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Research Article

Optimizing Vegetative Development of Papaya Seedlings Using Rice Husk Charcoal and Indigenous Microorganism Fertilizer

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ABSTRACT

Papaya (*Carica papaya* L.) is an important tropical fruit crop, but its productivity is often constrained by poor seedling quality during the nursery stage. This study evaluated the effects of rice husk charcoal and indigenous microorganism (MOL) fertilizer from banana weevil on the vegetative growth of papaya seedlings. A factorial randomized block design was applied with three levels of rice husk charcoal (0 g, 150 g, and 200 g per plant) and three levels of MOL fertilizer (0, 10, and 30 mLL^{-1}), replicated three times. Growth parameters observed included plant height and stem diameter, measured weekly for six weeks. Results indicated that rice husk charcoal had significant effects on plant height and stem diameter, particularly from the third week onward, with the highest dose producing the greatest improvements. MOL fertilizer significantly enhanced early growth, especially at two and three weeks, although differences diminished at later stages. Interaction effects were mostly non-significant, except for stem diameter at the third week, where the combination of no charcoal and the highest MOL dose resulted in the widest stems. The findings suggest that rice husk charcoal and MOL fertilizer independently enhance seedling vigor, with biochar providing sustained growth benefits and MOL stimulating early development. Their combined use offers a sustainable approach to papaya nursery management by improving seedling quality while reducing reliance on synthetic inputs. These results provide a basis for integrating organic amendments and microbial fertilizers into papaya cultivation systems.

Keywords: Papaya seedlings, Rice husk charcoal, Indigenous microorganism fertilizer, Vegetative growth, Sustainable agriculture.

INTRODUCTION

Papaya (*Carica papaya* L.) is an economically important fruit crop in tropical and subtropical regions, valued not only for its sweet fruit but also for its nutritional and medicinal properties. In Indonesia and many other tropical countries, papaya contributes to both household food security and commercial fruit markets. The crop is rich in vitamins A and C, carotenoids, and dietary fiber, and its demand continues to increase alongside shifts toward healthier diets and functional foods (Singh et al., 2023). Despite its economic potential, papaya productivity remains constrained by poor seedling quality, which often limits field establishment and reduces yield potential. Strong and vigorous seedlings are therefore essential for ensuring high crop performance and sustainable production systems (Chandra et al., 2024).

The early growth phase of papaya is highly sensitive to soil fertility and management practices. Seedlings require adequate nutrient availability and favorable soil structure to support rapid root and shoot development. In conventional nursery systems, reliance on chemical fertilizers often provides quick nutrient supply but may lead to soil degradation, reduced microbial activity, and long-term fertility problems (Hasanah et al., 2022). Consequently, there is growing interest in integrating organic amendments and biofertilizers into papaya seedling management to improve soil health and enhance seedling vigor (Almeida et al., 2022; Gunawan et al., 2023).

Rice husk charcoal, commonly known as biochar, is one such organic amendment widely studied for its positive effects on soil physical, chemical, and biological properties. Produced through the pyrolysis of rice husks, this material is abundant in rice-growing countries and has multiple agronomic benefits. Its porous structure improves soil aeration, water retention, and cation exchange capacity, while also serving as a habitat for beneficial microorganisms (Jindo et al., 2023). Biochar has been reported to enhance nutrient retention and reduce leaching losses, thereby improving fertilizer use efficiency (Gul et al., 2023). In papaya nurseries, rice husk charcoal can play a dual role: improving soil structure for better root penetration and acting as a slow-release medium for nutrients and water (Kusumawati et al., 2022).

