

Propagation of Arbuscular mycorrhizal fungi genus in durian rhizosphere soil using different host plants

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ABSTRACT

This study aimed to identify suitable host plants for propagating Arbuscular mycorrhizal fungi (AMF) commonly found in durian rhizosphere soil in Cai Lay district, Tien Giang province. Durian root and rhizosphere soil samples were collected from orchards aged over 15 years post-harvest, where no fertilizer was applied for the subsequent season, and the predominant genus of AMF was selected for propagation. The experiment was arranged in a completely randomized design (CRD) in a greenhouse, comprising four treatments, including three different host plants (*Durio zibethinus* Murr. - durian, *Zea mays* - maize, *Sorghum* sp. - sorghum), and a control treatment without a host plant. The results indicated that *Glomus* was the predominant genus of AMF in the durian rhizosphere soil, characterized by globose to subglobose spores with a smooth surface, ranging in color from light yellow to orange and yellow-brown, and a spore diameter ranging from 45 to 110 μm with 2 to 3 layers of spore wall. Overall, there was no significant difference in spore characteristics after one propagation cycle. The experiment suggested that maize and sorghum were suitable host plants for propagating the *Glomus* genus in durian rhizosphere soil, with AMF colonized root percentages of 87.79 and 93.93%, respectively. Notably, sorghum exhibited the highest increase in spore production, with the number of spores increasing by up to 66.16 times compared to before the experiment.

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1. Introduction

Durian (*Durio zibethinus* Murr.) stands as a prominent fruit crop in Vietnam, contributing significantly to the country's agricultural economy. However, challenges such as saltwater intrusion and climate change have posed significant threats to durian cultivation, particularly in Cai Lay district, renowned as the heartland of durian production in the Mekong River Delta region.

Arbuscular mycorrhizal fungi (AMF) represent a ubiquitous group of symbiotic fungi found in over 80% of plant roots. The survey results of Suharno et al. (2019) and Khaengraeng et al. (2021) showed the presence of AMF in durian rhizosphere soil in Indonesia and Thailand, respectively. Through extraradical hyphae, AMF supports plants accessing small pores in the soil that plant roots cannot reach (Galindo et al., 2022; Herms et al., 2022; Liu et al., 2022). In return, plants provide photosynthates such as sugar and lipids to AMF (Keymer & Gutjahr, 2018). Therefore, their presence in the rhizosphere soil and plant roots has been shown to enhance nutrient absorption, promote young plant survival, increase flower production (Ortas, 2007), and confer tolerance to drought (Amerian et al., 2001; Chitarra et al., 2016) and salinity (Khaliel, 2010; Parvin et al., 2022). Consequently, farmers can utilize AMF as a biofertilizer (Berruti et al., 2016) to reduce the amount of chemical fertilizer needed. It can be argued that the propagation and utilization of AMF in agriculture hold pivotal significance in maintaining ecosystem stability and sustainability. The initial step in AMF production involves propagation through a host plant (INVAM, 2024a), with research by Guar & Adholeya (2002) highlighting the host plant's crucial role in the efficiency of this

process. Some characteristics of suitable host plants for AMF propagation include strong roots, high photosynthetic capacity (INVAM, 2014a), and robust growth in greenhouse conditions (Nuridayati et al., 2019). However, the AMF sporulation efficiency of host plants depends on the type of spore and various environmental factors (Husna et al., 2017). Thus, this study aimed to identify suitable host plants for propagating the AMF genus prevalent in durian rhizosphere soil in Cai Lay district, Tien Giang province.

2. Materials and Methods

The greenhouse experiment was conducted at the Agronomy Research Station, and the data on AMF were analyzed in the laboratory of the Agronomy Faculty at Nong Lam University, Ho Chi Minh City, Vietnam.

2.1. Experimental materials

- Durian (*Durio zibethinus* Murr.): Durian seeds were obtained from local fruits propagated by seeds, with an average diameter ranging from 2.5 to 3.0 cm.
- Maize (*Zea mays*): The NK7328 cultivar, sourced from Syngenta company.
- Sorghum (*Sorghum* sp.): The OPV 88 Super BMR variety, originating from Vietnam Agricultural Academy.
- Containers and chemicals: Black plastic pots measuring 18 x 15 x 14 cm with 5 holes at the bottom of the pot and plastic plates 18 cm in diameter were used. Various chemicals including: sucrose, alcohol, KOH, NH_4OH , H_2O_2 , acid lactic, glycerin, HCl, trypan blue, acid lactic, PVA and iod were employed for AMF isolation and root treatment.

- Equipment: electronic scale, sieves with mesh sizes of 1.000, 750, 100 and 38 μm , Hermle Z306 centrifuge, Olympus CX21 microscope (Japan), Optika stereoscope, falcon tube 50 mL, Erlenmeyer flask, filter paper, wash bottle, petri dish, and pipet were utilized for experimental procedures.

