses, making ecoenzymes a potentially effective alternative source of magnesium in hydroponic systems.

The variations in pak choi leaf color observed in each treatment indicate that nutrient availability has a significant effect on the plants' physiological condition. The positive control treatment (AB mix) produced dark green, fresh leaves, indicating that the plants' nutritional needs were met and that chlorophyll biosynthesis was proceeding optimally. In contrast, in the negative control and the ecoenzyme treatment, the plant leaves exhibited

light green to yellowish colors (chlorosis), indicating nutrient deficiencies, particularly in nitrogen and, presumably, sulfur. These findings are supported by data on the percentage of physiological disorders, which show a high incidence of chlorosis in the negative control and a reduction in that incidence in the ecoenzyme treatment, although it is not yet on par with the conditions in the positive control. Based on these results, it can be concluded that ecoenzymes have the potential to serve as an alternative nutrient source for plants; however, their nutrient content is not yet sufficient to optimally meet the plants' nutritional needs, as the AB mix solution does in supporting the vegetative growth of pak choi.

### 3.2.5 Effect on wet weight and dry weight

The chart shown below Figure 6. presents the average fresh weight (wet weight) and dry weight (g) of plants across six treatment groups: Control+ (AB mix), Control- (no nutrient), and four ecoenzyme concentrations: 1.0%, 1.5%, 2.0%, and 2.5%. A large and clear disparity was recorded between Control+ and all other treatments for both parameters. Control+ achieved the highest fresh weight at 58.4 g and dry weight at 4.5 g. Among ecoenzyme treatments, fresh weight ranged from 12.6 g (1.0%) to 15.9 g (1.5%), while dry weight ranged from 1.4 g (1.0%) to 2.3 g (1.5%). Control- produced the lowest values of all, with 9.5 g fresh weight and only 1.0 g dry weight, reflecting the absence of any nutritional input. Interestingly, the 1.5% ecoenzyme treatment recorded the highest fresh and dry weight among all ecoenzyme concentrations, while the 2.0% and 2.5% values were slightly lower, suggesting a non-linear dose-response pattern at higher concentrations.

The dominance of Control+ (AB mix) across both parameters is attributable to its comprehensive and immediately bioavailable nutrient profile, especially its very high concentrations of N (9.90%), K<sub>2</sub>O (16.50%), and Ca (8.30%). Each of these nutrients plays a distinct and critical role in biomass accumulation. The amount of Potassium, present at 16.50% in AB mix, this align with research by Alharbi et al. (2024) which found that potassium plays an equally essential role in driving fresh weight by regulating cellular water uptake and turgor pressure. Potassium regulates water status, turgor pressure, and the movement of photosynthates, thereby contributing to overall plant growth, and potassium supplementation fosters favorable growth conditions, stimulates cell division, and promotes the synthesis of essential compounds, ultimately contributing to increased biomass production.