In parallel, the use of indigenous microorganism (IMO) fertilizers has gained attention as an affordable and sustainable approach to enhance soil biological activity. Locally derived microbial inoculants, including those prepared from banana weevil (bonggol pisang), provide a rich consortium of beneficial microorganisms such as lactic acid bacteria, actinomycetes, and fungi. These microbes promote nutrient mineralization, produce growth-promoting hormones, and suppress soilborne pathogens (Mulyono et al., 2023; Prasetyo et al., 2024). MOL (microorganism local) from banana weevil is particularly popular among smallholder farmers in Indonesia because of its accessibility, low cost, and effectiveness in improving soil fertility. When applied to seedlings, such biofertilizers can stimulate root growth, enhance nutrient uptake, and accelerate vegetative development (Harahap et al., 2022; Santosa et al., 2023).

The combined application of biochar and indigenous microorganism fertilizers may produce synergistic effects on plant growth. Biochar provides a favorable habitat and energy source for microbial colonization, while the microbes in turn improve nutrient cycling and availability within the soil–plant system. Several studies have reported that integrating biochar with microbial inoculants leads to greater improvements in plant growth and yield than when either amendment is used alone (Zhang et al., 2024; Alvarenga-Pérez et al., 2023). For instance, in vegetable crops, this combination enhanced nutrient uptake efficiency and biomass accumulation (Nguyen et al., 2022), while in fruit seedlings it improved survival rates and vigor (Rosas et al., 2023). Such interactions suggest that the integration of rice husk charcoal and MOL banana weevil fertilizer may be a promising strategy for papaya nursery management (Islami et al., 2022).

In addition to improving vegetative growth, organic amendments can contribute to sustainable agricultural practices. The use of rice husk charcoal promotes waste valorization in rice-producing regions, turning agricultural residues into valuable soil amendments (Syafrudin et al., 2023). Similarly, indigenous microorganism fertilizers reduce reliance on synthetic agrochemicals, lowering production costs and minimizing environmental impacts (Sari et al., 2023). These approaches are consistent with broader goals of climate-smart agriculture and circular economy strategies, which emphasize resource efficiency, environmental sustainability, and resilience to climate change (Raza et al., 2023).

Despite these potential benefits, scientific evidence on the combined effects of rice husk charcoal and indigenous microorganism fertilizer on papaya seedlings remains limited. Previous research has largely focused on individual effects, with few studies evaluating their interaction in nursery systems (Wijayanti et al., 2024). Given that seedling quality is a major determinant of papaya productivity, understanding these interactions is crucial for developing practical recommendations for farmers and nursery managers.

The present study was therefore conducted to evaluate the influence of rice husk charcoal and MOL banana weevil fertilizer on the vegetative growth of papaya seedlings. Specifically, it aimed to (i) assess the independent effects of rice husk charcoal and MOL application on plant height and stem diameter during the nursery phase, (ii) examine potential interactions between the two factors, and (iii) identify the most effective combination for optimizing seedling vigor. The results are expected to provide scientific insights and practical recommendations for integrating organic soil amendments and microbial fertilizers into papaya seedling management. By doing so, the study contributes to efforts to improve papaya productivity, promote sustainable soil management, and support environmentally friendly agricultural practices.

MATERIALS AND METHODS

The experiment was arranged in a randomized block design with two factors: rice husk charcoal and indigenous microorganism (MOL) fertilizer prepared from banana weevil. Rice husk charcoal was applied at three levels, namely without addition, moderate addition, and high addition, while MOL was applied at three levels corresponding to 0, 10, and 30 mL per liter of water. Each treatment combination was replicated three times, and every experimental unit contained papaya seedlings grown under identical nursery management.

Seedlings were established in polybags filled with a mixture of topsoil and rice husk charcoal according to treatment levels. MOL fertilizer was prepared through fermentation of banana weevil material following farmer-standard protocols and was diluted in water before application. The solution was applied directly to the seedling medium at designated concentrations throughout the vegetative growth period. All seedlings were maintained under uniform agronomic conditions to ensure that differences observed could be attributed to the treatments.

Observations were focused on vegetative growth parameters, specifically plant height and stem diameter, measured weekly from one to six weeks after planting. Plant height was recorded from the base of the stem at the soil surface to the highest growing point, while stem diameter was measured at the base of the plant using a caliper for accuracy. These parameters were chosen as indicators of seedling vigor and overall nursery performance.