2.2. Spores and media preparation

AMF spores were extracted from 20 rhizosphere soil samples obtained from durian plants aged over 15 years in Cai Lay district, Tien Giang province, within the 0 - 50 cm soil layer (Masri, 1991; Forster, 1995). The isolation procedure followed the wet sieving, de-canting, and sucrose centrifugation method outlined by Gerdemann & Nicolson (1963), conforming to the Vietnam's National Standards (MST, 2018). Subsequently, the most prevalent AMF genus in the collected samples was identified and selected as the source of AMF spores for propagation, adhering to Souza (2015) and INVAM (2024b) guidelines.

The mixture of coconut coir dust:sand:cow manure at a ratio of 1:1:1 was sterilized in an autoclave at 121°C for 30 min before being used as a medium for host plants to propagate AMF. This medium was chosen based on the result of Le et al. (2018) with slight modification. The physicochemical parameters of the medium were as follows: porosity (50.1%), air space (39.0%), water holding capacity (11.1%), $\text{pH}_{\text{H}_2\text{O}}$ (1:5) (5.7), organic matter (15.08%), total nitrogen (0.21%) and total phosphorus (0.24%).

2.3. Experimental design

A single-factor experiment was conducted using a completely randomized design (CRD) in a greenhouse, comprising four treatments with three replications. Each treatment consisted of five pots (Halim et al., 2019). The treatments

included T1: durian (*Durio zibethinus* Murr.), T2: maize (*Zea mays*), T3: sorghum (*Sorghum* sp.), and a control treatment (T4) without a host plant. To prevent the loss of AMF spores, pots were placed on plastic plates with bricks underneath, and all equipment was thoroughly cleaned with alcohol.

Seeds used in the study underwent sterilization using 70% alcohol and 1% NaOCl, followed by washing with distilled water five times (Fasusi et al., 2021). The sterilized pots, each containing 1,100 g of the prepared medium, were inoculated with 15 viable AMF spores. Two seeds of each crop were sown in each pot and covered with a 5 mm layer of the medium. The control treatment received the same AMF spore inoculation as the other treatments. Seedlings in all treatments and controls were watered daily and fertilized according to recommended doses outlined in Vietnamese standards for maize.

After two weeks of sowing, seedlings were thinned to ensure one plant per pot. The greenhouse study was conducted from November 2023 to January 2024, with average air temperatures ranging from 27.9 to 38.3°C and relative air humidity ranging from 42.0 to 58.0%. Temperature and humidity were monitored by the Digital Temperature Humidity Meter HTC-1. Water was withheld ten days before collecting AMF spores to induce spore production. Approximately 1 g of root samples was collected at depths of 0 to 5 cm after 30, 45, and 60 days to assess the percentage of AMF-colonized roots. At 90 days after propagation, media from five pots was mixed, and three subsamples weighing 100 g each were randomly selected to isolate and measure the average density of AMF spores, characteristics of AMF spores, AMF structures in roots (%), root size (cm) and weight (g).

2.4. Evaluation on the percentage of AMF colonized root and host plants root

The assessment of AMF colonized root percentage followed the methodology outlined by Phillip & Hayman (1970) and Dalpé & Séguin (2013) with minor adaptations: Roots were sectioned into 1 cm fragments totaling 1 g, treated with KOH 2.5% and microwaved for 2 min, followed by bleaching in H_2O_2 until roots turned white, then treated with HCl 1% for 5 min. Staining with trypan blue 5% and subsequent examination under a microscope at magnification 100X enabled visualization of AMF colonization structures in roots.

The percentage of AMF colonized root (%) = (number of AMF colonized root/total number of observed root) x 100

Root properties such as length (cm), fresh weight (g), and dry weight (g) were measured post-harvest. Root was dried at 70°C until the weight remained constant to identify the dry weight.

2.5. Evaluation of spores

The AMF spores were extracted using a modified version of the wet sieving, decanting, and sucrose centrifugation method outlined by Gerdemann & Nicolson (1963) and Vietnam's National Standards 12560-1:2018 (MST, 2018). Specifically, 100 g of the medium was mixed with 250 mL of distilled water, left to settle for 15 min, and then shaken at 150 rpm for 15 min. The solution was then decanted through mesh sizes of 1,000; 750; 100; and 38 μ m, washed with distilled water to remove debris, and centrifuged at 2,000 rpm for 10 min. The resulting spore solution was mixed with 50% sucrose solution, centrifuged again, and the AMF spores were deposited onto filter paper for counting their density under a stereoscope.

The density of AMF spores (number of AMF spores per pot) = (the average density of AMF spores x weight of media per pot)/100.

The capacity of AMF spores production (times) = (later density of AMF spores per pot - initial density of AMF spores per pot)/initial density of AMF spores per pot.

Spore characteristics, including shape, color, diameter, and the number of wall layers, were assessed using polyvinyl-lactose-glycerol (PVLG) solution and examined under a microscope according to Souza (2015) and INVAM (2024b) standards.

2.6. Data analysis

The collected data underwent analysis of variance (ANOVA) using Microsoft Excel and DSASTAT software, with a T-test employed to compare mean values between two groups. Treatment differences were assessed using the Least Significant Difference (LSD) at $P < 0.05$ or $P < 0.01$ levels of significance. Percentage data for AMF colonized root and host plant root were transformed to $\arcsin\sqrt{x}$ prior to ANOVA analysis following the method outlined by Gomez & Gomez (1984).

