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A Root Structure Architecture (Rsa) Study On Eggplant (*Solanum melongena* L.) Inoculated With Arbuscular Mycorrhizal Fungi (AMF) Biofertilizer

Mikee Louissa G. Yañez[1], Diana P. Paguntalan[1*]
[1]Division of Biological Sciences, College of Arts and Sciences
University of the Philippines Visayas, Miagao, Iloilo, Philippines
*Email: dppaguntalan@up.edu.ph

ABSTRACT. *Solanum melongena* L. is among the most economically valued horticultural crops globally. In the Philippines, the annual production of this staple crop increases continually. However, several biotic and abiotic factors deteriorate its overall growth and productivity. Recently, the use of sustainable biofertilizers such as arbuscular mycorrhizal fungi (AMF) is gaining interest because of their beneficial impacts on overall plant productivity. One way of examining plant productivity is through root structure architecture (RSA) assessment. Hence, this study aimed to investigate the effects of AMF on the RSA of eggplants to supplement valuable data on its beneficial effects as a biofertilizer. Seedlings were inoculated with four treatment conditions AMF + vermicompost (AMF + V), AMF alone (AMF), NPK fertilizer (NPK), and native soil (C) followed by RSA assessment Results showed that treatments AMF + V and AMF alone significantly promoted lateral root branching. Furthermore, the total diameter and surface area showed a significant increase under treatment AMF + V. Overall, the mycorrhizal-root association presented enhancement towards eggplant RSA which strongly establishes the efficacy of AMF as a promising solution in promoting sustainable agriculture.

Keywords : *Solanum melongena, arbuscular mycorrhizal fungi, root structure architecture, root colonization, biofertilizer*

INTRODUCTION

Eggplant *(Solanum melongena* L.*)* also called aubergine or brinjal belongs to the Solanaceae family along with other horticultural crops such as tomatoes and potatoes. It is considered a staple crop in Southeast Asian countries wherein China and India record the first and second largest eggplant productions worldwide, respectively. Records also showed that Asian nations produced an unprecedented amount of eggplant, accounting for 94% of the global eggplant area (Bhatti et al., 2013; International Service for the Acquisition of Agri-biotech Applications, 2022). In the Philippines, eggplant is locally known as '*talong'* and it is among the most popular vegetable crop (Chupungco et al., 2011). The annual production of eggplant in the country covers an average area of 21, 225 hectares (ISAAA, 2022).

However, several biological agents such as bacteria, fungi, and pests as well as abiotic stresses including drought and salinity are major constraints affecting crop yield and production (Sharma et al., 2021; Alabdallah & Alluqmani, 2022). One known causative agent of eggplant infestation is the root-knot nematode (RKN) resulting in stunted growth that could lead to reduced crop yield and even plant death (Sharma et al., 2021). Furthermore, increased levels of water shortage associated with drought have been pointed out to cause a decline in fruit yield of eggplants by up to 40% whereas increased salinity levels can alter interactive processes such as enzyme activity that can also lead to crop yield loss (Alabdallah & Alluqmani, 2002). To mitigate the detrimental effects of such stresses, farmers resort to high chemical-input agriculture which is an environmentally detrimental measure. Chemical fertilizers and agrochemicals are primarily utilized for improving plant growth and yield but it has been emphasized that the rising dependency of farming practices on these chemicals poses a great toll on soil productivity, ecosystem and human health, and agricultural sustainability (Kuila & Ghosh, 2022). In line with this, modern studies sought meaningful approaches toward the establishment of alternative biofertilizers with maximum benefits for the growth and development capacities of crops while reducing the harmful effects of chemical farming to uphold sustainable agriculture. Several formulations of biofertilizers had employed the utilization of beneficial microbes particularly arbuscular mycorrhizal fungi (AMF) which are known to yield high-quality plants through rhizosphere colonization. AMF are obligate symbionts that are known for their outstanding symbiotic relationship with plant roots (Lohman et al., 2018). The mutually beneficial association of fungi and plants allow the former to survive by colonizing the root of the latter in return for its improved nutrient and water. It emphasizes that assessment of the root structure architecture (RSA) is highly correlated with the establishment of plant-fungal symbiosis. The RSA permits a closer inspection of the impacts of AMF on the root morphology of a host plant by deliberating the trends of several root parameters along this symbiotic relationship (Caruso et al., 2021).

The beneficial effects of AMF inoculation have already been well established in agronomic crops (Bernaola et al., 2018) and it is comparable to the limited research done in horticultural crops. Eggplants and other horticultural crops serve economic importance and hold significant value in the agricultural industry of the Philippines demanding the need for research and development for its maximum yield and production. Furthermore, studies conducted related to this field had generally focused on the assessment of shoot growth parameters of plants as the main standpoint in evaluating the performance of the plant-mycorrhizal association. All of these imply that extended research in this field is necessary. Accordingly, studies must be aimed at assessing the symbiotic relationship between AMF and horticultural crops from the perspective of root growth parameters. Such growth assessment of the plant root system in horticultural crops would help in the amplification of established beneficial effects of AMF inoculation seen in the overall growth and yield of studied agronomic crops. Hence, the data of this study would have a valuable contribution in undermining the beneficial effects underlying the symbiotic relationship between mycorrhizal colonization and plant root growth parameters of eggplants that would be substantial in boosting their harvest yields.

