

# The Potential of Food Waste-Derived Organic Fertilizer Produced Using Biopore Technology on the Growth of Spinach (*Amaranthus hybridus*)

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## Abstract

Food-wasting behavior contributes significantly to the increasing volume of household organic waste, which has the potential to pollute the environment if not managed properly. This study aimed to describe the potential of food waste processed using the biopore technique as an organic fertilizer for the growth of spinach (*Amaranthus hybridus*) and to determine the optimal application concentration that promotes the best plant growth. This study employed an experimental method using a Completely Randomized Design (CRD). Five concentrations of biopore organic fertilizer were tested with four replications: P0 (control/no fertilizer), P1 (25 g), P2 (50 g), P3 (100 g), and P4 (150 g). The observed parameters included plant height (cm), number of leaves, and leaf area (cm<sup>2</sup>), which were measured periodically for four weeks after planting (WAP). The collected data were analyzed using Analysis of Variance (ANOVA), followed by the Least Significant Difference (LSD) test at a 5% significance level. The results showed that the application of biopore organic fertilizer derived from food waste had a significant effect on all growth parameters evaluated. Based on the post hoc analysis, treatment P4 (150 g/L concentration, equivalent to 15%) consistently produced the best growth performance. At the end of the observation period (4 WAP), P4 resulted in an average plant height of 13.23 cm, an average of 8 leaves per plant, and a leaf area of 6.10 cm<sup>2</sup>. These values were significantly higher than those of the control group (P0) and the other lower-concentration treatments. In conclusion, food waste decomposed through biopore holes has considerable potential to be utilized as an agronomically valuable organic fertilizer. A concentration of 15% (P4) is recommended as the most effective formulation for sustainably promoting the growth of *Amaranthus hybridus* L. plants.

**Keywords:** *Amaranthus hybridus* L.; Food waste; Organic fertilizer; Biopore holes; Plant growth.

## INTRODUCTION

Food waste behavior is not a new phenomenon; however, it remains a significant issue in society. This phenomenon frequently occurs in both household food consumption and restaurant settings. One of the primary contributing factors is a lack of self-control in regulating appetite, which leads individuals to take food portions that exceed their actual needs, thereby contributing to increased food waste. In addition, the habit of purchasing food items without proper planning often results in excessive buying that does not align with household requirements. These behaviors have consequently exacerbated the volume of food waste generated (Lutviyani et al., 2022). Indonesia is among the countries with a very high level of waste production, generating approximately 33,814,397.64 tons of waste, of which 53.79% originates from residential or household areas. The most dominant type of waste is food waste, accounting for approximately 39.26% of the total waste volume (Utami, 2023). Waste has long been recognized

as one of the major contributors to global warming, particularly through its role in increasing the Earth's surface temperature (Lingga et al., 2024).

The waste problem in Indonesia is not limited to flooding; it also involves ongoing concerns regarding the increasing volume and diversity of waste generated as a result of population growth and technological advancement (Jihan, 2023). Poorly managed waste can significantly reduce the quality of life of communities. Waste scattered throughout the environment creates health hazards, diminishes the aesthetic value of an area, and disrupts daily activities (Utami, 2023). Furthermore, waste serves as a breeding ground and habitat for insects and rodents, becoming a source of pollution and contamination of soil, water, and air, as well as a reservoir for harmful pathogens that threaten public health (Maliga et al., 2021). In addition, improper waste management practices, such as open burning and indiscriminate dumping, contribute to air pollution and unpleasant odors. Therefore, more environmentally

friendly and sustainable waste treatment methods are urgently needed to address these challenges (Setiawati et al., 2024).

