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Low-Level MYKOVAM® Inoculation Enhances Growth Performance and Biomass Accumulation in *Coffea arabica* Seedlings

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Abstract

Coffee arabica is highly valued in the Philippines for its superior taste and increasing demand. However, the industry continues to face challenges such as low yield, poor bean quality, and susceptibility to pests and diseases. Successful seedling propagation requires the use of biofertilizers to enhance nutrient and water uptake, improve tolerance, and protect against root pathogens. This study evaluated the effects of varying levels of MYKOVAM® on the growth performance and biomass production of *C. arabica* seedlings under nursery conditions. A Randomized Complete Block Design (RCBD) was employed with five treatments and four replications: C (0 g MYKOVAM®), T1 (5 g), T2 (10 g), T3 (15 g), and T4 (20 g). A total of 300 one-month-old seedlings were inoculated at the recommended rates. Growth parameters measured after three months included percent survival, leaf number, root collar diameter, height gain, root length, root biomass, and shoot biomass. Results showed that T1 significantly improved survival, height gain, leaf count, root biomass, and shoot biomass compared to other treatments, though no significant difference was observed in root collar diameter. T2 produced the longest root length, while T3 and T4 recorded the lowest means across most parameters. These findings suggest that the application of 5 g MYKOVAM® is the most effective level for enhancing growth and biomass production of *C. arabica* seedlings, offering a sustainable approach to improving coffee cultivation in the Philippines.

Keywords: Arbuscular mycorrhizal, Biofertilizer, Leaf count, Parameters, Root and Shoot Biomass, Soil physico-chemical analysis

1. Introduction

In recent years, environmentally sustainable farming practices have gained increasing attention, particularly the use of biofertilizers to enhance soil health and crop productivity in coffee plantations. Coffee is one of the world's most valuable agricultural commodities and is the second most traded agricultural product globally, after oil (Browning, 2018). Among coffee species, Arabica (*Coffea arabica L.*) remains the predominant coffee species, contributing the majority of global production in low-income countries (Davis *et al.*, 2012). Originating in Ethiopia, Arabica coffee thrives in unique geographic and ecological conditions, contributing to its reputation as the center of diversity for the species. Today, Arabica represents more than 75% of world coffee production and 90% of the global coffee market (Wintgens, 2012). Coffee also plays a vital role in the Philippine economy, where the country is among the few that can produce all four major varieties: Robusta, Arabica, Liberica, and Excelsa (Baltazar & Fabella, 2020). Historically, the Philippines ranked as the fourth largest exporter of coffee in 1880. However, production declined sharply in 1894 due to coffee leaf rust, a devastating fungal disease that reduced yields by 30–50% (Gonzales et al., 2023). In 2026, the Philippines is not ranked among the top global coffee exporters because the country remains a small-scale producer, with exports too low to appear in the global

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rankings (World's Top Exports, 2026). Beyond disease, soil degradation remains a pressing environmental challenge, with approximately 70% of the nation's agricultural land affected by acidification, fertility decline, and erosion (Food and Agriculture Organization of the United Nations, 2021). Farmers face additional constraints such as high fertilizer costs, shortened plantation lifespans, frequent replanting, and reduced yields, leading many to abandon coffee cultivation due to limited access to advanced technologies and persistent soil degradation (Orchard *et al.*, 2017). In addition, agriculture in the Philippines continues to face challenges related to soil fertility, high input costs, and environmental sustainability. In the early 1990s, the University of the Philippines Los Baños (UPLB) BIOTECH developed MYKOVAM®, which contains a consortium of arbuscular mycorrhizal fungi (AMF), primarily Glomus species (Aguilar et al., 2018). The spores and propagules germinate in the roots of the host plant. Eventually, the fungi enter the roots, take residence and develop a large number of external hyphae. MYKOVAM® biofertilizers can improve soil fertility and characteristics and can replace 60-85% of the chemical fertilizer required by plants (Sollestre and Hao, 2026). These fungi form symbiotic associations with plant roots, extending their hyphae into the soil to improve nutrient and water absorption. The formulation is carefully blended with sterilized carrier materials to ensure viability and ease of application. By combining diverse AMF species, MYKOVAM® provides broad adaptability across different crops and soil conditions, making it a versatile tool for sustainable agriculture in the Philippines (Shukla and Choudhary, 2025). This innovation was formally introduced to Philippine agriculture and later integrated into government initiatives such as the National Greening Program in 2012. MYKOVAM® is usually sold in powder or solid form in one-kilogram packs. It is applied by mixing it into the soil or placing it in the root zone during transplanting, and is commonly used in nurseries for seedlings before field planting. One kilogram can inoculate about 400 seedlings, with application done once at the seedling stage to promote long-term root colonization.

Reliance on chemical fertilizers raises concerns about long-term productivity and ecological balance. To address these issues, biofertilizers have been introduced as practical alternatives that improve plant growth while reducing dependence on synthetic inputs (Silvera-Pablo, 2025). MYKOVAM® is environmentally friendly and widely applicable to fruit trees, crops, reforestation species, and ornamentals (Lavelah *et al.*, 2021). Several studies in the Philippines have shown that MYKOVAM® significantly improves crop performance by enhancing nutrient uptake and plant resilience. Research on coconut seedlings in Laguna revealed that farmers found MYKOVAM® acceptable and effective, reporting better seedling vigor and growth. In application to tomato, MYKOVAM® influenced growth and yield performance, plant height, number of leaves, stem diameter, number of days to flowering, and among the treatment levels, 7 grams MYKOVAM® consistently showed better vegetative growth, producing taller plants, more leaves, thicker stems, and earlier flowering compared to the control and other application rates