3. Results and Discussion

3.1. The characteristics of AMF spores collected in rhizosphere soil of durian grown in Cai Lay district, Tien Giang province

The analysis of 20 durian rhizosphere samples collected from Cai Lay district, Tien Giang province revealed the presence of AMF spores, constituting more than 50% of the observed AMF population. These spores exhibited characteristic features consistent with the description provided by Souza (2015) and INVAM (2024b), indicative of their classification within the *Glomus* genus.

Specifically, the AMF spores displayed a globose or sub-globose morphology, with colors ranging from light yellow to orange and yellow-brown. Their spore surface appeared smooth, with a diameter spanning 47.5 to 110.0 μm and an

average diameter of 82.2 μm . Additionally, the spores exhibited 2 to 3 wall layers, and the subtending hyphae were straight and firmly attached to the spores (Figure 1).

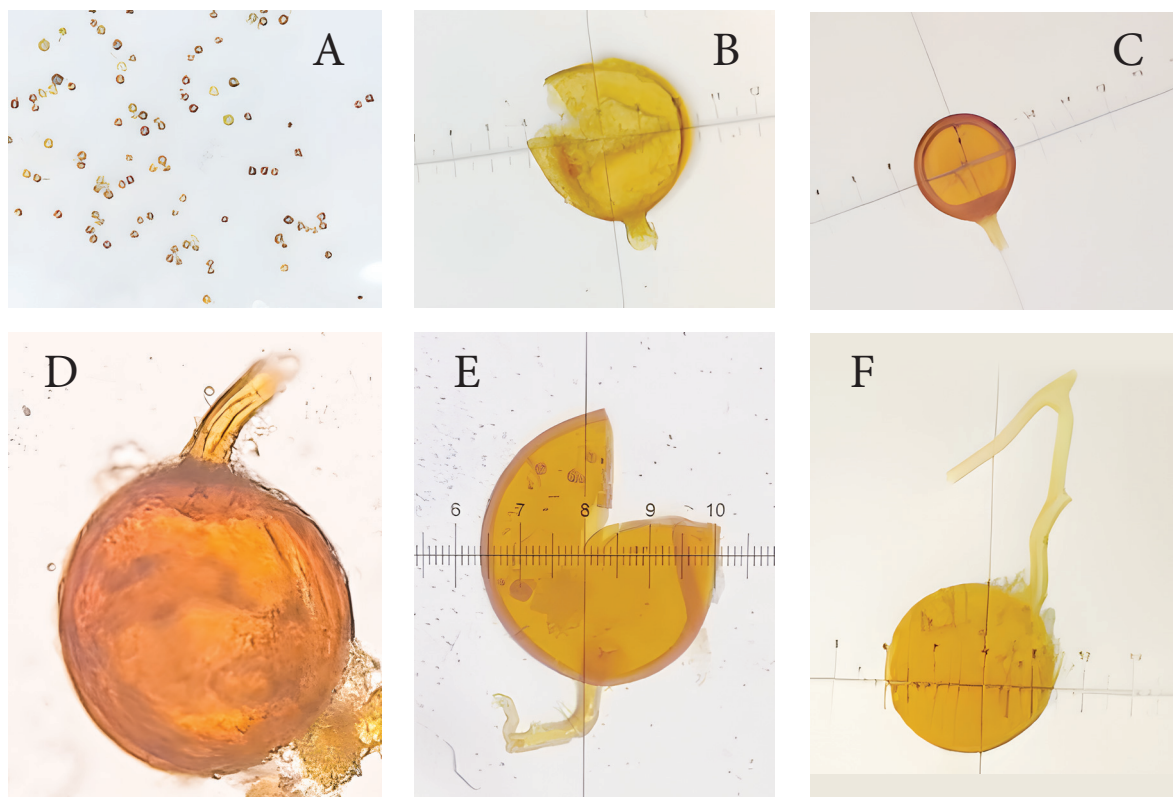


Figure 1. Isolated *Glomus* genus in durian rhizosphere soil in Cai Lay district, Tien Giang province was observed under a microscope at 100X (A) and 400X magnification (B - F).

The identification of *Glomus* genus species in the durian rhizosphere soil of Cai Lay district aligned with prior research conducted by Suharno et al. (2019) and Khaengraeng et al (2021), reported a similar prevalence of *Glomus* genus in durian rhizosphere soil in

Indonesia and Thailand, respectively. This finding reveals the widespread distribution of *Glomus* genus in durian cultivation regions, suggesting their potential significance in durian growth and development.

3.2. The structure of AMF in host plant root

AMF requires the presence of a host plant root for colonization and reproduction, as the root acts as an essential component in their life cycle (Brundrett, 2004). Upon encountering the root of a host plant, AMF penetrates it

through hyphae, forming arbuscular and vesicular structures within the root. The establishment of a symbiotic relationship begins when AMF spores make contact with the root, prompting the extraradical hyphae to differentiate into appressoria.