The potential for utilizing food waste is substantial when managed properly, as it can be processed into animal feed, organic fertilizer, or raw materials for renewable energy production. One approach that can be implemented to address this issue is the conversion of food waste into organic fertilizer, which has significant potential to support agricultural activities (Haryanta et al., 2023). Organic solid waste from the domestic sector can be reutilized as a source of essential nutrients for plants, contributing to improved soil fertility, enhanced soil structure, and the stimulation of beneficial soil microbial activity (Ali et al., 2013). Food waste is known to contain important nutrients such as nitrogen (N), phosphorus (P), and potassium (K), making it a promising and effective source of organic fertilizer (Gürel, 2024). One method of utilizing food waste to produce economically valuable organic fertilizer for communities is through the application of biopore technology. Biopore technology involves the creation of vertical holes in the soil that not only enhance water infiltration but also facilitate the natural decomposition of food waste into nutrient-rich compost. This process produces organic fertilizer that can be beneficially used for agricultural and environmental purposes (Meiyuntariningsih et al., 2022).

The construction of Biopore Infiltration Holes (BIHs) was chosen because the technique is easy to implement, simple to operate, and relatively inexpensive (Indriatmoko, 2015). Biopores can serve as an alternative method for mitigating floods and waterlogging through their function as infiltration holes, while simultaneously addressing organic waste management. Organic waste that would otherwise be burned can be converted into compost through the biopore system (Linda, 2016). The utilization of organic fertilizer produced from food waste decomposed in biopore infiltration holes has been shown to effectively enhance the growth of horticultural crops

(Akbar et al., 2018). Furthermore, organic fertilizer generated through biopore infiltration holes can be applied as a nutrient source for plants, thereby reducing dependence on chemical fertilizers. Previous research has demonstrated that biopore infiltration holes have a positive effect on the growth and yield of wheat, increasing crop productivity by up to 60.24% (Hatigoran et al., 2014).

Spinach (*Amaranthus hybridus*) is a short-lived crop that can be easily cultivated in various growing media, making it an ideal candidate for testing the effectiveness of organic fertilizers. The consistent application of compost derived from organic waste has been shown to enhance the vegetative growth of amaranth plants (Haryanta et al., 2023). Amaranth is also an important source of iron; therefore, green amaranth is widely used in food preparations, both as a main dish ingredient and as a component of snack products. Its ease of cultivation and maintenance has contributed to its popularity among farmers and its continued production to meet market demand (Eltiya et al., 2023). This study aimed to describe the potential of food waste as an organic fertilizer processed through biopore technology in promoting the growth of amaranth plants and to determine the optimal fertilizer concentration that provides the best growth performance for the crop.

## MATERIALS AND METHODS

### Study area

This study was conducted in a residential area of North Tatura Village, South Palu District, Palu City, Central Sulawesi Province, Indonesia, which served as the site for food waste collection and the construction of biopore infiltration holes. The planting of spinach seeds and the maintenance of the experimental plants were carried out in the greenhouse of the Faculty of Teacher Training and Education (FKIP), Tadulako University (Figure 1). The research was conducted over a four-month period, from January to April 2026.

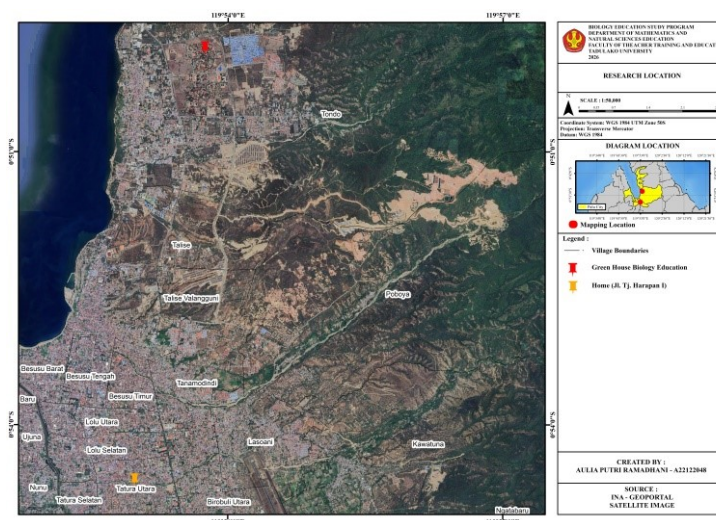


Figure 1. Map of the research location in green house and Palu City, Central Sulawesi, Indonesia.