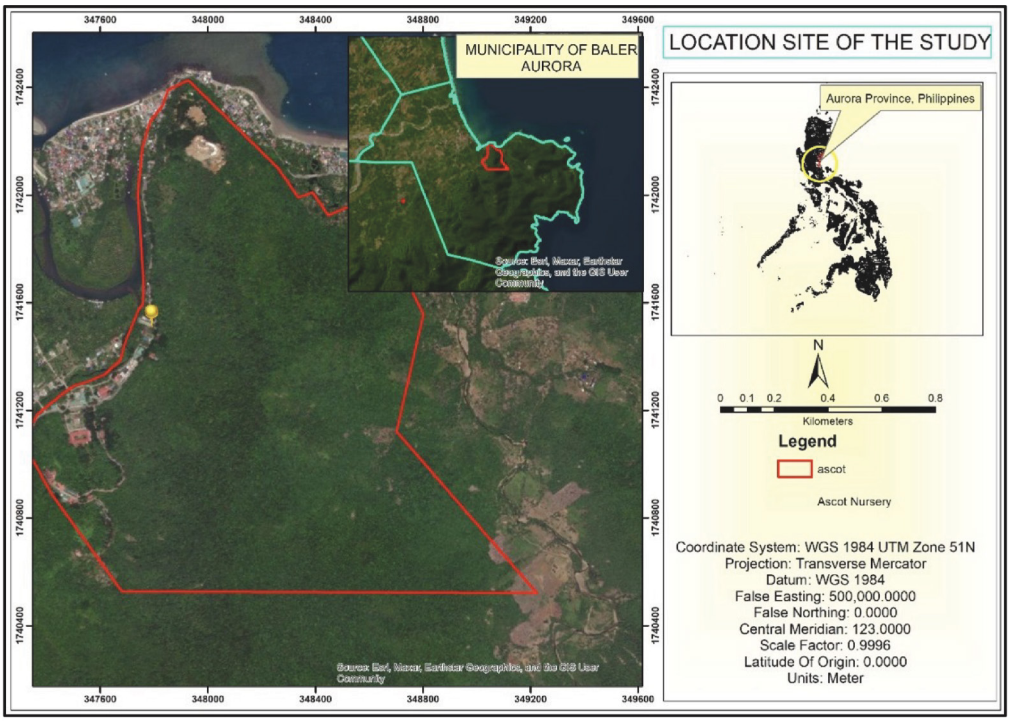

Figure 1. Map showing the research site and the surrounding area

(Sollestre and Hao, 2026). Trials on abaca, papaya, and sugarcane demonstrated increased root colonization by arbuscular mycorrhizal fungi, leading to improved tolerance against drought and soil-borne pathogens (Aguilar et al., 2018). Castañeto (2001) reported that *Vitex parviflora* (molave) seedlings treated with MYKOVAM® exhibited significantly higher survival rates and improved shoot development compared to untreated controls, highlighting its potential in forestry nurseries. Given its proven benefits in crops and forest trees, this study hypothesizes that varying levels of MYKOVAM® will significantly influence the growth and survival of *C. arabica* seedlings compared to untreated controls. Therefore, the objective of this research is to evaluate the effects of varying MYKOVAM® application levels on the survival and growth parameters of Arabica coffee seedlings, thereby contributing to sustainable coffee production practices in the Philippines.

2. Methodology

2.1 Description of the Study Area

The study was conducted in the Aurora State College of Technology (ASCOT) nursery during the cool, dry northeast monsoon season (Figure 1). ASCOT was located in Sitio Dicaloyungan, Barangay Zabali, Baler, Aurora, and spans a sprawling 196.06-hectare site. It is located at latitudes and longitudes of 15.744° N and 121.577° E, respectively, with an altitude of 164 to 260 feet above sea level and elevation ranging from 50 to 80 meters. The duration of the study was 4 months from November 2024 up to February 2025 (120 days). The area has a mean annual relative humidity of 82% with a mean annual temperature 26.7°C. This area is known for its high production potential of forest crops and a suitable habitat for native wildlife.

2.2 Seedlings and Media Preparation

Coffea arabica seeds were collected from a single seed source in San Luis, Aurora. Seeds were weighed using an analytical balance to ensure uniform mass and subsequently potted in black polyethylene bags measuring 6.35 × 6.35 × 12.7 cm. After two months, seedlings with uniform height and stem diameter were repotted into polyethylene bags measuring 7.62 × 7.62 × 20.32 cm, filled with a sterilized mixture of garden soil and sand at a 1:1 (v/v) ratio. Soil sterilization was conducted at the School of Forestry and Environmental Science Nursery using an oven calibrated at 82 °C for 3 hours. Seedlings were maintained in the ASCOT nursery screen house, with watering performed twice daily (morning and afternoon) and weeding carried out as necessary.

2.3 Preparation of MYKOVAM® as Treatment

1 kilo powder form MYKOVAM® per pack containing 12 species of Vesicular-Arbuscular Mycorrhizal (VAM) Fungi, soil-based biofertilizer intended for soil application, was procured from the UPLB AGORA National Institute of Applied Microbiology and Biotechnology (BIOTECH), University of the Philippines Los Baños, College, Laguna. The required amounts of MYKOVAM® were measured using an analytical balance to ensure accuracy. Seedlings were arranged in the nursery following a Randomized Complete Block Design (RCBD) with five treatments, including a control group, replicated 60 times for a total of 300 seedlings. The treatments consisted of: control (0 g), T1 (5 g per volume), T2 (10 g), T3 (15 g), and T4 (20 g) of MYKOVAM® (Table 1). The application was carried out by placing the biofertilizer 4 cm deep and 2 cm away from the base of each seedling.

Table 1. Different levels of MYKOVAM® were applied in this study.