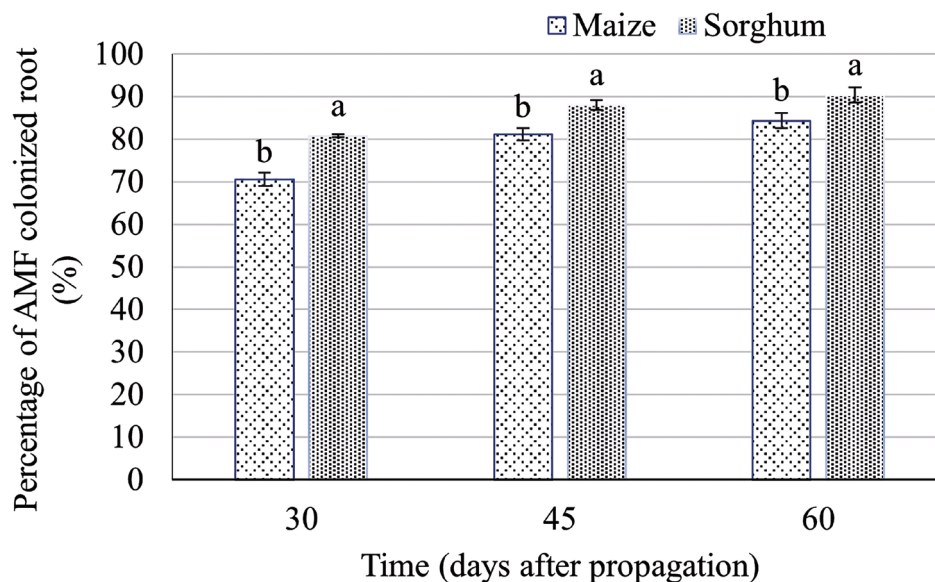


Figure 2. The percentage of maize and sorghum roots colonization by AMF after propagation time.

The effectiveness of host plants in establishing this symbiotic relationship and supporting AMF spore multiplication varies (Herawan & Putri, 2018). Survey results of host plant roots indicated the presence of AMF within the root cells of maize and sorghum at 30 days post-propagation. Notably, the percentage of AMF colonized roots differed significantly among host plants (Figure 2). Over time, as the durian plants exhibited slow growth, root samples were not collected until 30 - 60 days post-propagation. During this period, the percentage of AMF colonized roots gradually increased. At 30 days post-propagation, maize

and sorghum showed AMF colonized root percentages of 70.6 and 80.7%, respectively. This is consistent with Tran (2012), whose research indicated that AMF spores began to establish symbiosis in maize roots 20 days after inoculation and gradually increased over time. By day 60, these figures had further increased to 84.3% for maize and 90.4% for sorghum. These findings suggest that sorghum serves as an optimal host plant for propagating the *Glomus* genus in durian rhizosphere soil in Cai Lay district, Tien Giang province, particularly within the 30-60 day post-propagation period.

Table 1. The different structures of AMF in host plant root and the AMF colonized roots percentage at 90 days after propagation

Host plants	Percentage of AMF structure in root (%)			Percentage of AMF colonized root (%)
	Hyphae	Arbuscular	Vesicular	
Durian	39.9 (39.1)	67.9 (55.5)	56.0	69.5 (56.6 ^b)
Maize	60.7 (51.4)	65.6 (54.1)	52.8	87.8 (69.6 ^a)
Sorghum	53.7 (47.1)	64.5 (53.7)	64.3	93.9 (75.8 ^a)
F _{computed}	2.9 ^{ns}	0.1 ^{ns}	2.8 ^{ns}	40.4 ^{**}
CV (%)	13.8	10.6	10.6	4.0

CV (%): Coefficient of Variation. The value in parentheses was transformed to $\arcsin \sqrt{x}$; ns: non-significant; **: significant at 1% level; AMF: Arbuscular mycorrhizal fungi. Means followed by the same letter are not significantly different at the 1% level.

The results presented in Table 1 showed a non-significant difference in the percentage of AMF structures within roots across three host plants after 90 days of propagation. This suggests that the host plant selection did not influence the types of AMF symbiotic structures. Arbuscular was the common symbiotic structure in this experiment, representing of 64.5 - 67.9% of root colonization by AMF. Arbuscular structures occur typically develop in newly formed roots and serve as sites for nutrient exchange between AMF and plant (Alizadeh, 2011). Furthermore, Table 1 revealed that hyphal structures colonized 39.9 to 53.7% of roots, while vesicular structures colonized 52.0 to 64.3% of roots. This result is similar to the findings of Kadian et al. (2019), who observed that arbuscular and vesicular structures

were abundant in the roots of host plants after 90 days of propagation. Although the distribution of symbiotic structures was consistent across host plants, the AMF colonized roots percentage varied among them. The rate of AMF formation was contingent upon the root growth rate, which tends to be slower in durian compared to the two C4 plants. Consequently, at 90 days post-propagation, the percentage of durian root colonization by AMF was notably lower (68.5%) and significantly different compared to maize (87.8%) and sorghum (93.9%). Additionally, the utilization of different host plants did not alter the percentage of root colonization by AMF on maize and sorghum, as evidenced by the non-significant differences observed (Table 1).

