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Research Article

Residual effects of bagasse-derived compost, biochar, and biocompost on N, P, and K uptake efficiency, growth, and yield of shallot (*Allium cepa* L.) in Inceptisols

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Abstract

Organic matter is a source of slow-release nutrients, so its effects will not be exhausted in a single growing season. This study aims to determine the role of bagasse residues in the form of compost, biochar, biocompost, and NPK fertilizer on the growth, yield, and NPK uptake efficiency of shallots. The study employed a completely randomized factorial design with two factors. The first factor was bagasse residue, consisting of B1: no organic fertilizer, B2: compost, B3: biochar, and B4: biocompost (a mixture of biochar and compost). The application rate was 10 tons/ha. The second factor was A1: NPK 0%, A2: NPK 50% (recommendation) (362.5 tons/ha), and A3: NPK 100% (recommendation) (625 tons/ha). The research results show that the use of NPK 50% on compost residue (B2) and biocompost (B4) significantly increased plant height by 73.5% and 53.3%, respectively, the number of leaves by 101.8% and 104.8%, fresh tubers by 192.1% and 168. 5% compared to the Control (B1) and NPK 0% (A1), as well as nitrogen uptake efficiency of 34% and 20%, phosphorus of 18% and 10%, and potassium of 10% and 11%, respectively. The use of organic materials should be maintained to enhance sustainable fertilizer efficiency.

Keywords: Compost, Biochar, Absorption efficiency, Shallot growth, Shallot yield

Introduction

Shallot consumption in the domestic sector in 2021 reached 790,630 tons, with an average per capita consumption of 2.49 kilograms per month (Adhiwibowo *et al.,* 2022). The high demand for these commodities has encouraged farmers to use inorganic fertilizers intensively to increase agricultural productivity (Syamsiyah *et al.,* 2023). That will have a negative impact on the environment, reduce the quality of tubers, and lead to inefficient use of resources, which could threaten the quality and sustainability of soil function (Messele, 2016; Shura *et al.,* 2022). Therefore, it is necessary to implement sustainable and environmental-friendly agricultural practices (El-Naggar *et al.,* 2019).

The use of agroindustrial waste, such as bagasse in the form of compost or biochar, is one of the steps that can be taken. Bagasse is a waste product from the sugarcane milling process, which has a relatively high content of lignin and structural carbohydrates such as cellulose and hemicellulose (Haro *et al.,* 2024), so that special measures are required before it can be added to the soil. Composting and pyrolysis are methods used to accelerate the degradation process of lignin and cellulose contained in bagasse (Mentari *et al.,* 2021; Ardi *et al.,* 2023). The selection of biochar and compost as organic soil amendments because biochar is rich in stable C and P but low in N (Frimpong *et al.,* 2021), while compost can recycle N, C, P, and K nutrients.

Soil amendments such as compost and biochar have the characteristic that they release nitrogen, phosphorus, calcium, and magnesium into the soil slowly (Lanna *et al.,* 2018; Gezahegn & Martini, 2019; Syamsiyah *et al.,* 2024) so that the nutrients they contain can be stored for a long period of time and ensure a long-term residual effect that can be utilized in subsequent growing seasons (Ogundare *et al.,* 2015). Several studies have been conducted showing that the use of pine compost and biochar can increase peanut yields and improve soil properties in Mediterranean environments in the second growing season (Leogrande *et al.,* 2024), compost and biochar corn cobs residues can improve degraded tropical soils (Apori & Byalebeka, 2021), straw compost and husk biochar can increase rice plant growth (Herman & Resigia, 2021), compost residues and cow manure biogas can increase the rate of carbon mineralization (Coban *et al.,* 2016), and bagasse sludge residues and cotton biochar in metal-contaminated soil (Rehman *et al.,* 2020). However, information on bagasse residues in the form of compost or biochar or a mixture of both (biocompost) is still very limited. This study aims to investigate whether compost and biochar residues or biocompost from bagasse and NPK fertilizer can improve the uptake of N, P, and K nutrients, growth, and yield of shallot.