## Procedures

### *Biopore Infiltration Hole Construction and Compost Production*

The procedure began with the selection of a suitable site for the installation of biopore infiltration pipes. Cylindrical holes were created vertically in the soil using a crowbar, with a diameter of 10 cm and a depth of approximately 80 cm. After the holes were completed, perforated PVC pipes were inserted into the soil to maintain the stability of the holes and prevent collapse. Household organic food waste collected periodically was then added into the biopore holes as the primary raw material. The decomposition process occurred naturally within the soil through the activity of microorganisms, assisted by the addition of EM4 bioactivator, for approximately one month until the food waste was fully decomposed and transformed into mature organic compost ready for harvest.



Figure 2. Biopore holes.

### *Planting Media Preparation and Plant Maintenance*

Seeds of *Amaranthus hybridus* were first germinated in a sterile nursery medium until they were ready for transplanting. The main planting medium was prepared by mixing soil with organic fertilizer produced from the biopore decomposition process according to the designated treatments. The treatments consisted of: P0 = no organic fertilizer (control), P1 = 25 g organic fertilizer, P2 = 50 g organic fertilizer, P3 = 100 g organic fertilizer, and P4 = 150 g organic fertilizer. Uniform and healthy amaranth seedlings, aged 14 days after sowing, were transplanted into individual planting containers (polybags). Plant maintenance included controlled irrigation twice daily (morning and afternoon), manual weed removal, and regular monitoring for pest and

disease infestations throughout the vegetative growth period.

### *Measurement of Growth Parameters*

Plant growth parameters were measured weekly at 2, 3, and 4 weeks after transplanting (WAT). The primary parameters observed included plant height (cm), leaf number, and leaf area (cm<sup>2</sup>). Plant height was measured using a ruler from the base of the stem above the soil surface to the tip of the highest leaf. The number of leaves was determined by counting all fully expanded leaves. Leaf area was estimated using the maximum leaf length and width multiplied by the amaranth correction factor (0.602).

### Data Analysis

Quantitative data obtained from the measurement of plant growth parameters (plant height, number of leaves, and leaf area) were systematically tabulated and analyzed. Statistical analysis was performed using IBM SPSS Statistics software based on a Completely Randomized Design (CRD) consisting of five treatments and four replications. The data were subjected to a one-way analysis of variance (One-Way ANOVA) at a 95% confidence level ( $\alpha = 0.05$ ) to determine the significance of the effects of different concentrations of biopore-derived organic fertilizer. When significant differences were detected, the analysis was followed by the Least Significant Difference (LSD) test to compare the means among treatments.

## RESULT AND DISCUSSION

### *Plant Height of *Amaranthus hybridus**

The application of organic fertilizer derived from food waste processed through biopore technology significantly affected the height growth of *Amaranthus hybridus*. Differences in plant height were observed among the treatment groups throughout the experimental period, indicating that the concentration of biopore-derived organic fertilizer influenced plant growth. The development of plant height during the four-week observation period is presented in Figure 2.

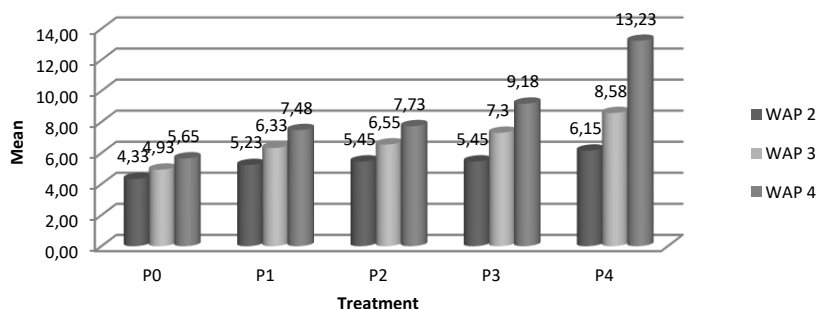


Figure 3. Growth in plant height of *Amaranthus hybridus* under different concentrations of biopore-derived organic fertilizer. P0 = control (without organic fertilizer), P1 = 25 g organic fertilizer, P2 = 50 g organic fertilizer, P3 = 100 g organic fertilizer, and P4 = 150 g organic fertilizer.