This study was conducted to establish a system of AMF inoculation in *S. melongena* L. as a biofertilizer for improving plant growth and development of horticultural crops. Through the observed root growth parameters, this study will contribute a new perspective in assessing the beneficial effects of AMF biofertilizers in eggplants and agricultural plants, in general. Furthermore, it will provide pieces of evidence supporting that enhanced RSA could indicate healthy plant growth and that application of AMF biofertilizer could help maximize such development. Finally, other common horticultural crops in the Philippines will essentially benefit from the findings of this research as it aims to provide significant data that can help promote sustainable agriculture.

This study generally examined the effects of AMF inoculation on selected root growth parameters in *S. melongena* L. grown in a greenhouse set-up experiment. The objectives were to analyze the root structure architecture of eggplant seedlings through root system parameters (presence of lateral roots, root length, root total diameter, and root surface area), and compute the percentage of root colonization in AMF-inoculated eggplant seedlings to provide a supplemental data that can be utilized to promote sustainable eggplant farming in the Philippines.

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MATERIALS AND METHODS

Source of AMF. The commercial AMF MYKOVAM® is a multispecies soil-based biological fertilizer comprising 12 species sourced from stressed environmental conditions (Elleva et al., 2018). This product includes chopped roots and spores from AMF which belong to the genera *Glomus*, *Gigaspora*, *Entrophospora*, and *Acaulospora* (Aguilar et al., 2018). This commercially available product was utilized as a source of mycorrhizal fungi in this experiment.

Experimental Design. This study implemented a complete randomized design to arrange the eggplant seedlings. There were four different treatment conditions with 5 replicates each namely: AMF and vermicompost (AMF + V), AMF alone (AMF), NPK fertilizer only, and native soil only (C).

Seed germination and treatment preparations. The seeds of *S. melongena* were collected from eggplant farms in Bgy. Oyungan, Miagao, Iloilo. Seeds were sown in a 5x10 holes seedling tray with hole dimensions of 4.8x4.8 cm and outer dimensions of 28x54 cm that is filled with soil and commercial substrate. At DAS (days after sowing)14, the selection of germinating seeds subject to transplant and treatment was conducted. The criteria for selection was based on the number of leaves and plant height wherein those having 4 to 6 leaves (Tomazelli et al., 2022) and similar heights were selected as s for treatment inoculations. The selected germinating seeds were transplanted into 18x16 cm plastic pots filled with different treatment conditions: (1) with AMF + vermicompost (AMF + V), (2) with AMF only (AMF), (3) with NPK fertilizer only (NPK) and (4) native soil only (control) (C). For the incorporation of treatment conditions, the AMF + V treatment contained 5 g of AMF, 400 g of vermicompost, and 600 g of native soil; the AMF treatment contained 5 g of AMF and 1000 g of native soil; the NPK treatment contained 1000 g of native soil and a tablespoon of NPK, and finally, the control or C contained 1000 g of purely native soil. A total of 20 pots were comprising the 4 treatment conditions with five replicates each.

Monitoring and plant care. Seedlings were monitored daily in terms of growth. Germinating seeds were sprinkled with a uniform amount of water (50 ml) enough to keep them moist, once a day or every other day depending on the amount of heat and sun exposure they received. Significant observable changes only in the shoot system such as the number and emergence of leaves, daily increment in stem height, and onset of flowering were recorded and photographed.

Preparation of samples before measurements. At DAS 60, root samples were collected from each treatment pot. For collection, the plastic pots were ripped off to keep the roots and substrates in place which helped avoid damaging the root structure or system. Then, the aboveground part of the plant and its root system were carefully washed with distilled water to remove the substrate completely. For storage and preservation, roots were wrapped with newspaper and were put in a zip lock with proper labels until usage. Stored roots were placed in the refrigerator at a pre-set temperature.

Measuring the RSA. At DAS 60, the effects of treatment conditions on root structure architecture were analyzed. Specifically, significant analyses focused on the presence of lateral root orders, root length (cm), root total diameter (mm), root surface area (cm2), root dry weight (mg), and root colonization (%). Ten root segments per pot (30 root segments) per treatment were selected. For the percentage root colonization, 2 root segments per pot were examined.

Identifying the lateral root. The presence of lateral roots was assessed following the methods of Suralta et al. (2010) and De Bauw et al. (2020). Lateral roots were identified either as L-type (higher order branching roots) or S-type (non-branching roots) (Suralta et al., 2010). Furthermore, L-type laterals were generally longer and thicker compared to S-type (De Bauw et al., 2020). The identification of lateral root type was done morphologically.

Measuring the root length. In measuring the primary root length, only the region of the primary root until its root tip was accounted which was then quantified through direct measurements indicated by Bohm (1979). In measuring the length of root segments, only 10 root segments were randomly collected from each replicate per treatment. First, the selected root segment was placed in a flat glass dish containing an amount of distilled water enough to wet the root sample. The overlapping roots were straightened with the aid of forceps and were held by a glass plate. Finally, the total root length (cm) was measured manually using a transparent ruler through eye inspection or with the aid of magnifying glass.

Measuring the total diameter. The total diameter was measured following the methods of Bohm (1979). The root samples were washed with distilled water and air-dried before measurement. The selected root segments were measured using a compound light microscope with a calibrated ocular micrometer.

Measuring the surface area.