Materials and Methods

Location and soil characteristics

This pot experiment was conducted between April 2024 and October 2024 at the Greenhouse of the Faculty of Agriculture, Sebelas Maret University, using soil taken from shallot fields in Mancasan Village, Baki District, Sukoharjo (7°38’12.6”S, 110°46’18.5”E) with characteristics of slightly acidic pH (6.58), moderate total soil N (0.39%), very low available P (1.89 mg/kg), low available potassium (0.30 mg/kg), low organic carbon (1.43%), and high cation exchange capacity (27.03 me/kg). In general, it has a low fertility level.

Experimental design

The study used a completely randomized design with a two-factor factorial design. The first factor contained B1: no organic material, B2: compost, B3: biochar, and B4: biocompost 1:4 (w: w). The second factor contained A1: NPK 0% (rec), A2: NPK 50% (rec), and A3: NPK 100% (rec). Compost, biochar, and biocompost were applied at a dose of 10 t/ha at the beginning of the study. The recommended NPK fertilizer dosage was 525 kg/ha, and the ZA fertilizer dosage was 185 kg/ha. NPK fertilizer was applied at 0, 14, and 36 MST, while ZA was applied at 30 MST using ring placement.

The surface morphology of the bagasse compost sample from SEM (Scanning Electron Microscope) analysis in Figure 1 shows a small portion of complex, interconnected, and moderately porous fiber structure. Bagasse compost has a linear multi-porous structure, connecting pores and making the connectivity of the porous network increasingly complex (Fu *et al.,* 2021). The characterization results of EDX (*Energy Dispersive X-ray Spectroscopy*) at various magnifications (Figure 1) show that the composition has a mass percentage of carbon (22.54%), oxygen (73.04%), magnesium (0.23%), aluminium (1.06%), silica (0.97%), potassium (1.02%), and calcium (1.14%). The high oxygen content in the compost indicates that a high fermentation process occurred during the composting process (Liu *et al.,* 2025), where most of the oxygen was consumed by microorganisms to degrade organic matter (Zeng *et al.,* 2013). The high level of fermentation in the compost is caused by the role of the EM4 starter and molasses added during the composting process, thereby positively influencing the quality of the resulting compost (Dewi & Kusnoputranto, 2022).

The planting medium in pots consists of Inceptisol soil that has been dried, smoothed, and filtered with a 2 mm sieve, with 5 kg per pot. Compost, biochar, and bagasse biocompost are added by burying them in the soil. The Tajuk variety shallot seedlings are planted in pots by making planting holes and inserting 1 bulb that has been cut 1/3 of the way from the tip. NPK fertilizer was applied 3 days after planting, at 0, 14, and 30 days after planting. Maintenance included weeding, pest and disease control, watering, and pruning. Harvesting and tissue sampling were conducted after the plants were 60-70 days old.

Parameter observation

Observation parameters include plant height, number of tillers, and number of leaves, which are counted and measured directly in the field when the plants are 56 days old, while fresh tuber weight and dry tuber weight are measured using the gravimetric method at 60 days old. Nitrogen analysis is performed using the Kjeldahl method (Chrisyariati *et al.,* 2014), while phosphorus and potassium analysis are performed using the wet digestion method with HNO_3 and $HClO_4$ (Webb & Adeloju, 2013).

Calculation of N, P, and K uptake efficiency values was performed using the formula (Pudjiwati & Mariam, 2022):

$$\text{Nutrient Utilization Efficiency}(\%) = \frac{\begin{array}{l}(\text{Uptake with fertilizer treatment}\\ -\text{Uptake without fertilizer})\end{array}}{\text{Nutrient content in fertilizer}} \times 100\%$$

Statistic analysis

The research data were analyzed using Analysis of Variance (ANOVA) followed by Duncan's Multiple Range test (DMRT) at a confidence interval of 5%. Pearson's correlation test was performed to determine the relationship between treatment parameters.

RESULTS AND DISCUSSION

Effects of compost, biochar, biocompost residue, and NPK on the growth and yield of shallots

Table 2 showed that increasing the NPK dosage in compost, biochar, and biocompost residues had a significant effect on plant height, number of leaves, and fresh bulbs ($p<0.001$), but no significant effect on the number of tillers and dry bulbs of shallots ($p>0.001$).