Number	Treatment Level (grams)
T0	Control
T1	5 grams
T2	10 grams
T3	15 grams
T4	20 grams

2.4 Parameters Gathered

2.4.1 Percent Seedling Survival

Percent seedling survival (PSS) was calculated as the number of surviving seedlings divided by the total number of transplanted seedlings, multiplied by 100 (Bhardwaj, 2014). Seedlings exhibiting dried aboveground biomass were classified as dead (Bad-e et al., 2020). This was determined three months after planting using the formula below:

$$PSS\% = \frac{Ns}{Nt}\, x\, 100$$

Where:
Ns = Number of seedlings survived after the observation period
Nt = Total number of seedlings transplanted

2.4.2 Leaf count

The number of leaves was recorded following the BBCH scale (Principal Stage 1 – Leaf Development). Observations were taken at both the initiation and termination of the experiment. Only fully expanded leaves were considered, corresponding to BBCH codes 11–19 (one to nine or more leaves unfolded). Newly emerging leaves (not yet unfolded) and senescent leaves were excluded from the count.

2.4.3 Root Collar Diameter

Root collar diameter (RCD) was measured using a vernier caliper, calibrated in 1 mm above the soil surface. Additionally, to ensure consistent measurements, the base of each seedling was marked with white paint to serve as a reference point (Bautista and Buhong, 2024).

2.4.4 Seedling Height

Height is measured from the base of the stem to the apical bud or growing tip using a ruler calibrated in cm. For consistency, a white paint marker was also used as a point of reference.

2.4.5 Root Length

The seedlings were carefully removed from the growing media and wash then laying the roots in the flat surface. The root length was measured from the root shoot up to the tip of the longest root for each plant using a ruler calibrated in centimeters.

2.4.6 Root and Shoot Biomass

Seven uniform-sized seedlings were selected as representatives of each treatment for these parameters. The roots and shoots were separated by cutting at the root collar using scissors. The fresh shoots and roots were weighed in an analytical balance from the Nano Technology Center of Aurora State College of Technology. Roots were separated from shoots and placed in labeled paper bags. Samples were oven-dried at 65°C for 72 hours until a constant dry weight was achieved, then weighed (±0.001 g).

2.5 Statistical Analysis

Two-way ANOVA was performed using JASP (v.0.16.1; JASP Team, 2022). Before analysis, the assumptions of normality and homogeneity of variances were verified. Normality of the measured and calculated parameters was assessed using the Shapiro–Wilk test, while homogeneity of variances was examined using Levene's test. Where necessary, data transformations were applied to parameters that did not initially meet these assumptions to ensure the validity of the analysis. ANOVA results with significant effects were subsequently subjected to Tukey's post hoc analysis, with the confidence level set at $p < .05$. Results of both ANOVA and Tukey's post hoc tests for each growth parameter are presented in tabular form, with corresponding p values reported.

3. Results and Discussions

3.1 Seedling Survival

A high survival rate reflects the healthy performance of planted seedlings, indicating strong adaptation to environmental conditions and the effectiveness of planting techniques. Ensuring high seedling survival is critical for the success of forestry initiatives such as forest plantations, reforestation, and forest restoration

Table 1. Summary of ANOVA with Tukey's post hoc analysis of the significant effect on MYKOVAM® in the percent survival of *Coffea arabica* seedlings

Source of variation	DF	Sum of Squares	Mean Square	*F*	*p*
Replication	59	37866.66	641.81	0.82^{ns}	0.8169
Treatment	4	31200.00	7800.00	9.96**	.001
Error	236	184800.00	783.05		
Total	299	253866.67			
Post hoc comparison – Seedlings survival					
Treatment (A)	**Treatment (B)**	**Mean difference (A and B)**	**SE**	***t***	P_{tukey}
C	T3	20.00	5.016	3.987	<.001***
C	T4	23.33	5.016	4.652	<.001***
T1	T3	20.00	5.016	3.987	<.001***
T1	T4	23.33	5.016	4.652	<.001***
T2	T3	16.67	5.016	3.323	.009**
T2	T4	20.00	5.016	3.987	<.001***

Note: * p < .05, ** p < .01, *** p < .001

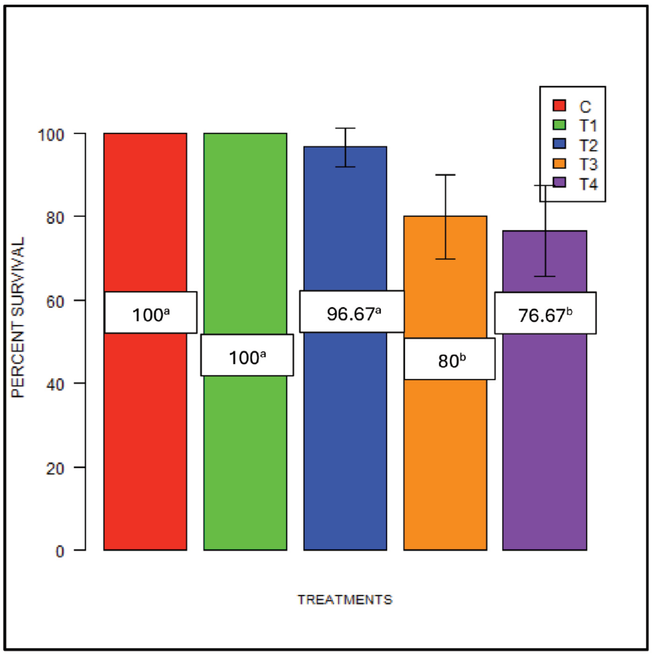

Figure 2.Percent seedling survival of *C. arabica* per treatment

(Bianchi *et al.*, 2019). After three months, seedling survival percentages (Figure 2) showed that both the T0 and T1 achieved 0.10 survival, while T2 recorded 0.9667, T3 0.80, and T4 0.7667. These results suggest that increasing the application level of MYKOVAM® in *C. arabica* seedlings may have adverse effects, as higher dosages were associated with reduced survival rates.

