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Growth Response of Robusta Coffee (Coffea canephora) Cuttings to Arbuscular Mycorrhizal Fungi Dosage Application in Ultisol

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ABSTRACT

Coffee production in Lampung Province faces significant challenges due to the dominance of Ultisol soils characterized by low fertility, high acidity, and phosphorus fixation. This study aimed to determine the optimal dosage of arbuscular mycorrhizal fungi (AMF) inoculum to enhance the growth of robusta coffee (Coffea canephora) cuttings in Ultisol growing media. The experiment was conducted at the State Polytechnic of Lampung from August to October 2025 using a Randomized Complete Block Design (RCBD) with four treatments: M0 (control without mycorrhizal), M1 (10 g mycorrhizal inoculum per plant), M2 (20 g per plant), and M3 (30 g per plant). Each treatment was replicated four times with three plants per experimental unit. Growth parameters measured included leaf number, plant height, and root volume at 0, 3, 9, and 12 weeks after transplanting. Results showed that the M1 treatment consistently produced superior growth performance across all parameters. At 12 weeks after transplanting, M1 achieved 21.44 leaves (53.1% increase), 38.69 cm plant height (48.7% increase), and 44.67 cm³ root volume (108.3% increase) compared to the control. Higher dosages (M2 and M3) showed diminishing returns, indicating excessive inoculum application may cause unfavorable carbon allocation dynamics. This study concludes that 10 g mycorrhizal inoculum per plant is the optimal dosage for enhancing robusta coffee cutting growth in Ultisol nursery systems.

Keywords: arbuscular mycorrhizal fungi, Coffea canephora, phosphorus mobilization, Ultisol soil, vegetative propagation

1. INTRODUCTION

Coffee is a strategic commodity that contributes significantly to Indonesia's economy through foreign exchange earnings, job creation, and agribusiness development (Jati et al., 2021). Indonesia ranks as the fourth-largest coffee producer in the world after Brazil, Vietnam, and Colombia, with a total production of 774.96 thousand tons in 2022 (BPS, 2022). Lampung Province contributes 15.6% of the national production, yielding 124.5 thousand tons; however, its productivity remains fluctuating due to suboptimal cultivation practices and limited nutrient availability (Evizal et al., 2022).

The main constraint to coffee productivity in Lampung is the dominance of Ultisol soils, which are characterized by low fertility and acidic pH (Prasetyo and Suriadikarta, 2006). Ultisols

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are marked by high phosphorus (P) fixation due to the solubility of aluminum (Al) and iron (Fe), causing P to bind in the form of Al-P and Fe-P complexes that are difficult for plants to absorb (Balemi and Negisho, 2012). This condition becomes a critical limitation considering that phosphorus is essential for root development, photosynthesis, and biomass accumulation, particularly during the seedling stage (Sharma et al., 2013).

The propagation of robusta coffee (*Coffea canephora*) through vegetative cuttings is an effective method for maintaining the superior traits of the mother plant (Davis et al., 2012). Although Robusta coffee exhibits high tolerance to environmental stress, the success of seedling establishment from cuttings largely depends on the optimization of the growing media and the availability of nutrients to support the initiation and development of the root system (Bertrand et al., 2015).

Arbuscular mycorrhizal fungi (AMF) offer a biological solution to overcome nutrient deficiencies in marginal soils. AMF form a mutualistic symbiosis with plant root systems, extending the nutrient absorption area through an external hyphal network (Smith and Read, 2008). This mechanism enhances the mobilization and uptake of phosphorus, making it 3–5 times more efficient compared to non-mycorrhizal plants (Sharma et al., 2017).

AMF enhance plant resistance to biotic and abiotic stresses, improve soil aggregation, and stimulate the production of phytohormones that promote plant growth (Begum et al., 2019; Rouphael et al., 2015). The application of AMF in nursery systems for plantation crops has shown positive outcomes in improving seedling growth, nutrient uptake efficiency, and plant vigor (Bati et al., 2015). However, specific research on the effectiveness of AMF in robusta coffee cuttings grown in Lampung's Ultisol soils remains limited. Therefore, the aim of this study is to determine the optimal mycorrhizal dosage to enhance the growth of robusta coffee cuttings.