Based on Table 3, bagasse residues in the form of compost (B2), biochar (B3), and biocompost (B4) significantly increased the height of shallot plants at 56 days after planting compared to those without organic matter (B1). Compost provided the highest increase (56.9%), followed by biochar (52.33%), and biocompost (30.56%). Increasing the NPK dose did not significantly affect plant

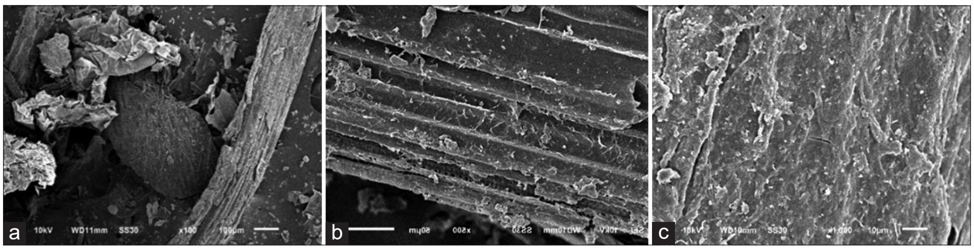

Figure 1: Results of SEM (Scanning Electron Microscope) analysis of bagasse composite. a) Magnification x100, b) Magnification x500 and c) Magnification x1000

height. This aligns with the results showing no significant differences in nutrient uptake between treatments (Table 6). The highest results were obtained with compost residue at 100% NPK (B2A3), but this was not significantly different from 50% NPK. These results indicate that NPK use can be reduced by up to 50% without significantly reducing plant height. Bagasse compost has a lower C/N ratio compared to biochar and biocompost (Table 1), allowing nitrogen to mineralize and be rapidly absorbed by plants. Nitrogen in compost residue plays a role in photosynthesis by increasing chlorophyll and leaf area index, thereby enhancing photosynthesis rates and plant height growth (Teshale & Tekeste, 2021). This is evidenced by the significant correlation between nitrogen uptake and plant height (r=0.331*).

Compared to residue without organic matter (B1), bagasse residue in the form of compost (B2), biochar (B3), and biocompost (B4) significantly increased the number of shallot leaves. Biochar provided the highest increase (88.9%), followed by compost (82.23%), and biocompost (78.83%). The addition of 50% (A2) and 100% (A3) NPK to biocompost and compost residues significantly increased the number of plant leaves, but in biochar residues, there was no significant interaction with increasing NPK doses. According to Mohamed *et al.* (2024), the addition of inorganic fertilizer to biochar stimulates microbial activity in increasing urease and dehydrogenase enzymes, thereby reducing the nutrient supply required by plants for leaf formation.

The highest number of leaves was found in compost residue with 100% NPK (B2A3), although the results were not significantly different from those with 50% NPK (Table 3). This result is in line with the higher N absorption efficiency value in compost residue with 50% NPK compared to 100% NPK (Figure 2). Compost residue improves soil structure and provides N, P, and K to support root growth and stimulate leaf growth (Hasnelly & Gatot, 2020). This is evidenced by the significant correlation test results between N, P, and K uptake and the number of red onion leaves (r=0.331*), (r=0.398*), and (r=0.480**).

The use of Bagasse residue in the forms of compost (B2) and bio-compost (B4) significantly increased the fresh bulb weight of red onions compared to the control without organic matter (B1), but in the form of biochar (B3) showed no significant results (Table 6). Compost provided the highest increase (169.9%), followed by bio-compost (75.9%) and biochar (57.4%). The highest fresh bulb weight of Shallot was obtained with biochar residue (B3) supplemented with 100% NPK (B3A3). Meanwhile, the use of compost and bio-compost residues with 50% NPK also significantly increased fresh bulb weight compared to other treatments. The use of compost residue was able to increase shallot yield through increased availability of nutrients such as N, P, K (Sadegh-Zadeh *et al.,* 2018; Manolikaki & Diamadopoulos, 2019), improvement of soil physical properties and nutrient retention in the root zone, which ultimately created conditions conducive to increasing shallot yield, thereby stimulating enlargement and formation of more bulbs (Darini, 2020; Hasnain *et al.,* 2023; Sapta Sara *et al.,* 2024). This is supported by the results of a significant correlation test between potassium and nitrogen uptake and fresh bulb weight (r=0.413*) and (r=0.771**).

There was no significant interaction between bagasse residuals in various forms and NPK in various doses on the number of shallot tillers (Table 4). This was because the number of tillers was more influenced by the genotype of the variety than by fertilization (Kahsay *et al.,* 2013).