Based on Figure 2, the average plant height of *A. hybridus* in the control treatment (P0, without biopore fertilizer) was 4.33 cm at 2 weeks after transplanting (WAT), 4.93 cm at 3 WAT, and 5.65 cm at 4 WAT. In treatment P1 (2.5% biopore fertilizer), the average plant heights were 5.23 cm, 6.33 cm, and 7.48 cm at 2, 3, and 4 WAT, respectively. Treatment P2 (5% biopore fertilizer) resulted in average plant heights of 5.45 cm, 6.55 cm, and 7.73 cm, whereas treatment P3 (10% biopore fertilizer) produced average heights of 5.45 cm, 7.30 cm, and 9.18 cm at the respective observation periods. The highest values were recorded in treatment P4 (15% biopore fertilizer), with average plant heights of 6.15 cm, 8.58 cm, and 13.23 cm at 2, 3, and 4 WAT, respectively. These results indicate a positive trend in plant height growth with increasing concentrations of biopore-derived organic fertilizer.

To evaluate the effects of the treatments on the growth of *A. hybridus*, the data were subjected to analysis of variance (ANOVA). The ANOVA results revealed that the planting media treatments had a highly significant effect on plant height, as indicated by an F-value of  $F(4,15) = 9.968$  with a significance level of  $P < 0.001$ . Since the significance value was substantially lower than the threshold of  $\alpha = 0.05$ , the differences among treatments were considered statistically significant. The treatment mean square was 11.647, while the error mean square was 1.168. These findings demonstrate that variations in the planting media significantly influenced the growth rate of amaranth plant

height. Therefore, a post hoc analysis was conducted to determine which treatment produced the best growth performance.

The results of the Least Significant Difference (LSD) test showed that all biopore fertilizer treatments (P1, P2, P3, and P4) significantly increased the plant height of *A. hybridus* compared with the control treatment (P0). Among all treatments, P4 produced the greatest increase in plant height and differed significantly ( $P < 0.05$ ) from all other treatments. The largest mean differences were observed between P4 and P0 (4.707 cm), followed by P4 and P1 (2.975 cm), P4 and P2 (2.737 cm), and P4 and P3 (2.007 cm). In contrast, no significant differences were detected among treatments P1, P2, and P3 ( $P > 0.05$ ). These findings suggest that the application of biopore-derived organic fertilizer at the P4 concentration was the most effective treatment for promoting plant height growth in *A. hybridus*.

#### Number of Leaves of *Amaranthus hybridus*

The application of organic fertilizer derived from food waste processed through biopore technology significantly affected the number of leaves of *A. hybridus*. Differences in leaf production were observed among the treatment groups throughout the experimental period, indicating that biopore-derived organic fertilizer promoted the vegetative growth of the plants. The development of leaf number during the four-week observation period is presented in Figure 3.