2. RESEARCH METHOD

Time and Location of Research

This research was conducted at the coffee nursery area of State Polytechnic of Lampung from August 2025 to October 2025. The study site was located in Bandar Lampung, Lampung Province, Indonesia, utilizing a shade house facility with controlled environmental conditions suitable for coffee cutting propagation.

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Experimental Design

The experiment was arranged in a Randomized Complete Block Design (RCBD) with a single factor consisting of four mycorrhizal dosage treatments. The treatments were designated as follows: M0 (control without mycorrhizal application), M1 (10 g mycorrhizal inoculum per plant), M2 (20 g mycorrhizal inoculum per plant), and M3 (30 g mycorrhizal inoculum per plant). Each treatment was replicated four times, resulting in 16 experimental units. Each experimental unit contained three coffee cuttings, yielding a total of 48 individual plants across the entire study.

Experimental Procedures

a. Site Preparation

A shade house measuring 3 × 6.5 m equipped with shade netting was utilized as the experimental area. The spacing between replications was maintained at 50 cm, while the spacing between treatments within each replication was 30 cm. Prior to the establishment of the experiment, the shade house area was thoroughly cleared of weeds and debris to minimize potential competition and pest harboring sites.

b. Growing Media Preparation and Polybag Filling

Polybags with dimensions of 20 × 25 cm and a capacity of approximately 2-3 kg were filled manually with growing media. The growing media consisted of a mixture of Ultisol topsoil and river sand to ensure adequate drainage while maintaining moisture retention properties suitable for cutting establishment. Filled polybags were subsequently arranged in the shade house according to the experimental layout.

c. Transplanting of Coffee Cuttings

Robusta coffee cuttings that had been previously prepared and showed signs of callus formation were carefully transplanted into the prepared holes. Following insertion of the cuttings, the holes were backfilled, and the surrounding media was gently compacted to ensure proper contact between the cutting and the growing medium while maintaining vertical orientation of the cutting.

d. Mycorrhizal Inoculum Application

Mycorrhizal inoculum was applied concurrently with the transplanting operation to maximize early colonization of the developing root system. The powdered inoculum was distributed directly into the planting holes at the base of each cutting according to the predetermined treatment doses (10 g, 20 g, and 30 g per plant). These dosage rates were selected based on previous research findings on mycorrhizal application in perennial crops. Immediately

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after inoculum placement, the cuttings were inserted into the holes to ensure direct contact between the mycorrhizal spores and propagules with the emerging adventitious roots.

Growth Parameters and Measurements

a. Plant Height (cm)

Plant height increment was measured using a standard ruler from the base of the cutting (soil surface level) to the apical growing point of the main stem. Height measurements were recorded at 0, 3, 9, 12, weeks after transplanting to monitor growth trends throughout the establishment period.

b. Leaf Number (leaves)

Total leaf count was determined manually by counting all fully emerged leaves on each plant. Leaf number was recorded at the same intervals as plant height (0, 3, 9, 12, weeks after transplanting) to assess the foliar development response to mycorrhizal treatments.

c. Root Volume (g)

Root length was measured using a ruler from the root collar to the longest visible root tip at 12 weeks after transplanting. This destructive measurement was conducted at the end of the experimental period to assess the overall root system development under different mycorrhizal treatments.

Data Analysis

Observation data were subjected to analysis of variance (ANOVA) at a 5% significance level. When significant differences among treatments were detected, means were further separated using the Least Significant Difference (LSD) test to determine which treatments differed significantly from one another.

3. RESULTS AND DISCUSSION

Effect of Mycorrhizal Application on Leaf Number

The application of mycorrhizal inoculum significantly influenced the leaf number of robusta coffee cuttings, particularly from 9 weeks after transplanting onwards. During the initial growth phase (weeks 0 and 3), all treatments showed relatively similar leaf numbers, ranging from 6.22 to 7.44 leaves in week 0 and 6.67 to 8.44 leaves in week 3. This similarity indicates that mycorrhizal colonization had not yet been fully established during the early establishment period.