The measurement of root surface area was calculated with a direct method utilizing the data of root length and total diameter. The product of root length, average diameter, and π determine the root surface area (Tagliavini et al., 1993). This also applies to the direct method of measurement reviewed by Bohm (1979) wherein the average diameter of a large number of individual roots, and total root length per sample were utilized for calculation.

$$Root\ surface\ area = root\ length\ \times average\ diameter\ \times \pi$$

Measuring root colonization. For root colonization, roots were cleared and stained first following the protocol of Philips and Hayman (1970). Roots were washed with tap water until sediments were removed. Then, roots were placed in a test tube and submerged in 50% ethyl alcohol solution for a minute and were rinsed with tap water afterward. Roots were then heated while being submerged in 10% KOH for several minutes until roots became soft and translucent. Roots were rinsed with tap water again and bleached using hydrogen peroxide followed by acidification using 2% hydrogen chloride for about 30 seconds. Excess HCl was discarded and without rinsing, roots were stained with methylene blue for 30 minutes. Finally, stained roots were mounted in 10% glycerol and viewed under a dissecting microscope for manual counting of arbuscules and vesicles present in the selected root segments. The percentage of root colonization was obtained using the following formula:

$$\%\ Root\ colonization = \frac{number\ of\ root\ segments\ colonized}{total\ number\ of\ root\ segments} \times 100$$

Data Analyses. All measurements were performed three times to ensure accuracy and consistency. The normality and homogeneity of variance assumptions were not satisfied, therefore ANOVA and the post-hoc Duncan’s Multiple Range Test could not be utilized in the analysis. Hence, a non-parametric version of ANOVA or the Kruskal-Wallis test was performed, and the median ± standard errors were evaluated by the non-parametric post-hoc Dunn-Bonferroni approach by using SPSS version 22.0 (SPSS Inc., Chicago, IL, USA). The A p-value of < 0.05 was considered as it is suggested as statistically significant (Wei et. al 2020).

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RESULTS AND DISCUSSION

Analysis of the RSA of *S. melongena* in the pot experiment

Based on morphological observations in the shoot system, AMF-inoculated eggplants (AMF + V and AMF) showed apparent visual differences in their shoot growth. Potted eggplants treated with AMF had grown taller as compared to the shorter NPK-treated eggplants and the control group. Similarly, the leaf area of AMF + V and AMF only were generally larger and wider based on eye inspection. It was also observed that the leaves sprouted earlier compared to the two treatment groups. The stems also of AMF-inoculated pots appeared longer and wider.

Figure 1. Shoot system of *Solanum melongena* under four different treatment conditions in a greenhouse setup (left to right: AMF + V, AMF, NPK, and C).

The root system in Figure 2 showed variable differences based on morphological observations. For instance, the thickness of root segments in treatments AMF + V, AMF only, and NPK was apparent compared with the slightly thin root segments of the control group. In contrast, the length of the primary nodal root in treatment groups AMF + V and AMF only was relatively shorter compared to the primary nodal root observed in NPK and C groups which could be directly attributed to the prominent coiling and bending of the nodal roots. Specifically, the NPK-treated eggplants exhibited the longest primary nodal root with an average of 107 cm whereas AMF + V and AMF had only 70 cm and 90 cm, respectively. Moreover, the C group had the shortest average length of primary nodal root with an average of 47 cm. However, despite the relatively shorter primary nodal root length observed in eggplants treated with AMF + V and AMF, these groups manifested thicker nodal root diameters and more numerous seminal and lateral roots among other treatments.

Figure 2. The root system of *Solanum melongena* under four different treatment conditions AMF + V (A), AMF (B), NPK (C), and Control (D).

Presence of lateral roots

The results in Table 1 show that among the 120 root segments measured (100%), 48 among those constituted the L-type roots (40%) whereas the other 72 constituted the S-root types (60%). Specifically, the AMF + V contributed the highest proportion of overall L-type roots making up 39.6% across all treatments. As can be seen in Figure 3, the presence of L-type root segments is significantly numerous in this treatment group. Furthermore, the same treatment group has the lowest proportion of S-root type, making up 15.3% across all treatments. The treatment group AMF only had the second highest proportion of L-root type, making up 22.9% across all treatments. It also had the second lowest proportion of S-root type, making up 26.4% across all treatments. NPK and Control groups had the least proportion of L-type roots, making up 18.8% across all treatments, but in terms of S-root

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type, they had the highest proportion, making up 29.2% across all treatments. These S-type root segments were shown in Figure 3.

Table 1. Presence of L-type and S-type roots.

Treatments	Root Types				
		L		S	
	Total Count of Root Segments	Count	Percentage within root type (%)	Count	Percentage within root type (%)
AMF + V	30	19	39.6	11	15.3
AMF	30	11	22.9	19	26.4
NPK	30	9	18.8	21	29.2
C	30	9	18.8	21	29.2
TOTAL	120	48		72	