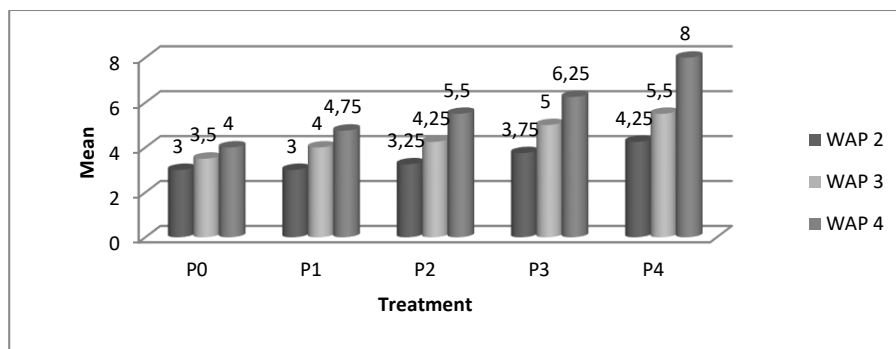


Figure 4. Mean number of leaves (leaves plant<sup>-1</sup>) of *Amaranthus hybridus* at 2, 3, and 4 weeks after transplanting (WAT).

Based on Figure 3, the average number of leaves of *A. hybridus* in the control treatment (P0, without biopore fertilizer) was 3.00 leaves at 2 weeks after transplanting (WAT), 3.50 leaves at 3 WAT, and 4.00 leaves at 4 WAT. In treatment P1 (2.5% biopore fertilizer), the average numbers of leaves were 3.00, 4.00, and 4.75 leaves at 2, 3, and 4 WAT, respectively. Treatment P2 (5% biopore fertilizer) resulted in average leaf numbers of 3.25, 4.25, and 5.50 leaves, while treatment P3 (10% biopore fertilizer) produced averages of 3.75, 5.00, and 6.20 leaves at the corresponding observation periods. The highest leaf numbers were observed in treatment P4 (15% biopore fertilizer), with averages of 4.25, 5.50, and 8.00 leaves at

2, 3, and 4 WAT, respectively. These results indicate that increasing concentrations of biopore-derived organic fertilizer promoted greater leaf production in *A. hybridus*.

To evaluate the effects of the treatments on leaf development, the data were subjected to analysis of variance (ANOVA). The results revealed that the planting media treatments had a highly significant effect on the number of leaves of *A. hybridus*, as indicated by an F-value of  $F(4,15) = 46.397$  with a significance level of  $P < 0.001$ . Since the significance value was substantially lower than the threshold of  $\alpha = 0.05$ , the differences among treatments were considered statistically significant. The treatment mean square was

3.614, whereas the error mean square was 0.078. These findings demonstrate that variations in the planting media significantly influenced leaf formation and development in amaranth plants. Therefore, further analysis using the Least Significant Difference (LSD) test was conducted to identify the treatments responsible for the observed differences.

The results of the Least Significant Difference (LSD) test indicated that the application of biopore-derived organic fertilizer significantly increased the number of leaves of *A. hybridus* compared with the control treatment (P0), except for treatment P1, which was not significantly different from the control ( $P = 0.052$ ;  $P > 0.05$ ). Among all treatments, P4 produced the highest number of leaves and differed significantly ( $P < 0.05$ ) from all other treatments. The largest mean differences were observed between P4 and P0 (4.15 leaves), followed by P4 and P1 (1.9975 leaves), P4 and P2 (1.5825 leaves), and P4 and P3 (0.915 leaves).

Furthermore, treatments P2 and P3 also resulted in significant increases in leaf number compared with the control treatment. These findings suggest that increasing concentrations of biopore-derived organic fertilizer positively influenced leaf development in *A. hybridus*. Overall, the P4 treatment was the most effective and optimal concentration for promoting leaf production and vegetative growth in amaranth plants.

#### Leaf Area of *Amaranthus hybridus*

The application of organic fertilizer derived from food waste processed through biopore technology had a significant effect on the leaf area of *A. hybridus*. Differences in leaf area development were observed among the treatment groups throughout the experimental period, indicating that biopore-derived organic fertilizer enhanced leaf expansion and overall vegetative growth. The development of leaf area during the four-week observation period is presented in Figure 4.