Table 1 presents the results of the two-way ANOVA, which revealed a significant difference in percent survival among treatments ($p < 0.001$). Tukey's post hoc test further indicated that both the T0 and T1 differed significantly from T3 and T4 ($p < 0.001$). Similarly, T2 showed significant differences compared to T3 (p = 0.009) and T4 (p = 0.001). In contrast, no significant difference was observed between T3 and T4 (p = 0.964). The results indicate that untreated seedlings may exhibit higher survival rates due to factors such as seed quality selection, provenance, and soil conditions. This observation is consistent with the findings of Abadayan and Coracero (2024), who reported that provenance and soil characteristics significantly influenced survival and growth in *Pterocarpus indicus*. Similarly, Aggangan *et al.* (2019) demonstrated that biofertilizer application increased plant survival rates to 0.92 to 0.95, compared to only 0.15 in untreated plants after 18 months in the field. Furthermore, Aggangan *et al.* (2013) revealed that MYKOVAM® application improved mine tailing soils by detoxifying heavy metals such as aluminum, thereby enhancing root colonization and copper accumulation. These effects contributed to improved growth and higher survival rates in *Jatropha curcas* seedlings and cuttings compared to non-mycorrhizal counterparts.

3.2 Leaf count

Seedlings that produce more leaves are more capable of photosynthesis and carbon dioxide assimilation, thereby generating sugars essential for growth and survival (Elleva *et al.*, 2018). The number of leaves varied greatly between treatments. A developmental stage between BBCH 12–13 (two to three leaves unfolded) was represented by the control group's average of 2.20 leaves. With slightly higher averages of 2.27 and 2.42 leaves, respectively, Treatments T1 and T2 were comparable to BBCH 13 (three unfolded leaves). On the other hand, Treatment T4 seedlings averaged 1.98 leaves, which corresponds to BBCH 12 (two leaves unfolded), whereas Treatment T3 showed the lowest mean leaf count (1.50 leaves), which corresponds to BBCH 11–12 (one to two leaves unfurled) (Figure 3). These findings imply that while higher application (T3 and T4) decreased leaf production, intermediate inoculation levels (T1 and T2) increased leaf development.

The results of the two-way ANOVA, which revealed a significant difference in the number of leaves produced among treatments ($p < .001$). Tukey's post hoc test indicated that T2 significantly increased leaf production in *C. arabica* compared to T3 (p = .001). Similarly, T1 and T0 contributed to higher leaf numbers relative to T3, with p values of .011 and .026, respectively. In contrast, no significant difference was observed between T3 and T4 (p = .243) (Table 2). Overall, these findings suggest that mixtures of MYKOVAM® and garden soil are suitable for enhancing leaf development in *C. arabica*. This effect is likely attributable to MYKOVAM® improving nutrient and water absorption, while garden soil provides

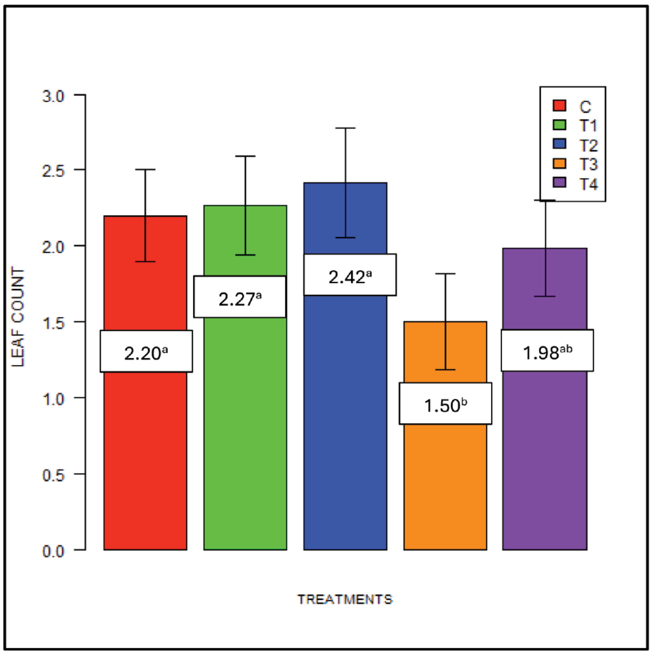

Figure 3. Leaf count of *C. arabica* seedlings per treatment

essential nutrients, moisture, and aeration to support seedling growth (Jimoh & Afolayan, 2020).

3.3 Root Collar Diameter

Large root collar seedlings are generally more adaptable to environmental conditions and exhibit higher survival rates in degraded areas (Dierauf & Garner, 1996). As shown in Figure 4, T1 produced the largest mean root collar diameter (0.745 mm), followed by the T0 with 0.717 mm. In contrast, T2 (0.563 mm), T4 (0.523 mm), and T3 (0.507 mm) recorded smaller diameters. These results suggest that the application of 5 g MYKOVAM® enhances water and mineral uptake, thereby contributing to increased root collar diameter in *C. arabica* seedlings. However, the two-way ANOVA revealed no statistically significant differences among treatments (p = .073; Table 3).