The treatment of bagasse residue in the form of compost (B2), biochar (B3), and biocompost (B4) with the addition of NPK at various doses did not have a significant effect on the dry weight of shallots (Table 5). This is due to the phenomenon of luxury consumption, where nutrients are absorbed in excess by the plant without affecting the plant's yield (Rosniawaty, 2021). However, the application of bagasse residue in the form of biochar and the addition of 100% NPK (B3A3) resulted in the highest dry bulb weight. The particles contained in the biochar can improve the absorption of organic compounds and microbial activity that promotes the decomposition of organic matter (Wardle

Table 1: Characteristics of compost, biochar, and biocompost

Variable	Compost	Biochar	Biocompost
pH H_2O	6.75	7.5	6.93
Carbon Organic (%)	28.32	16.98	26.65
Total of Nitrogen (%)	1.89	0.94	1.5
P_2O_5 (%)	2.07	0.98	1.48
K_2O (%)	2.5	1.6	1.87
C/N (%)	15	18.06	17.76

Table 2: Analysis of variance for growth and yield parameters of shallots

Parameter	Plant height	Tillers	Leaves	Fresh bulbs	Dry bulbs
B	0.000**	0.324^{ns}	0.000**	0.044*	0.264^{ns}
A	0.106^{ns}	0.417^{ns}	0.020*	0.099^{ns}	0.382^{ns}
B x A	0.010*	0.419^{ns}	0.001**	0.001**	0.318^{ns}

* - Significant effect, ** - Very significant effect, ns - No significant effect, B - Bagasse, A - NPK

Table 3: Effect of the interaction between compost residue, biochar, bagasse biocompost, and NPK on shallot height (cm), number of leaves (leaf) 56 MST, and fresh bulb weight (grams)

	Shallot height (cm)				Number of leaves (leaf)				Fresh bulb weight (grams)			
	B1	B2	B3	B4	B1	B2	B3	B4	B1	B2	B3	B4
A1	19.3^{aA}	30.3^{bA}	24.4^{bA}	25.2^{bA}	16.6^{aA}	30.26^{bA}	31.36^{bA}	29.6^{bA}	2.16^{aA}	4.83^{bA}	3.4^{abA}	3.8^{bA}
A2	30^{bC}	33.5^{cA}	31.4^{bA}	29.6^{aB}	30.26^{aC}	33.5^{bB}	29.43^{aA}	34.0^{bB}	6.5^{bB}	6.31^{bB}	3.76^{aA}	5.8^{bB}
A3	25.7^{aB}	34.4^{cA}	29.8^{bA}	26.2^{aA}	25.66^{aB}	34.43^{cB}	29.8^{bA}	33.0^{cB}	2.83^{aA}	6.5^{bB}	7.6^{cB}	6.6^{bcB}

The average figures followed by the same letter notation are not significantly different based on the results of the DMRT test at the 5% level. The lowercase letter notation is read horizontally, while the uppercase letter notation is read *et al.,* 2008), there by providing nutrients for plants such as potassium, which acts as an enzyme activator, carbohydrate formation, and the translocation of photosynthesis products (Gao *et al.,* 2021; Li & Gao, 2026), which can increase bulb weight and dry weight accumulation of shallots. This is supported by the significant correlation between potassium uptake and dry bulb weight (r=0.453*).

The effects of compost residue, biochar, biocompost bagasse, and NPK on the uptake and uptake efficiency of NPK

Table 6 shows that increasing the NPK dose in compost residue, biochar, and biocompost had a significant effect on the uptake efficiency of NPK (p<0.001), but no significant effect on shallot uptake at 56 DAP (p>0.001).

The use of biocompost residue with the addition of 100% NPK (B4A3) showed the highest increase in N uptake value of 206.6%, while the use of compost residue with 50% NPK (B2A2) showed the highest N uptake efficiency value of 34% (Figure 2). In line with Liu (2021), compost is able to increase nutrient uptake through microbial and enzymatic activity in the soil. Biochar can stimulate the rate of mineralization, nitrogen fixation, and control some autotrophic microbes in maintaining soil micronutrients from oxidation for plant uptake (Mandal *et al.,* 2021; Hou *et al.,* 2022). The use of biocompost with inorganic fertilizer can increase soil water retention, aggregate stability, and nutrient use efficiency in crop yields (Adekiya *et al.,* 2019; Sharma *et al.,* 2021).