Data obtained from each observation period were subjected to analysis of variance (ANOVA) appropriate for the factorial randomized block design. When significant effects were detected, treatment means were compared using the Duncan Multiple Range Test (DMRT) at the 5% probability level. Statistical analysis was conducted to evaluate the independent effects of rice husk charcoal and MOL as well as their interaction on the vegetative growth of papaya seedlings.

RESULTS

Effect of Rice Husk Charcoal on Plant Height

The application of rice husk charcoal influenced papaya seedling height at different observation periods. As shown in Figure 1, no significant differences were recorded at one week after planting, suggesting that organic matter had not yet decomposed sufficiently to release nutrients. At two and six weeks, the effects were significant, while very significant differences were observed between three and five weeks. The highest plant height was consistently recorded in seedlings grown with the highest dose of rice husk charcoal (A2), which reached 10.12 cm at three weeks and 29.10 cm at six weeks. In contrast, the lowest growth was observed in the medium dose treatment (A1), which averaged only 8.40 cm at three weeks and 25.10 cm at six weeks.

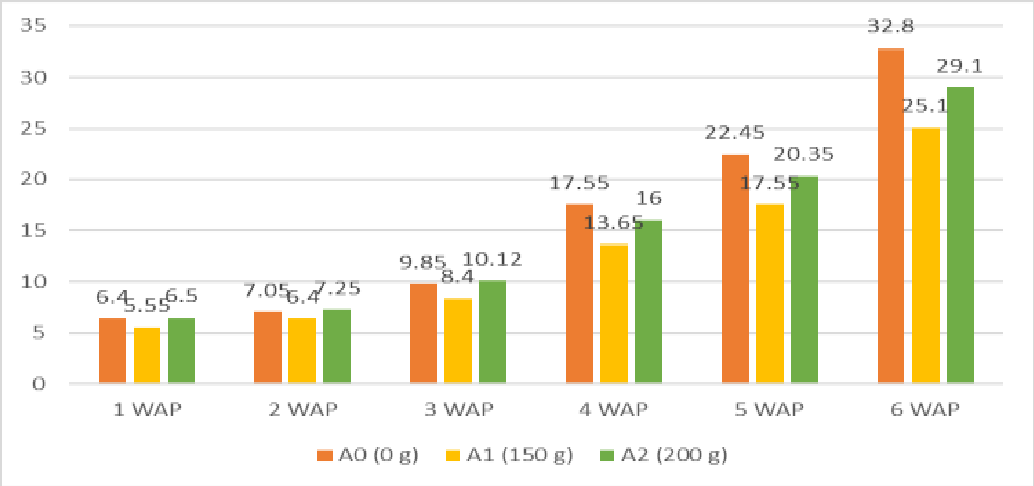

Fig. 1: Average Plant Height of Papaya Seedlings at 1–6 Weeks After Planting (WAP) as Affected by Rice Husk Charcoal.

These results suggest that the decomposition of rice husk charcoal contributed to nutrient availability after the second week, improving growth rates. The lower performance of the medium dose (A1) may be linked to limited leaf expansion, which restricted photosynthesis.

Effect of MOL Banana Weevil Fertilizer on Plant Height

The influence of MOL fertilizer is presented in Figure 2. Application of MOL significantly improved plant height at the second and third weeks, with the highest values recorded in M2 (30 mL/L), which reached 10.35 cm at three weeks. At four to six weeks, however, differences between treatments were not significant, suggesting that nutrient release from MOL alone was insufficient to sustain growth during later stages.