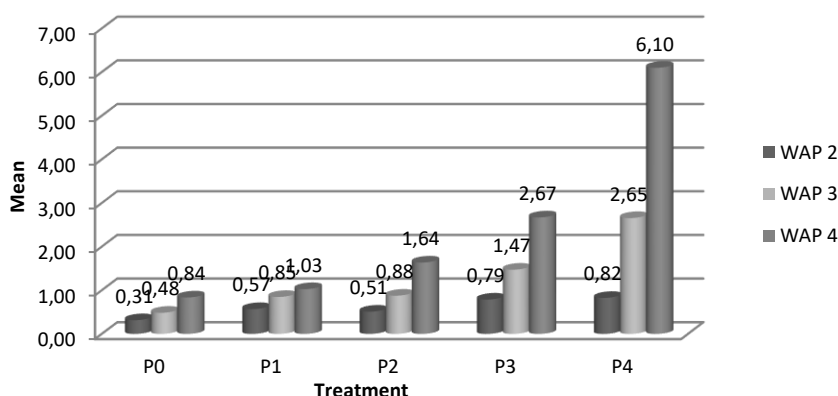


Figure 5. Mean leaf area (cm<sup>2</sup>) of *Amaranthus hybridus* at 2, 3, and 4 weeks after transplanting (WAT).

Based on Figure 4, the average leaf area of *A. hybridus* in the control treatment (P0, without biopore fertilizer) was 0.31 cm<sup>2</sup> at 2 weeks after transplanting (WAT), 0.48 cm<sup>2</sup> at 3 WAT, and 0.84 cm<sup>2</sup> at 4 WAT. In treatment P1 (2.5% biopore fertilizer), the average leaf areas were 0.57 cm<sup>2</sup>, 0.85 cm<sup>2</sup>, and 1.03 cm<sup>2</sup> at 2, 3, and 4 WAT, respectively. Treatment P2 (5% biopore fertilizer) produced average leaf areas of 0.51 cm<sup>2</sup>, 0.88 cm<sup>2</sup>, and 1.64 cm<sup>2</sup>, whereas treatment P3 (10% biopore fertilizer) resulted in average values of 0.79 cm<sup>2</sup>, 1.47 cm<sup>2</sup>, and 2.67 cm<sup>2</sup> at the corresponding observation periods. The largest leaf areas were observed in treatment P4 (15% biopore fertilizer), with averages of 0.82 cm<sup>2</sup>, 2.65 cm<sup>2</sup>, and 6.10 cm<sup>2</sup> at 2, 3, and 4 WAT, respectively. These results indicate that increasing concentrations of biopore-derived organic fertilizer promoted greater leaf expansion throughout the experimental period.

To determine the effects of the treatments on leaf area development, the data were analyzed using one-way analysis of variance (ANOVA). The results showed that

the planting media treatments had a highly significant effect on the leaf area of *A. hybridus*, as indicated by an F-value of  $F(4,15) = 10.313$  with a significance level of  $P < 0.001$ . Since the significance value was substantially lower than the threshold of  $\alpha = 0.05$ , the differences among treatments were considered statistically significant. The treatment mean square was 4.496, while the error mean square was 0.436. These findings demonstrate that variations in the planting media significantly influenced leaf expansion and development. Therefore, further analysis using the Least Significant Difference (LSD) test was conducted to identify the specific treatments responsible for the observed differences.

The results of the LSD test revealed that biopore-derived organic fertilizer significantly increased the leaf area of *A. hybridus* compared with the control treatment (P0). Significant effects became particularly evident in treatments P3 ( $P = 0.032$ ) and P4 ( $P < 0.001$ ), whereas treatments P1 and P2 did not differ significantly from the

control ( $P > 0.05$ ). Among all treatments, P4 produced the greatest leaf area and differed significantly ( $P < 0.05$ ) from all other treatments. The largest mean differences were observed between P4 and P0 (2.6500 cm<sup>2</sup>), followed by P4 and P1 (2.3775 cm<sup>2</sup>), P4 and P2 (2.1850 cm<sup>2</sup>), and P4 and P3 (1.5475 cm<sup>2</sup>). These findings indicate that the 15% biopore fertilizer treatment (P4) was the most effective concentration for promoting leaf expansion and maximizing leaf area development in *A. hybridus*.