The average N uptake efficiency in this study was 21.65%, which means that around 78% of the N nutrients were lost from the amount of N nutrients that were given (Figure 2). This aligns with Pudjiwati and Mariam (2022), where N nutrient loss can occur through denitrification (0.8-1.2%), leaching (10-15%), evaporation (11-50%), and N_2O emissions (0.9-1.8%).

Table 4: Effect of the interaction between compost residue, biochar, bagasse biocompost, and NPK on the number of tillers (seedlings)

	B1	B2	B3	B4
A1	5.66	8.66	8.66	8.30
A2	7.66	9.33	7.88	9.33
A3	7.66	9.66	8.00	8.66

Mean values followed by the same letter are not significantly different based on the results of the DMRT 5% level follow-up test

Table 5: Effect of the interaction between compost, biochar, bagasse biocompost, and NPK on shallot dry bulbs (grams)

	B1	B2	B3	B4
A1	1.41	2.96	2.51	1.69
A2	3.08	3.93	1.96	2.20
A3	1.68	3.20	4.33	4.17

Mean values followed by the same letter are not significantly different based on the results of the DMRT 5% level follow-up test

The biochar residue (B3) with the addition of 100% NPK (B3A3) showed the highest P uptake value or an increase of 62.2% and provided the highest P uptake efficiency value of 23% (Figure 3). The research results of Tobing *et al.* (2022) showed that the biochar treatment was able to produce higher efficiency values compared to other treatments. Biochar has a high retention capacity for P, thereby reducing nutrient leaching and improving nutrient use efficiency nutrisi (Major, 2009; Zulfita *et al.,* 2020; Azman *et al.,* 2024). These results are supported by a significant correlation test between P uptake and P uptake efficiency (r=0.497*). Newly-applied biochar is hydrophobic and contains functional groups, but the reactive surface of biochar expands over time after exposure to water and oxygen in the soil, which allows it to absorb nutrients, reduce leaching, and contribute to increased fertilizer use efficiency (Singh *et al.,* 2010; Chintala *et al.,* 2013).

The low efficiency of P nutrient uptake (Figure 3) is due to its low mobility and availability in the soil because of P fixation by other elements (Ginting *et al.,* 2018) and suboptimal fertilization rates (Zhou *et al.,* 2025). The immobile nature of P is caused by adsorption, precipitation, and conversion to organic forms (Glaser & Lehr, 2019). Low P availability in the soil can also be caused by P being carried away with the harvest in the previous growing season. According to estimates Salazar-Mejía and Bayuelo Jiménez (2024), around 65% of P added to the soil as fertilizer will be stored and transported in tubers in the form of phytic acid.

The addition of biochar residue with 100% NPK (B3A3) provided the highest K absorption value or an increase of 163.2% and provided the highest K absorption efficiency value of 24%. Accordingly, Cabello-Torres *et al.,* (2021), biochar acts as a soil amendment in facilitating slow nutrient desorption through polar affinity with functional groups in biochar. Meanwhile, the addition of compost can change the activity and community of microbes in dissolving K minerals in the soil, which can lead to an increase in tissue K concentration and more efficient use of K fertilizer (DeLuca *et al.,* 2024). This is in accordance with the results of a significant correlation test between K uptake value and K uptake efficiency (r=0.934*). According to Zhang *et al.* (2020), biochar has the ability to accelerate the conversion of slowly available K into available K by altering the mineral composition of clay and increasing K-solubilizing bacteria such as Phingomonas, Gaiella, and Elev-16S-1332.

Table 6: Analysis of variance for N, P, and K uptake and nutrient uptake efficiency

Parameter	Serapan N	Serapan P	Serapan K	Efisiensi N	Efisiensi P	Efisiensi K
B	0.063^{ns}	0.007**	0.017*	0.143^{ns}	0.121^{ns}	0.023*
A	0.501^{ns}	0.079^{ns}	0.009**	0.049*	0.031*	0.020*
B x A	0.880^{ns}	0.219^{ns}	0.255^{ns}	0.009**	0.029*	0.007**

* - Significant effect, ** - Very significant effect, ns - No significant effect, B - Bagasse, A - NPK