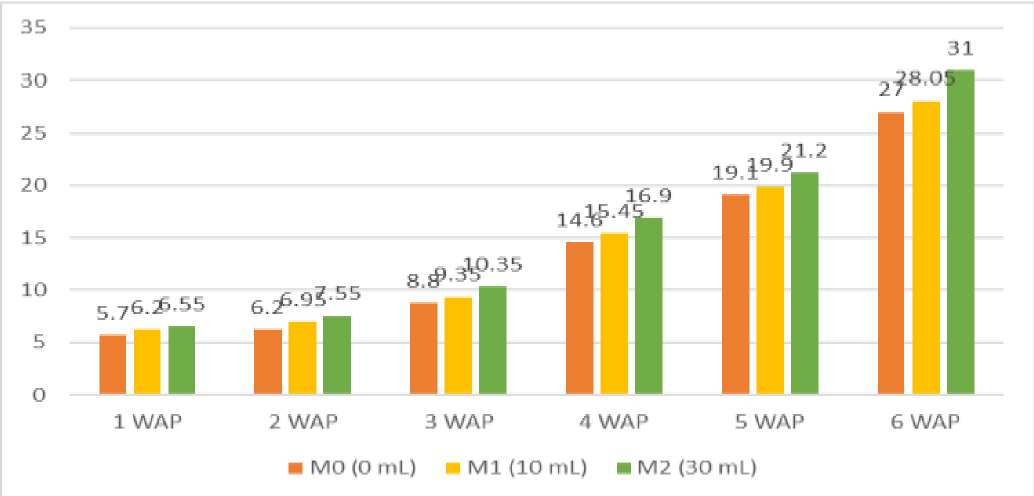

Fig. 2: Average Plant Height of Papaya Seedlings at 1–6 WAP as Affected by MOL Banana Weevil Fertilizer.

At early stages, MOL provided additional microbial activity and growth-promoting substances, which enhanced vegetative growth. However, the relatively low phosphorus content of MOL likely limited long-term effects.

Interaction Effects on Plant Height

The interaction between rice husk charcoal and MOL application is shown in Figure 3. No significant interactions were detected across most weeks, supporting the notion that these factors largely acted independently. Nevertheless, numerical trends suggested that combining the highest MOL dose with rice husk charcoal improved height compared to single applications, with A0M2 reaching 37.25 cm at six weeks.

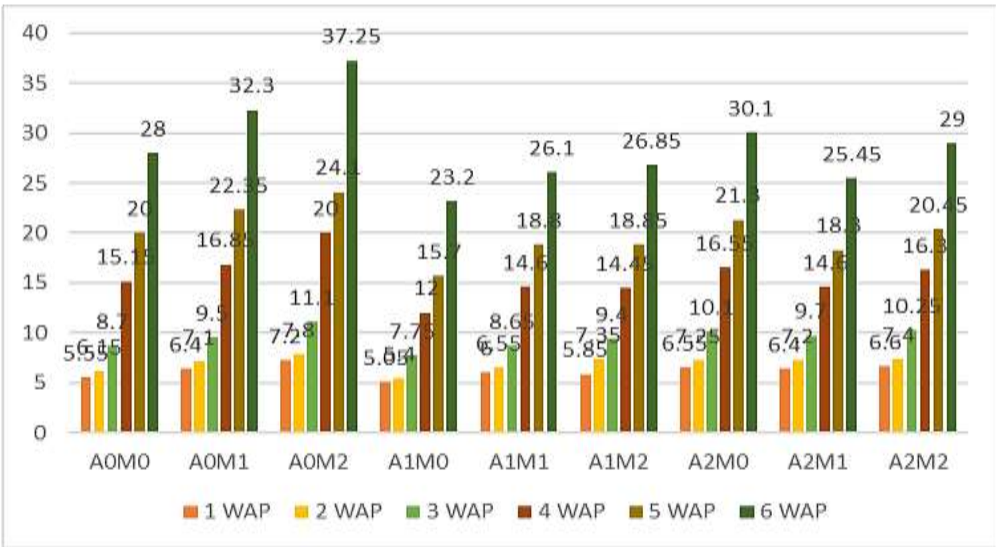

Fig. 3: Interaction of Rice Husk Charcoal and MOL Banana Weevil on Plant Height (cm) of Papaya Seedlings at 1–6 WAP

No significant interaction effects were confirmed statistically, possibly due to genetic constraints of papaya seedlings or the pH incompatibility between biochar (pH 8.5–9.0) and optimal papaya nursery conditions (pH 5.5–6.5).