3.3. Root characteristics of host plants

Table 2. The root of host plants at 90 days after propagation

Host plants	Root length (cm)	Root fresh weight (g)	Root dry weight (g)
Durian	9.4 ^b	0.9 ^c	0.1 ^c
Maize	38.9 ^a	24.1 ^a	3.6 ^a
Sorghum	40.2 ^a	11.1 ^b	2.3 ^b
F _{computed}	274.1 ^{**}	3499.1 ^{**}	1475.6 ^{**}
CV (%)	6.18	2.83	3.94

CV (%): Coefficient of Variation. **: significant at 1% level. In the same column, means followed by the same letter are not significantly different at the 1% level.

Root colonization by AMF constitutes a pivotal inoculum applicable in soil cultivation methodologies. According to Tran (2012), the introduction of AMF into maize-growing soil, coupled with subsequent root colonization, resulted in an accelerated establishment of the symbiotic relationship. AMF also heightened symbiosis within the root system compared to sole inoculation with spores. Table 2 showed that following a 90-day propagation period, discernible disparities emerged in the root length, as well as the fresh and dry weight of roots across various host plants. Specifically, durian exhibited the lowest root length and weight, attributed to its comparatively sluggish growth rate relative to the two C4 plants incorporated in this study, thereby influencing root morphology. In the meantime, while maize root length exhibited non-significant variance compared to sorghum, notable differences were observed in the fresh and dry root. These results differ from the findings of Halim et al. (2019), who reported that the difference in root weight between maize and sorghum was not statistically significant. The discrepancy could be due to variations in plant species or variety, harvest time, and environmental conditions, which also play a large role in determining root length and root fresh or dry weight.

3.4. Properties of spores after propagation and the capacity of AMF spores production by using different host plants

3.4.1. Properties of spores after propagation

The size and characteristics of spores, particularly the number of wall layers, serve as crucial parameters for distinguishing between different AMF genera (Oehl & Sieverding, 2004; Oehl et al., 2006; 2008). These wall layers are integral to the identification and classification process due to their high level of conservatism and phenotypic stability across varying environmental conditions such as soil type, host plant, and other biotic or abiotic factors (Souza, 2015). Consequently, when employing different host plants for propagation, the spore size and number of wall layers remain consistent, with non-significant differences observed through t-tests. Post-propagation, spore sizes ranged from 47.5 to 165.0 μm , with an average size of 82.9 μm , typically encompassing 2 to 3 wall layers. Microscopic examination revealed that the color of the spores remained largely un-changed, presenting hues of pale yellow to orange, and brown-yellow. However, some spores exhibited thicker wall layers, rendering them resistant to crushing even when subjected to pressure via PVLG.

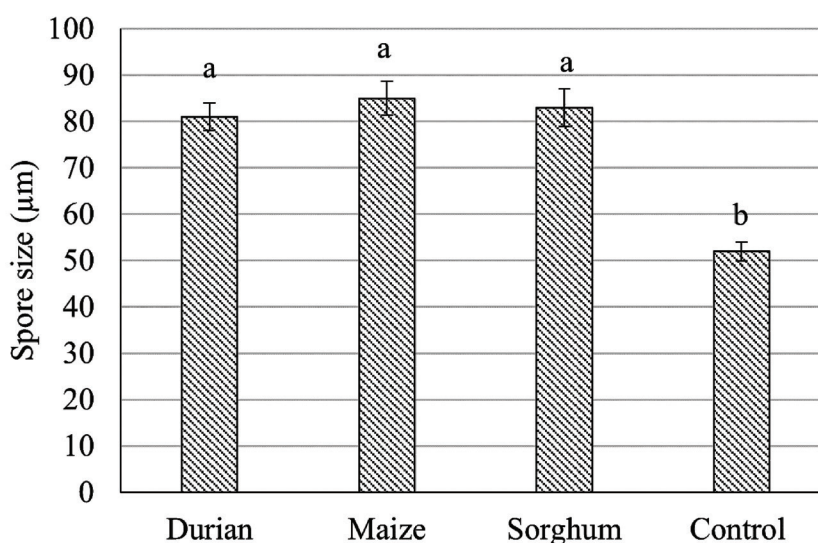
Table 3. Properties of AMF spores before and after propagation

Stage	Diameter (μm)	The number of wall layers
Before propagation	82.2 ± 4.5	2 - 3
After propagation	82.9 ± 2.0	2 - 3
T - test	ns	-

Mean $\pm$ SE; ns: non-significant ; AMF: Arbuscular mycorrhizal fungi.

Figure 3 suggests that spore size remained unaffected by the use of different host plants for propagation. Spore sizes observed under various host plant treatments did not exhibit statistically significant differences. However, in the control treatment (absence of host plant), spores experienced notable alterations after 90 days, particularly when subjected to coconut coir dust: sand: cow manure medium. Here,

approximately 36.67% of the spores were no longer intact, resulting in a decrease in spore diameter (ranging from 30 to 70 μm , with an average diameter of 51.7 μm). This change was significantly different when compared to other treatments. These findings suggest that *Glomus* spp. spores utilized in this experiment are unable to survive under greenhouse conditions without a host plant.