### Discussion

The application of organic fertilizer derived from food waste processed through biopore technology had a significant effect on increasing the plant height of green amaranth throughout the cultivation period, as indicated by a significance value of  $P < 0.001$  ( $P < 0.05$ ). This result demonstrates that the fertilizer treatments positively influenced plant height growth. During the vegetative growth phase, photosynthetic products and absorbed nutrients are primarily allocated to the division of apical meristem cells, which contributes to stem elongation and increased plant height. Plant growth and productivity are optimized when essential nutrients are available in balanced amounts in the soil, whereas growth rates decline when nutrient availability becomes limiting (Harsono, 2012). Vegetative growth is widely recognized as an indicator of efficient nutrient uptake and adequate nutrient availability within the growing medium (Loso & Haryanti, 2023). Consequently, higher rates of organic fertilizer application can promote greater increases in average plant height (Loso & Kriswantoro, 2025).

The application of biopore-derived organic fertilizer also significantly increased the number of leaves of *A. hybridus* during the cultivation period, as evidenced by a significance value of  $P < 0.001$  ( $P < 0.05$ ). These findings indicate that fertilizer application to the planting medium enhanced leaf formation and development. Optimal leaf growth occurs when nutrient availability is sufficient to support plant metabolic processes, thereby stimulating vegetative growth and increasing leaf production. The quantity of nutrients supplied to and absorbed by plants strongly influences vegetative growth rates, and adequate nutrient availability is a key determinant of plant biomass accumulation (Wardhana et al., 2015). The increase in leaf number is closely associated with increased plant height, as greater stem growth generally supports the formation of additional leaves. According to Rizqiani et al. (2007), plants require nutrients to support metabolic activities, particularly during the vegetative stage. Absorbed nutrients contribute to the development of leaves, stems, and roots, thereby enhancing photosynthetic efficiency. This finding is consistent with the statement of Taiz and Zeiger (2002), who reported that high photosynthetic activity promotes rapid vegetative growth.

Similarly, the application of organic fertilizer produced from food waste through biopore technology significantly increased the leaf area of green amaranth, as indicated by a significance value of  $P < 0.001$  ( $P < 0.05$ ). Nitrogen contained in organic fertilizer plays a crucial role in the synthesis of chlorophyll, proteins, and amino acids, thereby contributing to leaf expansion. Potassium (K), on the other hand, functions in enzyme activation, cell division, and cell elongation, while also regulating the translocation of photosynthetic products throughout the plant. These physiological functions contribute to increased leaf width and overall leaf area (Dikdik, 2014). Sebastian and Barunawati (2022) emphasized that plants require adequate nutrients to support metabolic processes during the vegetative stage. The absorbed nutrients facilitate the development of plant organs, including leaves, stems, and roots, thereby improving photosynthetic performance. In addition to its importance in evaluating photosynthetic capacity, leaf area measurement provides valuable information for estimating leaf yield potential (Susilo, 2012), assessing stomatal density and chlorophyll content (Solihin, 2014), determining the potential accumulation of heavy metals in leaves (Yudha et al., 2013), and evaluating leaf trichome and potassium content (Prihastanti, 2011). Therefore, the significant increase in leaf area observed in this study indicates that biopore-derived organic fertilizer effectively enhanced the vegetative growth and physiological performance of *A. hybridus*.

### CONCLUSIONS

The application of biopore-derived organic fertilizer significantly improved the growth of *Amaranthus hybridus* L., as evidenced by increases in plant height, number of leaves, and leaf area. Among all treatments, P4, consisting of 15% organic fertilizer (150 g per planting medium unit), was identified as the optimal dosage, producing the best vegetative growth performance with a mean plant height of 13.23 cm, an average of 8 leaves per plant, and a mean leaf area of 6.10 cm<sup>2</sup>.

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