The study findings indicate that the standard MYKOVAM® application rate of 5 grams per seedling, incorporated into the potting medium, produced a greater mean root collar diameter compared with the other tested dosages. A minimal amount of biofertilizer appears sufficient to establish an effective symbiotic relationship with plant roots, thereby enhancing nutrient and water absorption and promoting vigorous growth. However, the observed differences in root collar diameter were not statistically significant (p = .073), likely

Table 2. Summary of ANOVA with Tukey's post hoc analysis of the significant effect on MYKOVAM® in the number of leaves

Source of variation	DF	Sum of Squares	Mean Square	*F*	*p*
Replication	59	21.27	0.3604	1.05^{ns}	0.3855
Treatment	4	2.98	0.7495	2.19^{ns}	0.001
Error	236	80.81	0.3424		
Total	299	105.07			

Post hoc comparison – Seedlings leaf count

Treatment (A)	Treatment (B)	Mean Difference (A and B)	SE	*t*	P_{tukey}
C	T3	0.700	0.235	2.975	0.026
T1	T3	0.767	0.235	3.259	0.011
T2	T3	0.917	0.235	3.896	0.001

Note: * p < .05, ** p < .01, *** p < .001

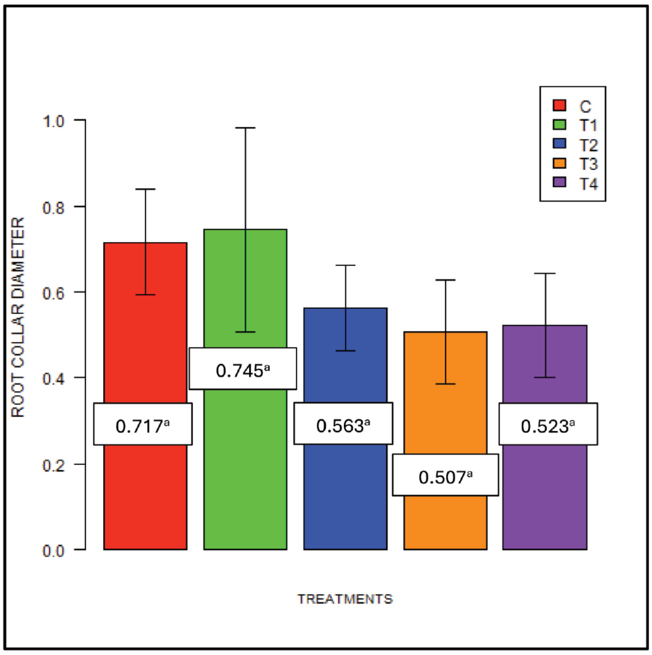

Figure 4. Root collar diameter of *C. arabica* seedlings per treatment

due to the moderate effect of MYKOVAM® on this trait and the relatively short experimental period. Notably, significant effects of MYKOVAM® were evident in root mass, leaf growth, shoot biomass, and root length. These results contrast with the findings of Aggangan *et al.* (2011), who reported that the combination of MYKOVAM® and BioN promoted the largest root collar diameter in *Sorghum bicolor*. Similarly, Aguilar *et al.* (2018) demonstrated that arbuscular mycorrhizal (AM) fungi increased stem diameter in abaca, sugarcane, and papaya compared with untreated plants.

3.4 Seedling Height

The height increment of *C. arabica* seedlings over the three months clearly demonstrates the influence of varying MYKOVAM® application rates on growth performance. Seedlings in Treatment 1 (5 grams) attained the greatest mean height (37.98 cm), followed by Treatment 2 (27.68 cm), the T0 (25.85 cm), Treatment 4 (24.93 cm), and Treatment 3 (16.83 cm) (Figure 5). These results indicate that a low inoculation level (5 grams) optimally promotes seedling growth and development, whereas higher application rates appear to suppress growth. The reduction in height observed at elevated doses may be attributed to nutrient competition, microbial imbalance, or stress responses associated with excessive root colonization. Such findings highlight the importance of optimizing biofertilizer dosage, as over-application may counteract the intended benefits of mycorrhizal inoculation.

The two-way ANOVA revealed a highly significant effect of MYKOVAM® application on seedling height gain ($p < 0.001$), confirming that treatment levels influenced growth performance (Table 4). Tukey's post hoc analysis further demonstrated that Treatment 1 (5 grams) produced a significantly greater increase in height compared to T3 and T4 ($p = 0.001$), as well as T0 and T2 ($p = 0.002$ and $p = 0.015$, respectively). T2 also enhanced seedling height relative to T3 ($p < 0.009$). In contrast, no significant differences were observed between the T0 and T2 and T4 ($p = 0.981$ and $p = 0.999$),

Table 3. Summary of ANOVA with Tukey's post hoc analysis of the significant effect on MYKOVAM® in the root collar diameter of *Coffea arabica* seedlings

Source of variation	DF	Sum of Squares	Mean Square	*F*	*p*
Replication	59	85.9867	1.4574	0.85^{ns}	0.7559
Treatment	4	30.4867	7.6217	4.45^{ns}	0.73
Error	236	403.91	1.7115		
Total	299	520.39			