**Figure 3.** Arbuscular mycorrhizal fungi spore size when propagation by different host plants.

3.4.2. The density of spore and the capacity of AMF spores production at 90 days after propagation

Using various host plants can significantly influence the sporulation dynamics of arbuscular mycorrhizal fungi (Bever et al., 1996). After 90 days of propagation, discernible differences were observed in the density of AMF per pot across different host plant treatments. Despite the initial source of spores being derived from durian rhizosphere soil, employing durian as a host plant for *Glomus* genus propagation resulted in the lowest average spore density per pot at the 90-day mark.

As highlighted by Husna et al. (2017), AMF symbiosis and sporulation are contingent upon various factors, including spore type, host plant species, and environmental conditions. Significant variations exist in symbiotic relationships across different genera within the same host plant species (Lapanjang et al., 2023). Consequently, while Selvakumar et al. (2016) reported maize as a more suitable host plant for propagating AMF species in rice rhizosphere soil compared to sorghum, our findings diverged. When maize served as a host plant for propagation, the AMF spore density of the *Glomus* genus in durian rhizosphere soil after 90 days of propagation was lower compared to using sorghum.

Table 4. The density of spore and the capacity of AMF spores production at 90 days after propagation

Host plants	Density of AMF spore (spores per pot)	The capacity of AMF spores production (times)
Durian	235.1 ^c	14.7
Maize	767.2 ^b	50.1
Sorghum	992.4 ^a	65.2
Control	15.0 ^d	0
F _{computed}	177.9 ^{**}	-
CV (%)	11.7	-

CV (%): Coefficient of Variation. **: significant at 1% level; AMF: Arbuscular mycorrhizal fungi. In the same column, means followed by the same letter are not significantly different at the 1% level.

Table 4 corroborated that sorghum was the most conducive host plant for propagating the *Glomus* genus, despite maize's popularity as a host plant for AMF propagation. These results were consistent with the findings of Halim et al. (2019) regarding the multiplication of *Glomus* and *Acaulospora*. The interaction between AMF type and the host plant is contingent upon environmental conditions and host plant characteristics, as different host plants provide varying levels of photosynthetic resources for AMF (Syamsiar, 2017).

The capacity for AMF spore production at 90 days post-propagation was notably high across most host plant treatments, with sorghum exhibiting a substantial increase in spore density approximately 66.6 times greater than the control. Additionally, when maize was employed as a host plant, the density of AMF spores reached a significant level (767.2 spores/pot), representing a considerable increase compared to the control. Hence, maize also emerged as a suitable host plant for propagating AMF in this research.

4. Conclusions

The study elucidated the prevalence and characteristics of Arbuscular mycorrhizal fungi (AMF) in the durian rhizosphere soil of Cai Lay district, Tien Giang province. Analysis of 20 rhizosphere soil samples revealed *Glomus* as the dominant AMF genus, exhibiting distinctive traits such as a globose or subglobose morphology, pale yellow, orange, and yellow-brown coloration, and a smooth surface texture. These characteristic properties persisted following a 90-day life cycle propagation using different host plants. Remarkably, maize and sorghum were identified as conducive host plants for propagating these *Glomus* AMF sources. Further investigations could explore the impact of additional propagation cycles on maize and sorghum to assess the effect of propagation time on AMF production capacity. Such insights hold promise for optimizing AMF propagation strategies to enhance nutrient uptake and promote sustainable durian cultivation practices.

Conflict of interest

The authors have no conflicts of interest to declare.

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References

- Alizadeh, O. (2011). Mycorrhizal symbiosis. *Advanced Studies in Biology* 3(6), 273-281.
- Amerian, M. R., Stewart, W. S., & Giffiths, H. (2001). Effect of two species of arbuscular mycorrhizal fungi on growth, assimilation and leaf water relations in maize (*Zea mays* L.). *Aspects of Applied Biology* 63, 1-6.
- Berruti, A., Lumini, E., Balestrini, R., & Bianciotto, V. (2016). Arbuscular mycorrhizal fungi as natural biofertilizers: Let's benefit from past successes. *Frontiers in Micro-biology* (6), 1-13. <https://doi.org/10.3389/fmicb.2015.01559>.
- Bever, J. D., Morton, J. B., Antonovics, J., & Schultz, P. A. (1996). Host-dependent sporulation and species diversity of arbuscular mycorrhizal fungi in a mown grassland. *Journal of Ecology* 84(1), 71-82. <https://doi.org/10.2307/2261701>.
- Brundrett, M. (2004). Diversity and classification of mycorrhizal associations. *Biological Reviews* 79(3), 473-495. <https://doi.org/10.1017/S1464793103006316>
- Chitarra, W., Pagliarani, C., Maserti, B., Lumini, E., Siciliano, I., Cascone, P., & Guerrieri, E. (2016). Insights on the impact of arbuscular mycorrhizal symbiosis on tomato tolerance to water stress. *Plant Physiology* 171(2), 1009-1023. <https://doi.org/10.1104/pp.16.00307>.
- Dalpé, Y., & Séguin, S. M. (2013). Microwave-assisted technology for the clearing and staining of arbuscular mycorrhizal fungi in roots. *Mycorrhiza* 23(4), 333-340 <https://doi.org/10.1007/s00572-012-0472-9>.
- Fasusi, O. A., Amoo, A. E., & Babalola, O. O. (2021). Propagation and characterization of viable arbuscular mycorrhizal fungal spores within maize plant (*Zea mays* L.). *Journal of The Science of Food and Agriculture* 101(14), 5834-5841. <https://doi.org/10.1002/jsfa.11235>.
- Forster, J. C. (1995). Soil sampling, handling, storage and analysis. In Kassem, A., & Pao-lo, N. (Eds.). *Methods in applied soil microbiology and niochemistry* (49-121). London, UK: Academic Press.
- Galindo, C. T., Lynch, J. P., Six, J., & Hartmann, M. (2022). Improving soil resource up-take by plants through capitalizing on synergies between root architecture and anatomy and root-associated microorganisms. *Frontiers in Plant Science* 13, 577. <https://doi.org/10.3389/fpls.2022.827369>