However, a marked differentiation among treatments became evident at 9 weeks after transplanting. The M1 treatment (10 g mycorrhizal inoculum) produced the highest leaf number with 18.78 leaves, which was significantly different from all other treatments. This was followed

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by M2 (16.44 leaves) and M3 (15.22 leaves), while the control treatment (M0) exhibited the lowest leaf number at 11.33 leaves. By week 12, the M1 treatment maintained its superiority with 21.44 leaves, representing an increase of 53.1% compared to the control. The leaf number development across all treatments and observation periods is presented in Table 1.

Table 1. Effect of Mycorrhizal Application on Leaf Number of Robusta Coffee Cuttings at Different Observation Periods

Treatment	Leaf Number (Leaves)			
	Week 0	Week 3	Week 9	Week 12
M0	7,33 a	8,33 b	11,33 a	14,00 a
M1	6,78 a	8,44 b	18,78 c	21,44 c
M2	7,44 a	8,11 b	16,44 bc	19,56 bc
M3	6,22 a	6,67 a	15,22 b	17,89 b

Note: Numbers followed by the same letter in the same column are not significantly different according to LSD test at 5% level.

The enhanced leaf production in mycorrhizal-treated plants can be attributed to improved nutrient uptake, particularly phosphorus, which plays a crucial role in photosynthesis and energy metabolism (Chen et al., 2018). Mycorrhizal fungi extend their hyphal network beyond the root depletion zone, thereby increasing the effective absorption area for nutrients (Genre et al., 2020). This improved nutrient status promotes vegetative growth and leaf initiation. Similar findings were reported by Puschel et al. (2016), who observed that mycorrhizal application in perennial crops resulted in increased leaf area and leaf number due to enhanced nutrient mobilization.

The superior performance of the M1 treatment over higher dosages (M2 and M3) suggests an optimal colonization density. Excessive inoculum application may lead to competition among mycorrhizal propagules or an imbalance in the carbon allocation between the host plant and the fungal symbionts (Kiers et al., 2016). This phenomenon indicates that higher dosages do not necessarily translate to better plant performance, as the symbiotic relationship requires an appropriate balance between fungal colonization and plant carbon economy.

Effect of Mycorrhizal Application on Plant Height

Plant height responded positively to mycorrhizal application, with treatment effects becoming progressively more pronounced over time. At weeks 0 and 3, plant heights across treatments were relatively uniform, ranging from 10.14 to 12.10 cm and 11.14 to 16.90 cm, respectively. This initial uniformity reflects the lag phase required for mycorrhizal establishment and functional symbiosis development.

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By week 9, the M1 treatment demonstrated superior height growth at 30.31 cm, significantly surpassing all other treatments. The M2 treatment achieved 22.11 cm, while M3 and M0 showed the lowest heights at 18.08 cm and 20.48 cm, respectively. At the final observation (week 12), M1 maintained its dominance with a height of 38.69 cm, representing a 48.7% increase over the control treatment (26.01 cm). The complete plant height data across all observation periods is shown in Table 2.

Table 2. Effect of Mycorrhizal Application on Plant Height of Robusta Coffee Cuttings at Different Observation Periods

Treatment	Plant Height (cm)			
	Week 0	Week 3	Week 9	Week 12
M0	11,84 b	15,63 b	20,48 ab	26,01 a
M1	10,59 a	16,90 b	30,31 c	38,69 b
M2	12,10 b	15,02 b	22,11 b	30,12 a
M3	10,14 a	11,14 a	18,08 a	25,85 a

Note: Numbers followed by the same letter in the same column are not significantly different according to LSD test at 5% level.

The enhanced height growth in mycorrhizal-treated plants is closely associated with improved phosphorus nutrition. Phosphorus is essential for energy transfer through ATP formation, which directly supports cell division and elongation processes (Malhotra et al., 2018). Furthermore, mycorrhizal colonization stimulates the production of phytohormones such as auxins and cytokinins, which regulate apical meristem activity and stem elongation (Rouphael et al., 2015).