Effect of Rice Husk Charcoal on Stem Diameter

Rice husk charcoal application significantly increased stem diameter, with very significant effects observed from the first to the sixth week (Figure 4). The highest dose (A0) recorded 8.50 mm at six weeks, compared with only 6.75 mm in A1.

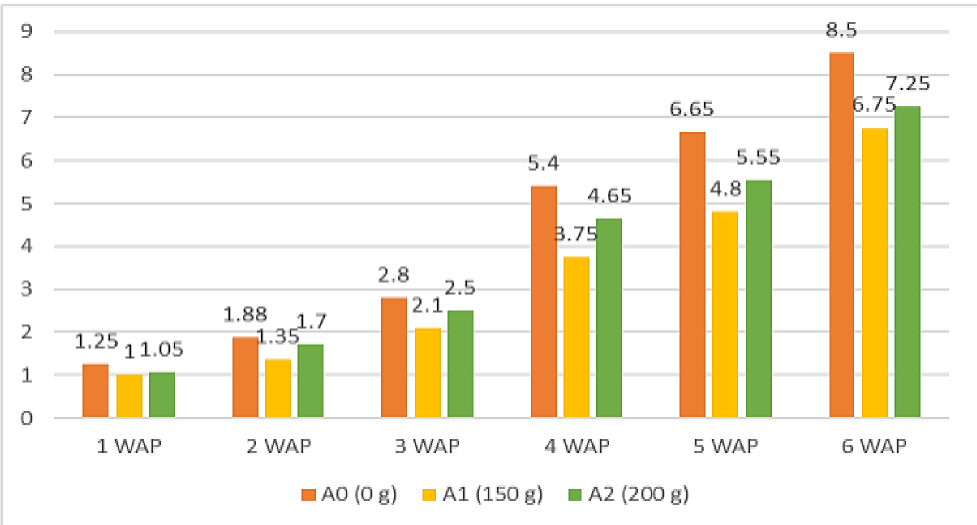

Figure 4. Effect of Rice Husk Charcoal on Stem Diameter (mm) of Papaya Seedlings at 1–6 WAP.

These improvements may be attributed to nitrogen, potassium, and calcium content in rice husk charcoal, which support photosynthesis and structural growth.

Effect of MOL Fertilizer on Stem Diameter

MOL fertilizer significantly influenced stem diameter at one to three weeks but showed no significant differences from four to six weeks (Figure 5). The highest value was observed in M2, with 7.95 mm at six weeks, compared with 7.15 mm in the control (M0).

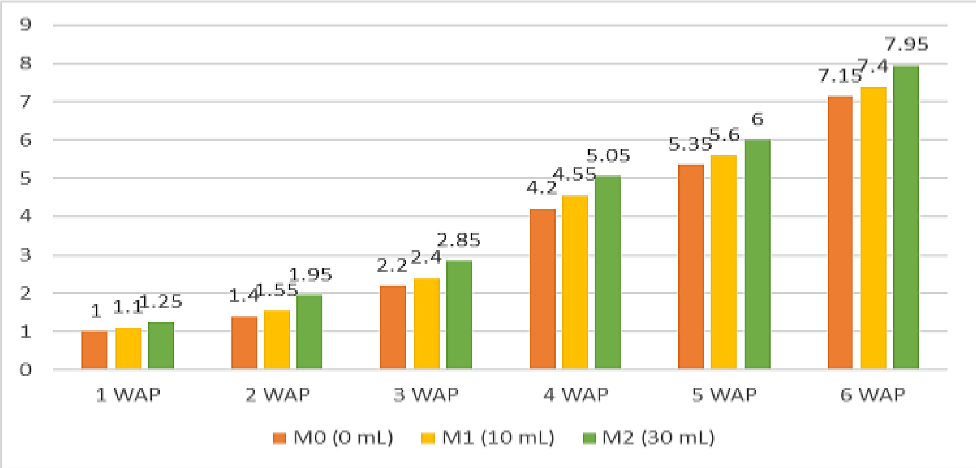

Fig. 5: Effect of MOL Fertilizer on Stem Diameter (mm) of Papaya Seedlings at 1–6 WAP