- Gaur, A., & Adholeya, A. (2002). Arbuscular-mycorrhizal inoculation of five tropical fod-der crops and inoculum production in marginal soil amended with organic matter. *Biology and Fertility of Soils* 35, 214-218.
- Gerdemann, J. W., & Nicolson, T. H. (1963). Spores of mycorrhizal endogone species ex-tracted from soil by wet sieving and decanting. *Transactions of The British Myco-logical Society* 46(2), 235-244. [https://doi.org/10.1016/S0007-1536\(63\)80079-0](https://doi.org/10.1016/S0007-1536(63)80079-0).
- Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research*. Los Baños, Philippines: International Rice Research Institute.
- Halim., Arma, M. J., Sarawa., Rakian, T. Co., Tufaila, M., Resman., Rembon, F. S., Hisein, W. S. A., Syair., Mariadi., & Kandari, A. M. (2019). Propagation spores of arbuscu-lar mycorrhiza fungi and rooting colonization characteristic's on different host plants. *GSC Biological and Pharmaceutical Sciences* 8(1), 078-083. <https://doi.org/10.30574/gscbps.2019.8.1.0114>.
- Herawan, T., & Putri, A. I. (2018). Effects of Arbuscular mycorrhiza and host plant *Portulaca* sp. against sandalwood plantlet aclimation (*Santalum album* L.) *Journal of Forest Plant Breeding* 12(2), 151-161. <https://doi.org/10.20886/jpth.2018.12.2.151-161>.
- Hermes, C. H., Hennessy, R. C., Bak, F., Dresbøll, D. B., & Nicolaisen, M. H. (2022). Back to our roots: Exploring the role of root morphology as a mediator of beneficial plant-microbe interactions. *Environmental Microbiology* 24(8), 3264-3272. <https://doi.org/10.1111/1462-2920.15926>.
- Husna, F. D., Tuheteru, A. A., & Renggaala, A. F. (2017). Fungal Sporulation Local Ar-buscule mycorrhiza origin of nail wood rhizosphere [*Pericopsis mooniana* (Thw) Thw] affected dosage of red hyponex. *Ecogreen* 3, 79-88.
- INVAM (The International Collection of Vesicular Arbuscular Mycorrhiza Fungi). (2024a). Host plant choice. Retrieved March 1, 2024, from <http://invam.ku.edu/host-plant-choices>.
- INVAM (The International Collection of Vesicular Arbuscular Mycorrhiza Fungi). (2024b). Species descriptions. Retrieved March 1, 2024, from <http://invam.ku.edu/species-descriptions>.
- Kadian, N., Yadav, K., Jangra, E., & Aggarwal, A. (2019). Influence of host plant and rice straw as substrate on mass multiplication of arbuscular mycorrhizal fungi for large-scale agricultural application. *International Journal of Recycling of Organic Waste in Agriculture* 8(Suppl. 1), 21-26. <https://doi.org/10.1007/s40093-019-0255-9>.
- Keymer, A., & Gutjahr, C. (2018). Cross-kingdom lipid transfer in arbuscular mycorrhiza symbiosis and beyond. *Current Opinion in Plant Biology* 44, 137-144. <https://doi.org/10.1016/j.pbi.2018.04.005>.
- Khaengraeng, C., Thitithanakul, S., Sontikul, Y., & Pechwang, J. (2021). Survey of arbus-cular mycorrhizal fungi in chemical farming and organic farming system of durian orchard in Surat Thani. *Khon Kaen Agriculture Journal* 49, 260-264.
- Khaliel, A. S. (2010). Effect of salinity stress on mycorrhizal association and growth response of peanut infected by *Glomus mosseae*. *Plant, Soil and Environment* 56(7), 318-324. <https://doi.org/10.17221/204/2009-PSE>.
- Lapanjang, I., Zakaria, E., Edy, N., & Barus, H. N. (2023). Effectiveness of multiple culture of arbuscular mycorrhizal fungi (AMF) from the rhizosphere of cocoa on host plant *Pueraria javanica*. *IOP Conf. Series: Earth and Environmental Science* 1253, 012032. <https://doi.org/10.1088/1755-1315/1253/1/012032>.
- Le, Y. H. T, Le, A. H., Mai, L. D. T., & Duong, H. V. (2018). Isolation of mycorrhizal fungi from maize cultivation soil and the production of biofertilizer from these-fungi. *VNU Journal of Science: Natural Science and Technology* 34(3), 1-9. <https://doi.org/10.25073/2588-1140/vnunst.4743>.