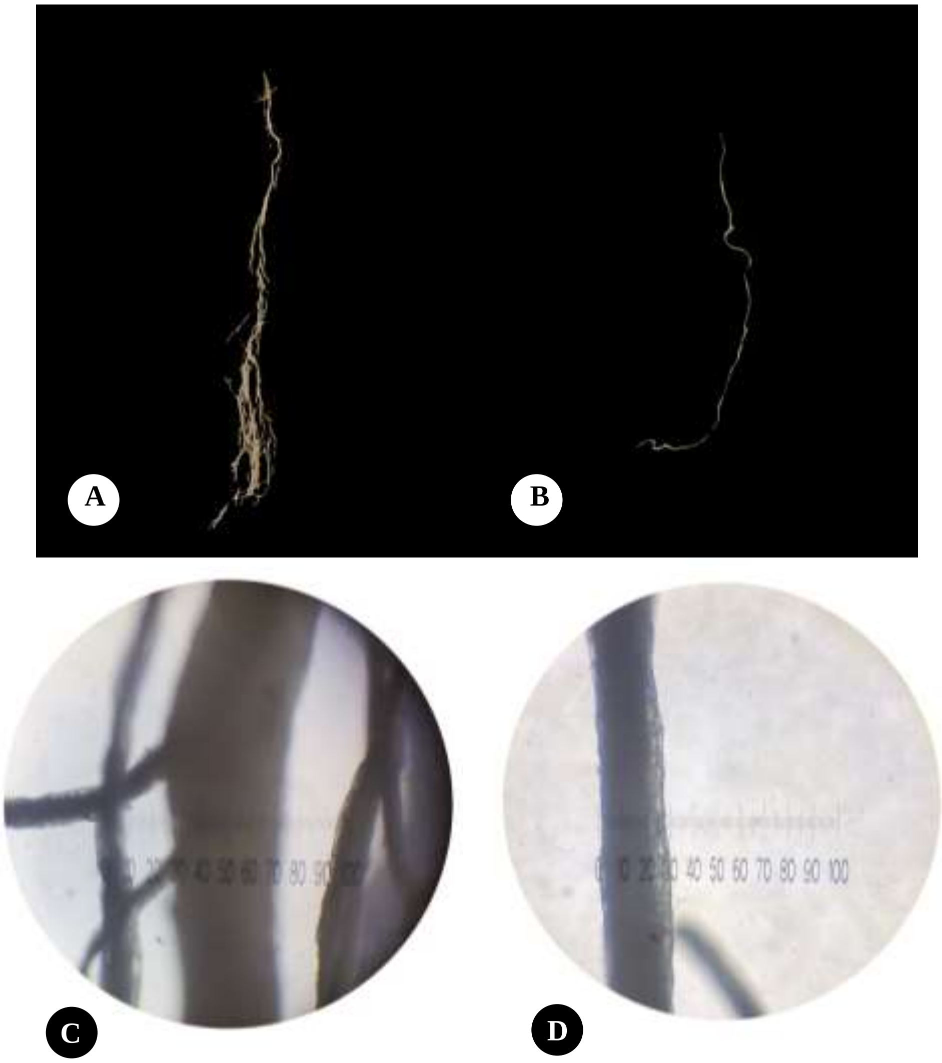

Figure 3. Morphological (A) and microscopic pictures (100x total magnification) (C) of L-root type segment under treatment AMF + V and morphological (B) and microscopic pictures (100x total magnification) (D) of S-root type segment under Control group.

Evaluation of selected RSA parameters

The result in Table 2 shows that only the RSA parameters diameter (mm) and surface area differ significantly in terms of treatment (p-value<0.05). This implies that there were differences in the effect of the four treatment types on the diameter and surface area of the eggplant roots. Specifically, the diameter of eggplants treated with AMF + V (0.715) and AMF only (0.620) showed a significant difference in the diameter among the treatments. Such significant differences were also observed in treatments AMF + V (15.344) and AMF only (14.858) towards the promotion of root surface area. With this, only these RSA parameters were subjected to the post-hoc Dunn-Bonferroni approach to determine the treatment types that differ from each other because other parameters did not yield a significant p-value.

Table 2. Kruskal-Wallis Test results on length (cm), diameter (mm), lateral root, and surface area.

Treatments	Root Length (cm)	P-value	Diameter (mm)	P-value	Surface Area	P-value	Lateral Root	P-value
AMF + V	6.350[a]	0.094	0.715[a]	0.000	15.344[a]	0.012	12.000[a]	0.248
AMF	7.650[a]		0.620[a]		14.858[ab]		10.000[a]	
NPK	6.950[a]		0.475[b]		11.348[b]		9.000[a]	
Control	8.600[a]		0.415[b]		11.494[b]		11.000[a]	

**values with the same letter are not significantly different with each other*

Post-Hoc test Dunn-Bonferroni approach for total diameter and surface area

Figure 4 shows that treatment AMF + V had the highest median rating of 0.715 for diameter which is an implication that of all the treatment types, this treatment group was the most effective in increasing root diameter. The treatment AMF followed this with a diameter median rating of 0.620. The NPK and C group had a close median value of 0.415 and 0.475, respectively. Results also showed that the effects of AMF + V and AMF on increasing root diameter are significantly different. Moreover, Figure 5 shows that treatment AMF + V had the highest median rating of 15.3435 for the surface area which is an implication that of all the treatment types, this treatment group was the most effective in increasing root surface area. The treatment AMF followed this with a diameter median rating of 9.8429. The NPK and C group had a close median value of 11.4938 and 11.3482, respectively. Results also showed that the effects of AMF + V towards increasing root diameter are significantly different from the effects of NPK and C group whereas the AMF alone is significantly different among all treatments.