The stimulation of early growth by MOL is linked to its microbial composition and organic acids, though limited nutrient supply may explain the lack of long-term effects.

Interaction Effects on Stem Diameter

As shown in Figure 6, no significant interactions were observed for stem diameter at most weeks. However, a strong interaction appeared at the third week, with the combination of no charcoal and the highest MOL dose (A0M2) producing the widest diameter at 3.75 mm.

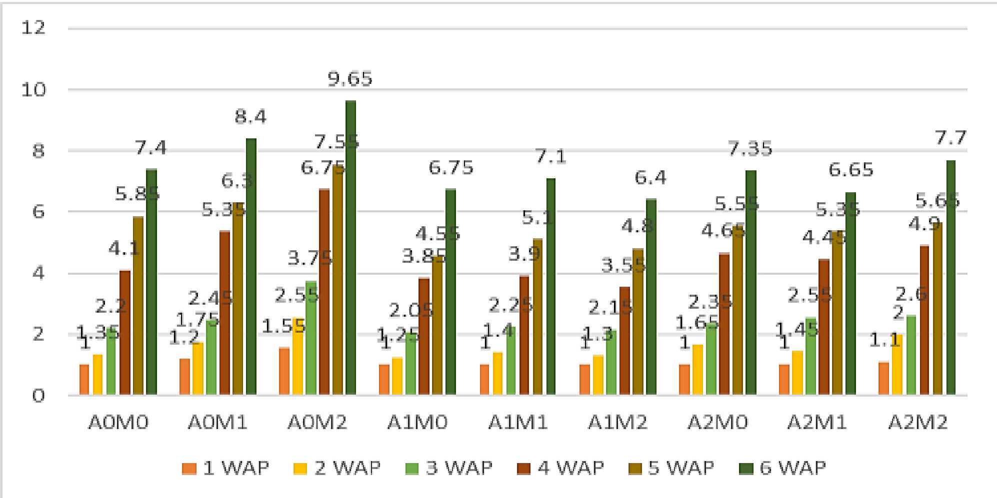

Fig. 6: Interaction of Rice Husk Charcoal and MOL Fertilizer on Stem Diameter (mm) of Papaya Seedlings at 1–6 WAP.

These findings indicate that while each factor independently influenced stem diameter, their combination sometimes produced temporary synergistic effects, especially under early-stage nutrient demand.

DISCUSSION

The present study demonstrated that both rice husk charcoal and indigenous microorganism (MOL) fertilizer derived from banana weevil influenced the vegetative growth of papaya seedlings, as reflected in plant height and stem diameter over a six-week nursery period. While each factor exerted distinct effects, occasional interactions were observed, particularly in stem diameter at the third week. These findings emphasize the complementary role of organic amendments and biofertilizers in supporting early crop development (Kirkby & Mengel, 2023; Sarker et al., 2024).

Rice husk charcoal significantly improved seedling growth parameters after the second week of planting, with the most consistent effects observed from the third to sixth week. The highest dose of rice husk charcoal promoted taller plants and thicker stems compared with lower doses. These improvements can be attributed to the unique physical and chemical properties of biochar. Its porous structure enhances soil aeration, water retention, and root proliferation, while its cation exchange capacity increases the retention of essential nutrients such as nitrogen, potassium, and calcium. Recent studies confirm that biochar improves nutrient availability and supports the establishment of beneficial microbial communities, both of which accelerate seedling growth (Bashir et al., 2023; Godlewska et al., 2023; Paneque et al., 2024).