- Liu, C. Y., Guo, X. N., Wu, X. L., Dai, F. J., & Wu, Q. S. (2022). The Comprehensive effects of *Rhizophagus intraradices* and P on root system architecture and p transportation in *Citrus limon* L. *Agriculture* 12(3), 317. <https://doi.org/10.3390/agriculture12030317>.
- Masri, M. (1991). Root distribution of durian (*Durio zibethinus* Murr.) cv. D 24 *MARDI Research Journal* 19(2), 183-189.
- MST (Ministry of Science and Technology) (2018). Standard No. TCVN 12560-1:2018 date on December 28, 2018. Biofertilizers - The determination of endomycorrhizae density - Part 1: counting the number of endomycorrhizae spores with the wet sieving technique in combination with flotation centrifugation. Retrieved September 20, 2023, from <https://thuvienphapluat.vn/TCVN/Nong-nghiep/TCVN-12560-1-2018-Phan-bon-vi-sinh-vat-mat-do-nam-re-noi-cong-sinh-Phan-1-918076.aspx>.
- Nuridayati, S. S., Prasetya, B., & Kurniawan, S. (2019). Propagation different types of Arbuscular mycorrhiza across various host plant types. *Journal of Land and Land Resources* 6, 1375-1385.
- Oehl, F., & Sieverding, E. (2004). *Pacispora*, a new vesicular arbuscular mycorrhizal fungal genus in the Glomeromycetes. *Journal of Applied Botany and Food Quality* 78, 72-82.
- Oehl, F., Souza, F., & Sieverding, E. (2008). Revision of *Scutellospora* and description of five new genera and three new families in the arbuscular mycorrhiza forming Glomeromycetes. *Mycotaxon* 106, 311-360.
- Oehl, F., Sýkorová, Z., Redecker, D., Wiemken, A., & Sieverding, E. (2006). *Acaulospora alpina*, a new arbuscular mycorrhizal fungal species characteristics for high mountainous and alpine regions of the Swiss Alps. *Mycologia* 98(2), 286-294. <https://doi.org/10.3852/mycologia.98.2.286>
- Ortas, A. V. (2007). Field trials of bioinoculants. In Oelmüller, R., & Varma, E. (Eds.). *Modern tools and techniques* (397-413). Berlin, Germany: Springer-Verlag. https://doi.org/10.1007/978-3-540-70865-0_26.
- Parvin, S., Van, G. M., Yeasmin, T., Verbruggen, E., & Honnay, O. (2022). Effects of single and multiple species inocula of arbuscular mycorrhizal fungi on the salinity tolerance of a Bangladeshi rice (*Oryza sativa* L.) cultivar. *Mycorrhiza* 30(4), 431-444. <https://doi.org/10.1007/s00572-020-00957-9>.
- Phillips, J. M., & Hayman, D. S. (1970). Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. *Transactions of The British Mycological Society* 55(1), 158-161. [https://doi.org/10.1016/S0007-1536\(70\)80110-3](https://doi.org/10.1016/S0007-1536(70)80110-3).
- Selvakumar, G., Kim, K., Walitang D., Chanratana, M., Kang, Y., Chung B., & Sa, T. (2016). Trap culture technique for propagation of Arbuscular mycorrhizal fungi using different host plants. *Korean Journal of Soil Science and Fertilizer* 49(5), 608-613.
- Souza, T. (2015). *Handbook of Arbuscular Mycorrhiza fungi*. Cham, Switzerland: Springer International Publishing AG.
- Suharno, S., Agustini, V., Tanjung, R. H. R., & Sufaati, S. (2019). Arbuscular mycorrhizal fungi (AMF) associated with *Durio zibethinus* L. in Manokwari Regency, West Papua, Indonesia. *Jurnal Pemuliaan Tanaman Hutan* 13(2), 61-69. <https://doi.org/10.20886/jpth.2020.13.2.61-69>.
- Syamsiar, S. (2017). Effect of shading and mycorrhizal inoculants on growth of cacao seedlings on red and yellow podzolic soil andosol agroland. *Journal of Agricultural Sciences* 22, 188-196.
- Tran, T. T. D. (2012). *Research on the symbiosis of Arbuscular Mycorrhizal fungi on maize (Zea mays L.) in Southern East region of Vietnam* (Unpublished doctoral dissertation). Nong Lam University, Ho Chi Minh City, Vietnam.