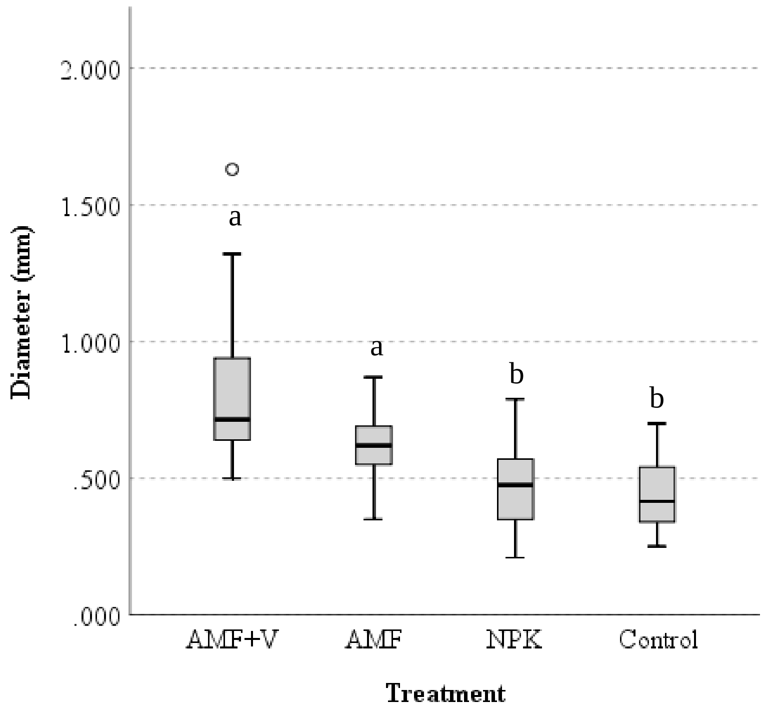

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Figure 4. Boxplot for median ratings of diameter in all four treatment conditions.

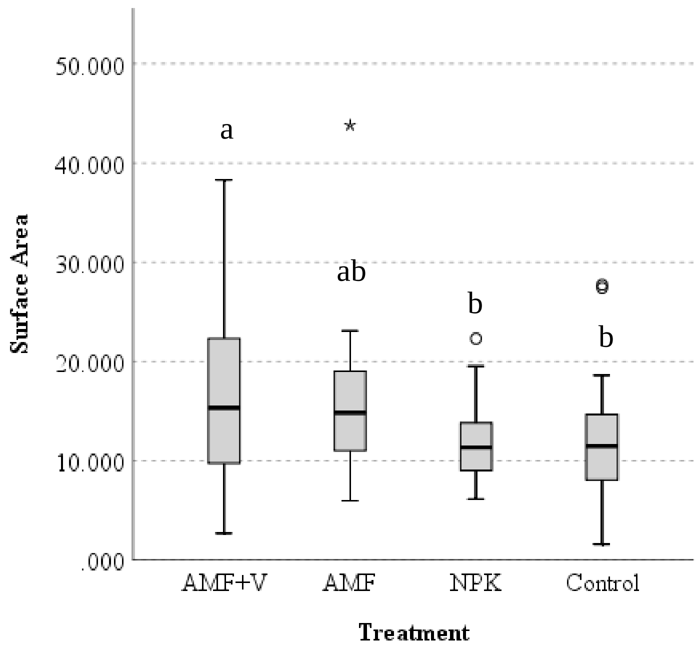

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Figure 5. Boxplot for median ratings of surface area in all four treatment conditions.

Table 3 shows that the Kruskal-Wallis test provided strong evidence ($p<0.001$) of a difference between the median ratings of at least one pair of groups in terms of diameter. Dunn's pairwise tests were carried out for the six pairs of groups. There was strong evidence ($p=0.002$, $p<0.001$, Bonferroni correction adjustment) of a difference between the treatments NPK and AMF, NPK and AMF + V, C and AMF, and C and AMF + V. There was no evidence of a difference between the other pairs.

Table 3. Pairwise comparisons of the four treatment types using the Dunn-Bonferroni approach on the RSA parameter diameter (mm) and surface area.

Pairwise comparisons (treatment 1- treatment 2)	**p-values**	
	Diameter (mm)	**Surface Area**
NPK - Control	1.000	1.000
NPK - AMF	<0.001*	0.210
NPK - AMF+V	<0.001*	0.046*
Control - AMF	0.002*	0.216
Control - AMF+V	<0.001*	0.048*
AMF - AMF+V	0.079	1.000

**values with significant difference (p<0.05).*

The table also shows that the Kruskal-Wallis test provided strong evidence ($p=0.012$) of a difference between the median ranks of at least one pair of groups in terms of surface area. Dunn's pairwise tests were carried out for the four pairs of groups. There was evidence ($p=0.066$, $p=0.068$,) of a difference found between the treatment types NPK and AMF + V, and C and AMF + V. There was no evidence of a difference between the other pairs.

Percentage of root colonization in AMF-inoculated *S. melongena*

Figure 6 shows the presence of arbuscules, fungal hyphae, and vesicles in the root segments of *S. melongena* treated with AMF biofertilizer which provides a strong indication of established mycorrhizal colonization in the eggplant roots. Specifically, the treatment group AMF + V showed a greater percentage of root colonization of 73.65%. Furthermore, this treatment group exhibited a countable presence of fungal hyphae. Moreover, these structures were also observed in the root segments obtained from *S. melongena* treated with AMF only. However, the rate of colonization in this group is relatively lower at only 55.10%. Vesicles were also found present in the same treatment group.