Note: ^{ns} p > .05, * p < .05, ** p < .01, *** p < .001

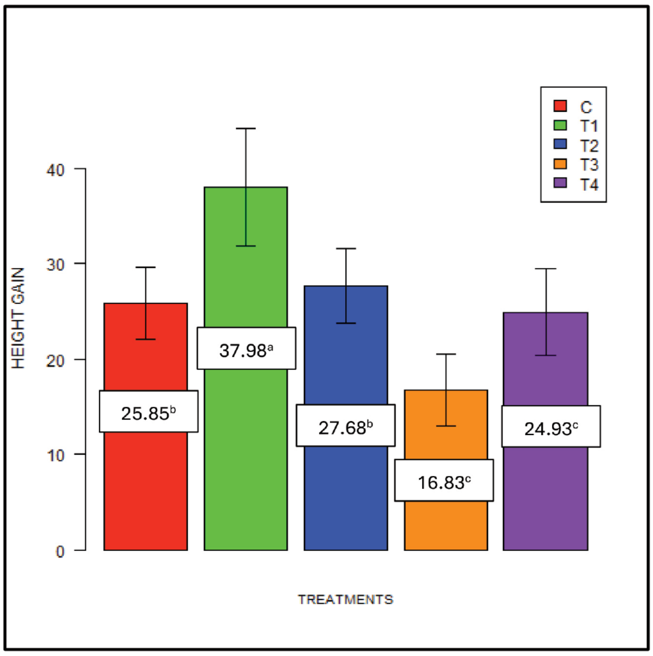

Figure 5. Seedling height gain of *C. arabica* seedlings per treatment

nor between T2 and T4 (p = 0.918). Similarly, T3 and T4 did not differ significantly (p = 0.099). These findings indicate that low-level application (5 grams) optimally promotes seedling growth, whereas higher application rates fail to confer additional benefits. The growth enhancement is consistent with the role of arbuscular mycorrhizal fungi in facilitating nutrient acquisition. MYKOVAM® application successfully colonized the roots, improving the uptake of phosphorus, nitrogen, and micronutrients (Zn, Cu, Fe) from the garden soil–sand substrate, thereby supporting vigorous seedling development (Miransari, 2013). Comparable results were reported by Abadayan and Coracero (2024), who found that MYKOVAM® inoculation significantly improved the height of *Pterocarpus indicus* seedlings relative to untreated and chicken manure treatments, underscoring the broad applicability of mycorrhizal biofertilizers in enhancing early growth performance across species.

3.5 Root Length

Root length in *C. arabica* serves as a critical indicator of seedling vigor and the plant's capacity to access water and nutrients from the soil. Among the seedlings treated, T2 produced the longest mean root length (63.77 cm), outperforming all other treatments and the control group. T1 (60.83 cm) and the T0 (60.48

Table 4. Summary of ANOVA with Tukey's post hoc analysis of the significant effect on MYKOVAM® in the height gain of *Coffea arabica* seedlings

Source of variation	DF	Sum of Squares	Mean Square	F	p
Replication	59	16612.04	281.56	0.85^{ns}	0.7672
Treatment	4	13767.95	3441.99	10.40^{**}	0.001
Error	236	78107.65	330.96		
Total	299	108487.64			
Post hoc comparison – Seedlings height gain					
Treatment (A)	Treatment (B)	Mean difference (A and B)	SE	t	P_{tukey}
C	T1	-12.133	3.272	-3.709	0.002**
C	T3	9.017	3.272	2.756	0.048*
T1	T2	10.308	3.272	3.148	0.015*
T1	T3	21.150		6.465	0.001***
T1	T4	13.050		3.989	0.001***
T2	T3	10.850		3.317	0.009**

Note: ^{ns} p > .05, * p < .05, ** p < .01, *** p < .001

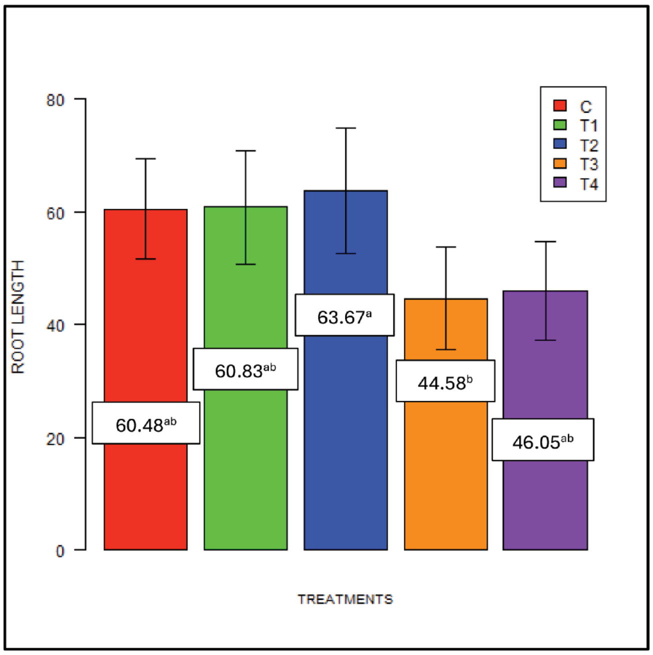

Figure 6. Root length of *C. arabica* seedlings per treatment

cm) also exhibited relatively strong performance compared to T4 (46.05 cm) and T3 (44.58 cm) (Figure 6). These results suggest that moderate inoculation levels enhance root elongation, whereas excessive MYKOVAM® application may suppress root growth. Such reductions could be attributed to nutrient competition, microbial imbalance, or stress responses associated with over-colonization. Moreover, the observed trade-off between shoot and root development highlights the allocation of carbohydrates and nutrients within the plant. Increased leaf production appears to divert assimilates toward shoot growth and leaf maintenance, thereby limiting resources available for root elongation. This finding underscores the importance of balancing inoculation levels to optimize both above- and below-ground growth, ensuring seedlings develop robust root systems capable of supporting long-term establishment and resilience under field conditions.

The two-way ANOVA revealed a significant effect of MYKOVAM® application on seedling root length ($p < 0.009$), indicating that treatment levels influenced below-ground development (Table 5). Tukey's post hoc analysis showed that T2 produced a significantly greater root length compared to T3 ($p = 0.047$). However, no other treatments contributed significantly to root elongation in *C. arabica*. These findings suggest that moderate inoculation levels enhance root system development, whereas higher or lower application rates do not provide additional benefits. The observed improvement in root length is consistent with previous reports on the role of arbuscular mycorrhizal fungi in promoting root system expansion. Aguilar *et al.* (2018) demonstrated that

Table 5. Summary of ANOVA with Tukey's post hoc analysis of the significant effect on MYKOVAM® in the root length of *Coffea arabica* seedlings

Source of variation	DF	Sum of Squares	Mean Square	*F*	*p*
Replication	59	54575.24	925.00	0.59^{ns}	0.9917
Treatment	4	19767.35	4941.84	3.14^{**}	0.009
Error	236	371282.25	1573.23		
Total	299	445624.84			
Post hoc comparison – Seedlings root length					
Treatment (A)	Treatment (B)	Mean difference (A and B)	SE	*t*	P_{tukey}
T2	T3	19.183	6.937	2.765	0.047*

Note: ^{ns} p > .05, * p < .05, ** p < .01, *** p < .001

MYKOVAM® inoculation significantly enhanced root length and overall root system development in papaya, abaca, and sugarcane seedlings compared to untreated plants, highlighting the broad efficacy of mycorrhizal biofertilizers across diverse species. This alignment reinforces the potential of MYKOVAM® to improve root vigor in coffee seedlings, thereby supporting greater nutrient and water acquisition and enhancing resilience under variable field conditions.