Interestingly, the medium dose of charcoal produced lower growth than either the control or the higher dose. This suggests that suboptimal application may alter soil structure or nutrient dynamics unfavorably, potentially restricting root expansion. Similar patterns have been reported in horticultural seedlings, where moderate biochar levels sometimes reduce growth by increasing substrate alkalinity or transiently immobilizing nutrients (Awasthi et al., 2022; Agegnehu & Yadav, 2023). Given that rice husk charcoal often has an alkaline pH, its effects depend strongly on dosage, feedstock, pyrolysis temperature, and the buffering capacity of the growth medium (Wu et al., 2023).

The application of MOL banana-weevil fertilizer enhanced seedling height and stem diameter at early stages, particularly during the second and third weeks after planting. At higher concentrations, MOL produced taller plants and wider stems compared with lower concentrations or the control. This effect is consistent with the diverse microbial population in MOL—lactic acid bacteria, actinomycetes, yeasts, and filamentous fungi—that contribute to nutrient mineralization, biological nitrogen fixation, and the production of phytohormones such as indole-3-acetic acid and gibberellins (Bhardwaj et al., 2023; Glick, 2023; Raza et al., 2024).

The absence of significant MOL effects at later growth stages suggests that nutrient supply from this liquid biofertilizer alone was insufficient to sustain continued rapid growth. MOL typically contains limited plant-available phosphorus and potassium, which are critical for ongoing vegetative development and cell wall strengthening. As seedlings grew larger, their nutrient demand likely exceeded the capacity of MOL to provide sufficient quantities, leading to convergence of growth responses across treatments (Backer et al., 2023; Saenchai et al., 2022). Strategically combining MOL with mineral sources or composted organics could therefore provide a more balanced nutrient profile (Hartmann et al., 2023).

Although most growth parameters were not significantly affected by interactions between rice husk charcoal and MOL, a notable exception occurred for stem diameter at week three, where the combination of no charcoal and the highest MOL concentration produced the thickest stems. One plausible explanation is that MOL-stimulated microbial activity and organic acids temporarily increased P availability in the absence of pH elevation from biochar. Phenolic acids and low-molecular-weight organic compounds in such inoculants can chelate Al/Fe and reduce phosphate fixation, improving early stem thickening (Compant et al., 2023). These results highlight that the effectiveness of combined amendments can depend on short-term rhizosphere chemistry, dose, and plant developmental stage.

The lack of consistent interaction effects across all growth stages may also be linked to the genetic characteristics of papaya seedlings, which exert a strong influence on growth patterns. As classic growth analysis indicates, plant performance integrates both internal (genetic) and external (environmental and management) factors; early vigor traits often show high heritability but remain modulated by nutrient and water status (Poorter et al., 2022; van der Molen et al., 2024). The relatively stable performance across treatments suggests that while external inputs improved growth, the genetic baseline of papaya seedlings constrained variability to some degree.

The improvements in height and stem diameter under biochar and MOL application align with the physiological roles of nitrogen, phosphorus, potassium, and calcium during early growth. Nitrogen supports chlorophyll synthesis and leaf production, directly underpinning photosynthetic capacity and height growth; potassium regulates enzyme activation, osmoregulation, and carbohydrate transport; calcium contributes to structural integrity through pectin cross-linking in the cell wall; while available phosphorus supports energy metabolism and root development (Hawkesford et al., 2023; White et al., 2023). Microbial inoculants complement these functions by enhancing nutrient mineralization, solubilizing phosphorus, producing siderophores, and synthesizing auxins and ACC-deaminase to modulate root architecture (Galindo et al., 2023; Khan et al., 2024). Together, these mechanisms explain the observed improvements in seedling vigor.