The growth pattern observed in this study aligns with research by Sharma et al. (2017), who reported that AMF application in perennial crops significantly increased plant height due to enhanced nutrient acquisition and improved root system architecture. The superior performance of M1 over higher dosages further confirms that an optimal inoculum density is critical for maximizing the benefits of mycorrhizal symbiosis without inducing excessive carbon drain on the host plant.

Effect of Mycorrhizal Application on Root Volume

Root volume measurements at 12 weeks after transplanting revealed significant differences among treatments. The M1 treatment produced the highest root volume at 44.67 cm^3, which was significantly greater than all other treatments. This was followed by M2 with 31.89 cm^3, while M3 (22.33 cm^3) and M0 (21.44 cm^3) showed the lowest and statistically similar root volumes. The M1 treatment achieved a 108.3% increase in root volume compared to the control. The root volume data for all treatments is presented in Table 3.

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Table 3. Effect of Mycorrhizal Application on Plant Height of Robusta Coffee Cuttings at Different Observation Periods

Treatment	Root Volume (cm^3)
M0	21,44 a
M1	44,67 c
M2	31,89 b
M3	22,33 a

Note: Numbers followed by the same letter in the same column are not significantly different according to LSD test at 5% level.

The substantial increase in root volume under mycorrhizal treatment can be attributed to several mechanisms. First, mycorrhizal colonization enhances nutrient uptake, particularly phosphorus, which is critical for root development and energy metabolism (Wang et al., 2017). Second, the external hyphal network effectively extends the root system's functional volume, improving water and nutrient absorption capacity (Begum et al., 2019). Third, mycorrhizal fungi produce growth-promoting substances and enzymes that stimulate lateral root formation and root branching (Frew et al., 2021).

Enhanced root development is particularly important for coffee cuttings, as a robust root system determines the success of transplanting establishment and subsequent field performance (Covre et al., 2018). A well-developed root system improves anchorage, drought tolerance, and nutrient foraging capacity, which are essential for long-term plantation productivity (DaMatta et al., 2018).

The diminishing returns observed at higher mycorrhizal dosages (M2 and M3) may be explained by carbon limitation theory. As mycorrhizal colonization increases, the carbon demand by fungal symbionts also increases, potentially exceeding the optimal cost-benefit ratio for the host plant (Kiers et al., 2016). When carbon allocation to mycorrhizal fungi becomes excessive, the plant's growth and development may be constrained despite improved nutrient access. This phenomenon underscores the importance of determining the optimal inoculum dosage for each specific crop-soil system.

4. CONCLUSIONS

This study successfully demonstrated that arbuscular mycorrhizal fungi application significantly enhanced the growth of robusta coffee cuttings in Ultisol soil conditions. The application of 10 g mycorrhizal inoculum per plant (M1 treatment) consistently produced superior

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results across all measured parameters, achieving a 53.1% increase in leaf number, 48.7% increase in plant height, and 108.3% increase in root volume compared to the control treatment. The observed improvements can be attributed to enhanced nutrient acquisition, particularly phosphorus mobilization, and the stimulation of phytohormone production that promotes vegetative growth and root system development.

The findings indicate that higher mycorrhizal dosages (20 g and 30 g per plant) did not provide additional benefits and, in some cases, resulted in diminished growth responses compared to the optimal 10 g dosage. This pattern suggests that excessive inoculum application may lead to unfavorable carbon allocation dynamics between the host plant and fungal symbionts. Therefore, for practical application in robusta coffee nurseries utilizing Ultisol growing media, a mycorrhizal inoculum dosage of 10 g per plant is recommended to maximize seedling quality while maintaining cost-effectiveness. Future research should investigate the long-term field performance of mycorrhizal-treated coffee seedlings and explore the interaction effects between mycorrhizal inoculation and other soil amendments in Ultisol management strategies.

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