3.6 Root Biomass

Root biomass is a critical indicator of seedling adaptation to soil conditions and reflects the plant's capacity to absorb water and nutrients, thereby increasing its survival potential (Markesteijn and Poorter, 2009). As indicated in Figure 7, T1 produced the highest mean root biomass (0.4966 grams), outperforming all other treatments and the control. T3 (0.1721 grams) and T2 (0.1387 grams), also contributed to improved root biomass compared to Treatment 4 (0.1090 grams), and T0 (0.0639 grams). These findings suggest that low-level MYKOVAM® inoculation (5 grams) optimally enhances root biomass accumulation, while excessive application rates may limit root development. The improved root biomass under optimal inoculation highlights the role of arbuscular mycorrhizal fungi in strengthening below-ground structures, which in turn supports greater nutrient and water uptake and enhances seedling resilience under variable environmental conditions.

The two-way ANOVA revealed a highly significant effect of MYKOVAM® application on root biomass production in *C. arabica* seedlings ($p < 0.001$), indicating that inoculation levels strongly influenced below-ground development (Table 6). Tukey's post hoc analysis showed that T1 (5 g) produced significantly greater root biomass compared to all other treatments ($p = 0.001$). T3 also enhanced root biomass relative to the T0 and T4 ($p < 0.001$ and $p = 0.002$, respectively), while T2 yielded higher root biomass than the T0 ($p < 0.001$). In contrast, no significant differences were observed between the T0 and T2 and T4 ($p = 0.981$ and $p = 0.999$), nor between T2 and T4 ($p = 0.918$). Similarly, the T0 and T2 did not differ significantly from T4 ($p = 0.640$ and $p = 0.407$). These results highlight that low-level inoculation (5 g) optimally promotes root biomass accumulation, whereas higher application rates fail to provide consistent benefits. The findings are consistent with those of del Rio *et al.* (2024), who reported that MYKOVAM® and MYKOPLUS® inoculation increased root biomass of *Coffea canephora* (Robusta) by 59% in acidic soils compared with uninoculated controls, an effect attributed to enhanced mycorrhizal colonization. Together, these results reinforce the role of arbuscular mycorrhizal fungi in strengthening root systems, thereby improving nutrient and water uptake and supporting seedling resilience under challenging soil conditions.

3.7 Shoot Biomass

Shoot biomass serves as an important indicator of seedling vigor, as larger leaf area enhances photosynthetic activity, supports rapid growth, and improves the plant's ability to recover under stressful environmental conditions. T1 produced the highest mean shoot biomass (2.44 grams), outperforming

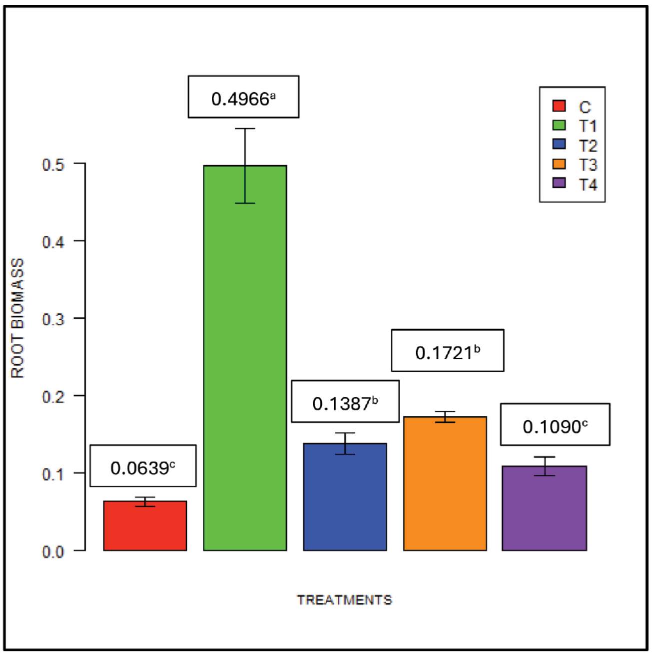

Figure 7. Root biomass of *C. arabica* seedlings per treatment

Table 6. Summary of ANOVA with Tukey's post hoc analysis of the significant effect on MYKOVAM® in the root biomass of *Coffea arabica* seedlings

Source of variation	DF	Sum of Squares	Mean Square	*F*	*p*
Replication	59	0.2086	0.0035	0.35^{ns}	0.9917
Treatment	4	7.1542	1.7886	179.14**	0.001
Error	236	2.3563	0.0100		
Total	299	9.7162			

Post hoc comparison – Seedlings root biomass

Treatment (A)	Treatment (B)	Mean difference (A and B)	SE	*t*	P_{tukey}
C	T1	- 0.433	0.017	- 25.420	<.001***
C	T2	- 0.075	0.017	- 4.400	<.001***
C	T3	- 0.108	0.017	- 6.359	<.001***
T1	T2	0.358	0.017	21.020	<.001***
T1	T3	0.325	0.017	19.061	<.001***
T1	T4	0.388	0.017	22.766	<.001***
T3	T4	0.064	0.017	3.705	0.022**

Note: ^{ns} p > .05, * p < .05, ** p < .01, *** p < .001

all other treatments and the control. T3 (1.09 g) also contributed to improved shoot biomass compared to T4 (0.91 g), T0 (0.77 grams), and T2 (0.67 grams) (Figure 8). These findings suggest that low-level MYKOVAM® inoculation (5 grams) optimally promotes shoot biomass accumulation, while higher application rates provide limited benefits. The enhanced shoot biomass under optimal inoculation highlights the role of arbuscular mycorrhizal fungi in increasing leaf production and photosynthetic capacity, thereby strengthening seedling resilience and growth potential.