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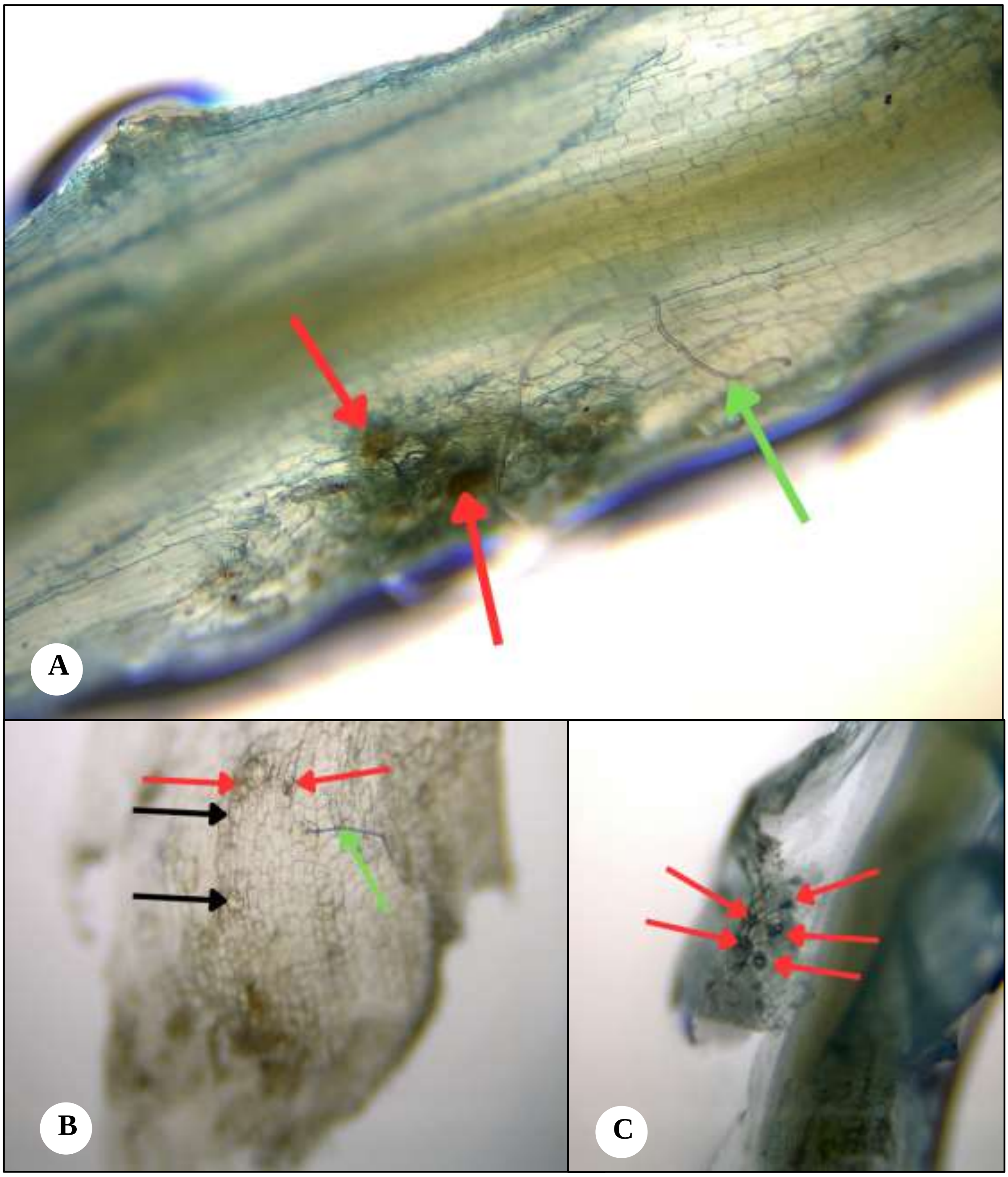

Figure 6. Microscopic pictures (400x total magnification) of arbuscules (red arrow), fungal hyphae (green arrow), and vesicles (black arrow) observed in root segments of *Solanum melongena* treated with AMF + V.

Discussion

It has been reported that the Philippine annual production of *S. melongena* falls at a rate of 0.2% as recorded from the total production increase of 240.90 thousand metric tons in 2017 to 244.03 thousand metric tons in 2021 (Philippine Statistics Authority, 2023). Several infestations and poor growth quality remain bottlenecks to the robust production of eggplants locally. Currently, AMF is gaining increased attention as a substitute biofertilizer that could aid well in the overall growth and development of several crops around the world. In this way, crop yield and production would essentially benefit as well. In this study, the AMF was evaluated through the growth enhancements it induced in the RSA of eggplants as means of validating the established efficacy of AMF. The data obtained in this study highly suggests its potential as a biofertilizer in crop farming, especially in eggplant farming.

The cross-tabulation of root types provides complementary knowledge to the established association of AMF in promoting root branching to its host plant which aids in better nutrient uptake and water acquisition (Wu et al., 2013; Hashem et al., 2016; Jabborova et al., 2021). In this study, the highest percentage of L-root types and consequently, the lowest percentage of S-root types obtained from eggplants treated with AMF + V (Table 1) holds strong evidence for the promotion of lateral root branching. Furthermore, the abundance of S-root type recorded from the root systems of eggplants in the NPK group and C group suggests that these treatments could promote relatively minimal root branching. It has been described that L-root types contribute to the length and thickness of the root system (De Bauw et al., 2020) whereas S-type roots account for simple or nonbranching roots (Suralta et al., 2010). The presence of lateral roots shows a positive correlation with the observable branching and thickness of the root segments. Such evidence is also consistent with the strong significance of higher-order lateral roots in extending the coverage of the root system which has an advantage in reaching the nutrient and water reservoirs in the vicinity (Wu & Guo, 2014).