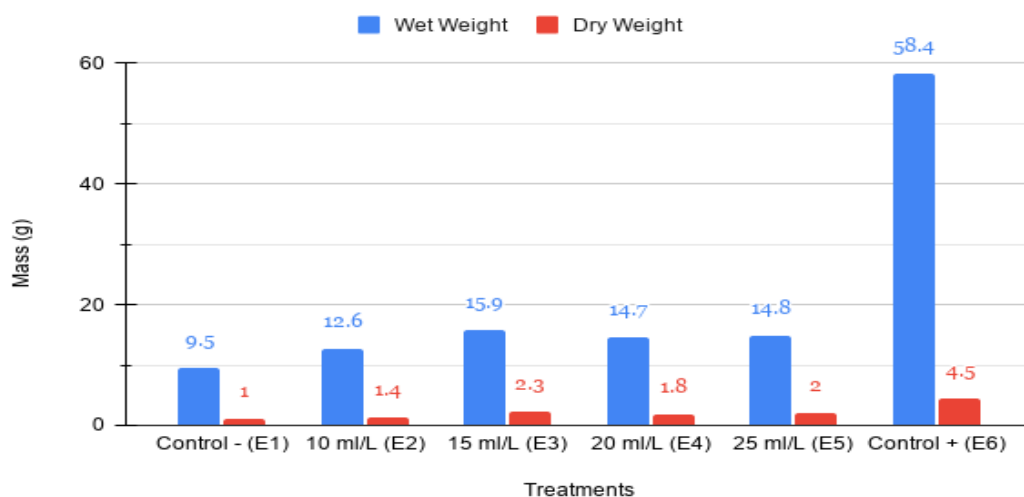


Fig. 6. Average wet weight and dry weight pak choi from week 1 to week 8 for each treatment

The exceptionally high fresh weight of Control+ (58.4 g) compared to all ecoenzyme treatments (12.6–15.9 g) is therefore a direct expression of the superior potassium-mediated water retention and cell turgor maintenance provided by AB mix. The exogenous application of potassium significantly increased total plant fresh weight, dry weight, and leaf area, as potassium's loading into the xylem mediates hydraulic conductance that aids

plants in maintaining cell turgor, stomatal aperture, and gas exchange rates (Kataria & Singh., 2022).

All four ecoenzyme concentrations (1.0%–2.5%) produced fresh weights (12.6–15.9 g) and dry weights (1.4–2.3 g) that were markedly higher than Control– but substantially lower than Control+. The relatively modest dry weight values across ecoenzyme treatments (1.4–2.3 g) compared to Control+ (4.5 g) reflect the limited nitrogen availability from ecoenzyme, which constrains protein synthesis and structural dry matter accumulation. The use of organic nutrient solutions resulted in plants with smaller leaf area, plant height, stem diameter, and fresh biomass compared to those grown under inorganic fertilizer treatment, confirming the consistent pattern of organic nutrient sources yielding lower biomass than their synthetic counterparts in hydroponic systems (Alneyadi et al., 2024).

Based on the observation results, nutrient availability had a significant effect on the biomass accumulation of pak choi, as reflected in the fresh weight, dry weight, moisture content, and the ratio of the two; the positive control (AB mix) showed the highest results for all parameters, indicating sufficient nutrient availability to support photosynthesis and growth, whereas the negative control and the ecoenzyme treatment yielded lower values due to physiological disturbances resulting from limited nutrient availability. Among the treatments, the ecoenzyme concentration of 25 mL/L appeared to yield the best results based on various observations, showing a pattern of improved vegetative growth as the ecoenzyme concentration increased. Overall, ecoenzyme has not yet been able to replace the role of the AB mix as a sole nutrient source in meeting the nutritional requirements for the vegetative growth of pak choi in a wick-system hydroponic medium. Further research is needed to combine ecoenzymes with other organic materials that can significantly increase the supply of macronutrients and micronutrients required by the plants, in order to develop a nutrient mixture that can make a tangible contribution to the vegetative growth of pak choi and serve as a single organic nutrient solution in wick-fed hydroponic systems.

#### 4. Conclusions

The nutrient content of the ecoenzyme was lower than that of the AB mix, with differences observed in the organic carbon content of the ecoenzyme solution. All treatments over the 8-week period showed increased growth, with a trend of increasing yield as the concentration increased. The most optimal ecoenzyme concentration for plant height, number of leaves, greener leaf color, as well as the fresh and dry weights of pak choi in the wick hydroponic system was the 2.5% ecoenzyme treatment, although there were no significant differences among all treatments.

The conversion of fruit and vegetable waste into ecoenzyme from this research support a zero-waste approach, which implicate it's alignment with SDG number 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Further research could focus on identifying the bacteria and the enzymes they produce in the mixed vegetable and fruit ecoenzyme blend. Further research could also explore the use of nutrient-rich organic waste to increase the nutrient content of the ecoenzyme, with the goal of developing an organic nutrient formulation that is self sufficient without the need for chemical fertilizers.

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#### Author Contribution

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