The two-way ANOVA revealed a highly significant effect of MYKOVAM® application on shoot biomass production in *C. arabica* seedlings ($p < 0.001$), confirming

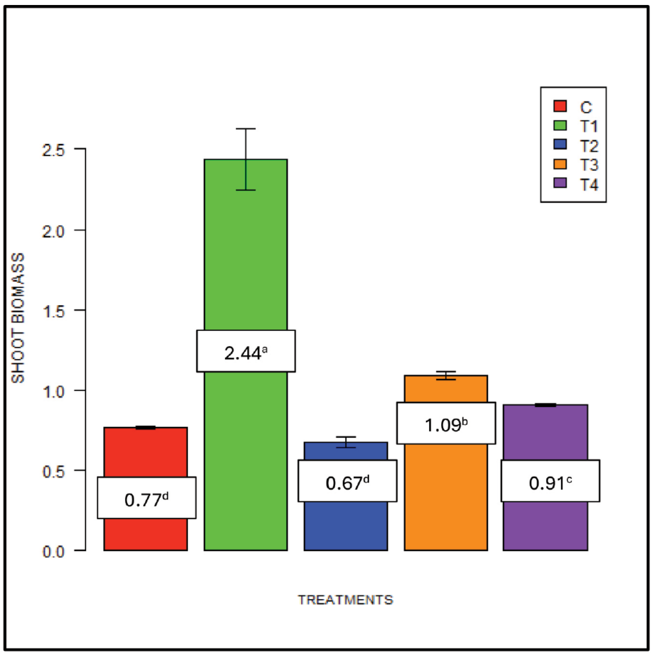

Figure 8. Shoot biomass of *C. arabica* seedlings per treatment

that inoculation levels influenced above-ground growth. Tukey's post hoc analysis showed that T1 (5 grams) produced significantly greater shoot biomass compared to all other treatments (p = 0.001). T3 also enhanced shoot biomass relative to the control and T2 (p < 0.001), and differed significantly from T4 (p = 0.034). In contrast, no significant differences were observed between the control and T2 (p = 0.587), nor between the control and T4 (p = 0.172) (Table 7). These results highlight that low-level inoculation optimally promotes shoot biomass accumulation, while higher application rates fail to provide consistent benefits. The enhanced shoot biomass under optimal inoculation reflects the role of arbuscular mycorrhizal fungi in improving nutrient acquisition, particularly potassium and phosphorus, and in facilitating water uptake. These physiological benefits support more extensive leaf development and photosynthetic activity, thereby strengthening seedling vigor and resilience under stress conditions. Similar outcomes were reported by Aguilar *et al.* (2018), who found that MYKOVAM® inoculation significantly increased biomass production in abaca, papaya, and sugarcane seedlings compared to untreated controls. Their study demonstrated increases from 47.07 g to 56.09 grams in abaca, 5.95 g to 7.05 g in papaya, and 19.14 g to 20.65 g in sugarcane, underscoring the broad applicability of mycorrhizal biofertilizers in enhancing above-ground growth across diverse crop species.

4. Conclusion

The results of the study demonstrate that the recommended application rates of MYKOVAM®, specifically T1 (5 g) and T2 (10 g), are effective biofertilizer levels for enhancing the growth of *Coffea arabica*. Both treatments significantly improved the growth performance of inoculated seedlings compared with the control. Nevertheless, the control treatment (T0) and T1 recorded the highest survival rate, with 100 % survival, outperforming T2, T3, and T4. Among all treatments, the 5 g MYKOVAM® application showed superior performance over the control and other application rates, as evidenced by greater root collar diameter, increased seedling height, and higher root and shoot biomass. In contrast, the 10 g treatment (T2) exhibited the most pronounced improvement in leaf production and root length relative to all other treatments, including the control. Based on the significant improvements observed in percent survival, number of leaves, seedling height, root length, shoot biomass, and root biomass, the application of MYKOVAM® (arbuscular mycorrhizal) is strongly recommended as an effective biofertilizer for enhancing plant growth performance. Its application at early growth stages and direct placement in the root zone are recommended to maximize mycorrhizal colonization and nutrient uptake, thereby enhancing overall plant growth performance.

Table 7. Summary of ANOVA with Tukey's post hoc analysis of the significant effect on MYKOVAM® in the shoot biomass of *Coffea arabica* seedlings

Source of variation	DF	Sum of Squares	Mean Square	*F*	*p*
Replication	59	8.0482	0.1364	1.61^{ns}	0.2170
Treatment	4	125.17	31.2933	2.66***	0.001
Error	236	27.69	0.1173		
Total	299	160.91			
Post hoc comparison – Seedlings shoot biomass					
Treatment (A)	Treatment (B)	Mean difference (A and B)	SE	*t*	P_{tukey}
C	T1	- 1.669	0.064	- 26.268	<.001***
C	T2	- 0.325	0.064	-5.109	<.001***
T1	T2	1.762	0.064	27.159	<.001***
T1	T3	1.345	0.064	21.159	<.001***
T1	T4	1.528	0.064	24.039	<.001***
T2	T3	0.418	0.064	6.573	<.001***
T2	T4	0.235	0.064	3.693	0.022**
T3	T4	0.183	0.064	2.880	0.034*

Note: ^{ns} p > .05, * p < .05, ** p < .01, *** p < .001

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