Among the RSA parameters examined, the data gathered were significant ($p<0.05$) to confirm the responsiveness of the root diameter and surface area towards the inoculation of AMF. Accordingly, researchers of related studies have confirmed that increased morphological traits in inoculated eggplants allow these plants to develop coarse RSA compared to uninoculated plants (Caruso et al., 2021). Thus, increased diameter and surface area strongly account for the apparent relatively coarser and denser root system of the AMF + V group as can be observed in Figure 2. Improved RSA parameters have been studied to confer advantageous qualities on plants that would aid in performing various biological mechanisms that enable them to withstand destructive environmental conditions (Caruso et al., 2021). Furthermore, a study had shown that positive alterations induced by mycorrhizal treatment on root parameters like total diameter could be highly correlated with the modified nutritional status of plants (Yao et al., 2009) suggesting that scrutiny on this biological aspect could delineate the induced enhancements of AMF obtained in this study. However, in terms of root length the data for AMF + V and AMF only were statistically insignificant. The primary nodal root of AMF-treated groups were observed to follow a bending growth compared to the linear nodal roots of NPK and C groups which partly accounts for their relatively low median rating. This result parallels the observable curling and/or bending of plant root hairs stimulated by AMF as a product of its interactions and other microorganisms in the soil (Goss et al., 2017). Such interactions are essential in allowing these microorganisms to establish themselves in the root system of host plants to aid in their metabolite exchanges (i.e., nitrogen fixation) (Goss et al., 2017).

The observable presence of arbuscules, fungal hyphae, and vesicles as shown in Figure 6 showed a successful establishment of mycorrhizal root colonization. Accordingly, the results of this study demonstrated that mycorrhizal colonization is well-established in the root system of eggplants with treatments AMF + V and AMF alone. This advancement is possibly attributed to the synergistic effect produced by AMF and vermicompost by which a study has communicated that the presence of organic substrates makes the supply of carbon and other nutrients sufficient and readily available permitting accelerated root colonization (Ghani et al., 2022). However, there is no sufficient data in this study that could correlate the abundance of arbuscules in AMF + V as an indication that its application has more efficacy

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over the application of AMF alone towards promoting root mycorrhizal colonization. According to the results obtained, the root colonization rate between these two treatment groups is essentially the same (p-value>0.05). Nonetheless, the current data of this study is sufficient to claim that the performance of AMF to establish root colonization was successful and independent of the treatment incorporation whether as single (AMF alone) or dual treatment (AMF and other conditions or treatments). Still, thorough examination and further investigation are deemed necessary in this aspect following a study that revealed that synergistic effect in dual treatments gives more efficacy in overall plant growth (Ghani et al., 2022). Apart from the arbuscules observed, growths of fungal hyphae and vesicles have been observed. These structures were deemed to have an active involvement in the storage and upregulation in the transport of major nutrients such as phosphorus (P) and nitrogen (N) of the roots (Kuila & Ghosh, 2022). More specifically, the proliferation of fungal hyphae owes a capacity for the plant root system to contact areas beyond its normal reach (Kuila & Ghosh, 2022).

CONCLUSION

The findings of this study provided an important basis that AMF, as a sustainable biofertilizer, is effective in enhancing the RSA parameters of *S. melongena*. The morphological changes observed in the RSA parameters of eggplants were highly indicative of the ability of this mycorrhizal biofertilizer to affect major benefits to its overall growth and development. Specifically, the abundance of lateral root branching in AMF-inoculated eggplants could enhance the water uptake of the host plant equipping it with better adaptive qualities in withstanding common farming stresses such as massive drought. Moreover, the significant promotions in diameter and surface area of the roots are a major contribution to the overall improvement of nutrient absorption of its host plant through varying mechanisms. Finally, the high colonization rate entailed in the AMF and vermicompost implies a synergistic effect on the overall plant performance by making nutrients, especially carbon, accessible and readily available for uptake.

Recommendation

This study promotes the use of AMF as a sustainable biofertilizer over the chemical or NPK fertilizer. Generally, the researcher recommends further studies aimed at exploring beneficial effects associated with the use of AMF that would optimize its use in the field of agricultural industry. Further assessment and evaluation of other RSA parameters such as lateral root unit using ranking the presence of higher-order roots would help in specifying the degree or intensity of lateral branching induced by the AMF in the root system. Also, the use of digital software intended for measuring RSA parameters will provide substantial grounds for comparison and verification of the measurements done manually.

REFERENCES

Aguilar, E., Elleva, L. I. F., Garcia, G. R., Fabro, D. M. A., Divina, F. A., II, & Aggangan, N. (2018). Arbuscular mycorrhizal fungi increased root-mycorrhizal association and enhanced seedling growth of abaca, papaya, and sugarcane. *Journal of the International Society for Southeast Asian Agricultural Sciences*, *24*(2), 22–

29. http://issaasphil.org/wp-content/uploads/2019/01/3.-AGUILAR-et-al-2018-Seedling-Inoculam-Mycovam-FINAL.pdf

Alabdallah, N. M., & Alluqmani, S. M. (2022). The synthesis of polysaccharide crude nanoparticles extracts from Taif rose petals and its effect on eggplant seedlings under drought and salt stress. *Journal of King Saud University - Science*, *34*(5), 102055. https://doi.org/10.1016/j.jksus.2022.102055

Bernaola, L., Cosme, M., Schneider, R. W., & Stout, M. (2018). Belowground inoculation with arbuscular mycorrhizal fungi increases the local and systemic susceptibility of rice plants to different pest organisms. *Frontiers in Plant Science*, *9*. https://doi.org/10.3389/fpls.2018.00747