For nursery management, our results suggest that higher doses of rice husk biochar can enhance papaya seedling vigor by improving the physical habitat for roots and increasing nutrient retention, provided pH remains within an optimal range. MOL biofertilizer delivers an early pulse of growth promotion, though its effects taper without supplementary nutrient inputs. The most practical approach for smallholder nurseries may therefore be a combined regime: a structurally beneficial biochar substrate blended into the potting mix, complemented by periodic MOL drenches and a modest, balanced mineral nutrient supply (Jindo et al., 2023; Zhang et al., 2024; Xu et al., 2024).

These findings also align with broader sustainability goals. Using rice husk charcoal valorizes a ubiquitous agricultural residue in rice-growing regions and contributes to carbon sequestration, while locally prepared MOL reduces dependence on imported synthetic inputs and builds farmer capacity to manage soil biology (Lehmann &

Joseph, 2022; Smith, 2023). Such practices support climate-smart, circular agriculture by improving input efficiency, mitigating nutrient losses, and enhancing resilience to abiotic stress (Liang et al., 2023; Teutscherova et al., 2023).

Although this study provides clear evidence of benefits from biochar and MOL in papaya nurseries, several limitations deserve mention. First, trials were conducted under controlled nursery conditions, and responses may differ under field heterogeneity and episodic stress (heat, drought, pathogens). Second, only above-ground vegetative traits were assessed; future work should include root system architecture, leaf area index, chlorophyll fluorescence, and gas-exchange measurements to mechanistically link amendments to photosynthetic performance (Saitou et al., 2022). Third, we did not follow plants post-transplant to quantify survival, time to flowering, or marketable yield—outcomes that ultimately determine the economic value of nursery interventions.

Future research should refine dose–response relationships for rice husk biochar across pyrolysis temperatures and particle sizes, and test combinatorial regimes pairing MOL with compost teas, rock phosphate, or low-rate NPK to achieve balanced nutrition. Metagenomic or metabolomic profiling of the rhizosphere under MOL–biochar combinations would illuminate microbially mediated mechanisms (e.g., hormone biosynthesis, P solubilization, organic acid production). Finally, techno-economic assessments and lifecycle analyses are needed to evaluate profitability and environmental footprints at scale (Edeh et al., 2022; O'Connor et al., 2024).

Conclusions

The results of this study demonstrate that both rice husk charcoal and indigenous microorganism (MOL) fertilizer derived from banana weevil contribute positively to the vegetative growth of papaya seedlings. Rice husk charcoal significantly enhanced plant height and stem diameter from the third week onward, reflecting its ability to improve soil aeration, water retention, and nutrient availability. The highest dose consistently produced taller and sturdier seedlings compared with lower applications. MOL fertilizer, on the other hand, stimulated growth primarily at the early stages, particularly during the second and third weeks, by enhancing microbial activity and supplying growth-promoting compounds. Although its long-term effects were limited, MOL provided an initial boost to seedling vigor.

Interaction effects between the two amendments were generally not significant, though the combination of no charcoal and high MOL concentration produced temporary improvements in stem diameter at the third week. This suggests that while both inputs are beneficial independently, their synergy is influenced by soil chemistry and stage of plant development.

From a practical perspective, the integration of rice husk charcoal and MOL biofertilizer offers a sustainable strategy for papaya nursery management. These amendments recycle agricultural by-products, reduce reliance on synthetic fertilizers, and support soil health, aligning with the principles of climate-smart agriculture. Further research is recommended to evaluate field performance after transplanting, assess additional physiological traits, and refine optimal combinations for long-term productivity.

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Author's Contribution: Azkaah Wijyanti conceived the idea and drafted the manuscript.

Generative AI Statements: The authors confirm that no generative-AI tools (including DeepSeek) were used in the writing or preparation of this manuscript.

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Author's Contribution: JOK, NKO, and SOA conceptualized and designed the study, developed the research instruments, and supervised data collection. ASE drafted the manuscript. All authors did significant contributions to improving the final version of the manuscript.

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