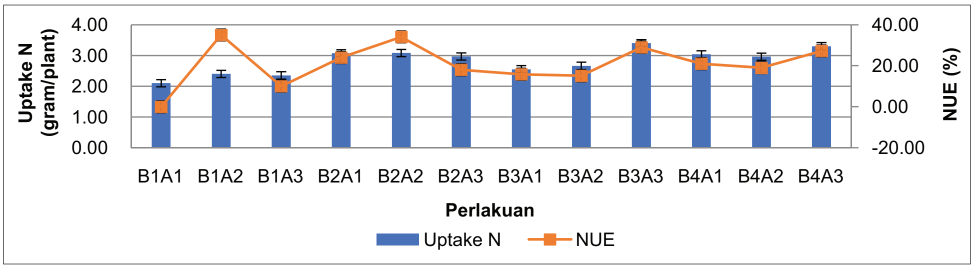

Figure 2: Effect of treatment on N uptake and uptake efficiency in shallots. B1-no organic fertilizer, B2-compost, B3-biochar, B4-biocompost 1:4 (w:w), A1-NPK 0%, A2-NPK 50%, A3-NPK 100%

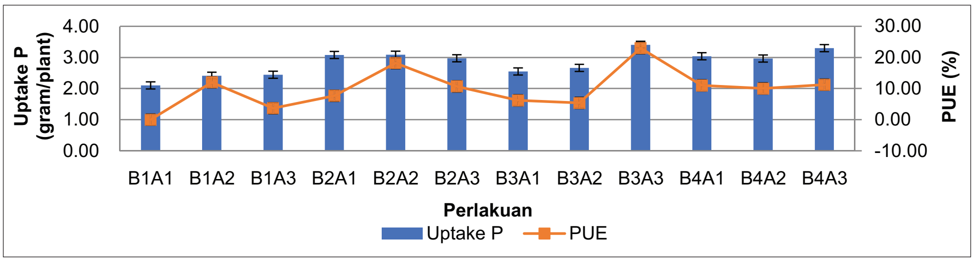

Figure 3: Effect of treatment on P uptake and uptake efficiency in shallots. B1-no organic fertilizer, B2-compost, B3-biochar, B4-biocompost 1:4 (w:w), A1-NPK 0%, A2-NPK 50%, A3-NPK 100%

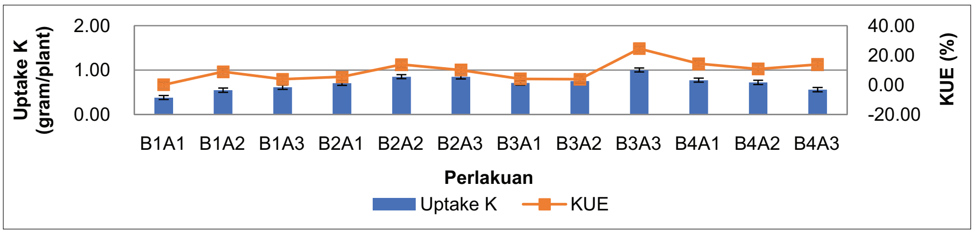

Figure 4: Effect of treatment on K uptake and uptake efficiency in shallots. B1-no organic fertilizer, B2-compost, B3-biochar, B4-biocompost. A1-NPK 0%, A2-NPK 50%, A3-NPK 100%

The average K uptake efficiency for each treatment was relatively low (Figure 4), which may be due to strong K binding by minerals in the soil. Paul *et al.* (2026), Inceptisol soil has a 2:1 illite mineral type, which has a high capacity to absorb potassium, thereby reducing its availability to plants.

Conclusion

Bagasse residues in various forms interactions with NPK fertilizer on plant height, leaf number, and tuber number, as well as uptake efficiency, with the highest increase observed in compost residue (B2) and biochar residue (B4) when combined with NPK fertilizer at 50% of the recommended rate, resulting in increased plant height, leaf number, and fresh tuber weight. Meanwhile, biochar residue achieved the highest increase when combined with NPK fertilizer at 100% of the recommended rate.

Author contributions

Jauhari Syamsiyah formulated the research concept and study design and acted as the principal investigator. Triyani Dewi oversaw the research methodology and provided scientific guidance throughout the study. Lukman Ari Anggoro and Lidya Zaela Wijaya conducted the field experiments, collected and analysed the data, and prepared the initial draft of the manuscript. Hery Widijanto participated in the review of the manuscript, critical evaluation, and refinement. All authors have reviewed and approved the final manuscript.

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