Bhatti, K. H., Kausar, N., Rashid, U., Hussain, K., Nawaz, K., & Siddiqi, E. H. (2013). Effects of biotic stresses on egg plant (*Solanum melongena L.*). *World Applied Sciences Journal*, *26*(3), 302–311. https://doi.org/10.5829/idosi.wasj.2013.26.03.13460

Böhm, W. (1979). Root parameters and their measurement. *Methods of Studying Root Systems*, 125–138. https://doi.org/10.1007/978-3-642-67282-8_12

Caruso, T., Mafrica, R., Bruno, M., Vescio, R., & Sorgonà, A. (2021). Root architectural traits of rooted cuttings of two fig cultivars: Treatments with arbuscular mycorrhizal fungi formulation. *Scientia Horticulturae*, *283*, 110083. https://doi.org/10.1016/j.scienta.2021.110083

Chupungco, A. R., Elazegui, D. D., & Nguyen, M. R. (2011). Seed system, production, and marketing of eggplant in three major producing provinces in the Philippines. *Philippine Journal of Crop Science*, *36*(2), 37–47. https://www.cabi.org/gara/mobile/FullTextPDF/2011/20113312474.pdf

De Bauw, P., Ramarolahy, J. A., Senthilkumar, K., Rakotoson, T., Merckx, R., Smolders, E., Van Houtvinck, R., & Vandamme, E. (2020). Phenotyping root architecture of soil-gown rice: A robust protocol combining manual practices with image-based analyses. *Cold Spring Harbor Laboratory*. https://doi.org/10.1101/2020.05.13.088369

Elleva, L. I. F., Garcia, G. R., Divina, F. A., II, Fabro, D. M. A., Aguilar, E. A., & Agangan, N. S. (2018). Response of MYKOVAM treated *Lakatan* banana plantlets to water deficit. *Philippine Journal of Crop Science*, *43*(2), 56–62. https://www.cabi.org/gara/FullTextPDF/2018/20183300826.pdf

Ghani, M. F. A., Ali, A. T., Atif, M., Ali, M., Amin, B., & Cheng, Z. (2022). arbuscular mycorrhizal fungi and dry raw garlic stalk amendment alleviate continuous monocropping growth and photosynthetic declines in eggplant by bolstering its antioxidant system and accumulation of osmolytes and secondary metabolites. *Frontiers in Plant Science*, *13*. https://doi.org/10.3389/fpls.2022.849521

Goss, M. J., Carvalho, M. A. P. V., & Brito, I. M. (2017). Impacts on host plants of interactions between AMF and other soil organisms in the rhizosphere. *Functional Diversity of Mycorrhiza and Sustainable Agriculture.* https://doi.org/10.1016/b978-0-12-804244-1.00005-8

Hashem, A., Abd_Allah, E. F., Alqarawi, A. A., Al-Huqail, A. A., & Shah, M. A. (2016). Induction of osmoregulation and modulation of salt stress in *Acacia gerrardii* Benth. by arbuscular mycorrhizal fungi and *Bacillus subtilis* (BERA 71). *BioMed Research International*, *2016*, 1–11. https://doi.org/10.1155/2016/6294098

International Service for the Acquisition of Agri-biotech Applications. (2022). *Bt Eggplant*. ISAAA.org. https://www.isaaa.org/resources/publications/pocketk/48/default.asp

Jabborova, D., Kannepalli, A., Davranov, K., Narimanov, A. A., Enakiev, Y. I., Syed, A., Elgorban, A. M., Bahkali, A. H., Wirth, S., Sayyed, R. Z., & Gafur, A. (2021). Co-inoculation of rhizobacteria promotes growth, yield, and nutrient contents in soybean and improves soil enzymes and nutrients under drought conditions. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-01337-9

Kuila, D., & Ghosh, S. (2022). Aspects, problems and utilization of Arbuscular Mycorrhizal (AM) application as bio-fertilizer in sustainable agriculture. *Current Research in Microbial Sciences*, *3*, 100107. https://doi.org/10.1016/j.crmicr.2022.100107

Lohman, M., Ziegler-Ulsh, C., & Douds, D. (2018, November 12). *How to Inoculate Arbuscular Mycorrhizal Fungi on the Farm, Part 1*. Rodale Institute. https://rodaleinstitute.org/science/articles/how-to-innoculate-arbuscular-mycorrhizal-fungi-on-the-farm-part-1/

Philippine Statistics Authority. (2023). *2017-2021 Crops Statistics of the Philippines* (ISSN-2021-0487). https://psa.gov.ph/sites/default/files/Crops%20Statistics%20of%20the%20Philippines%2C%202017-2021.pdf

Phillips, J. L., & 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-IN18. https://doi.org/10.1016/s0007-1536(70)80110-3

Sharma, M., Saini, I., Kaushik, P., Aldawsari, M. S., Balawi, T. A., & Alam, P. (2021). Mycorrhizal fungi and *Pseudomonas fluorescens* application reduces root-knot nematode *(Meloidogyne javanica)* infestation in eggplant. *Saudi Journal of Biological Sciences*, *28*(7), 3685–3691. https://doi.org/10.1016/j.sjbs.2021.05.054

Suralta, R. R., Inukai, Y., & Yamauchi, A. (2010). Dry matter production in relation to root plastic development, oxygen transport, and water uptake of rice under transient soil moisture stresses. *Plant and Soil*, *332*(1–2), 87–104. https://doi.org/10.1007/s11104-009-0275-8

Tagliavini, M., Veto, L., & Looney, N. (1993). Measuring root surface area and mean root diameter of peach seedlings by digital image analysis. *HortScience*, *28*(11), 1129–1130. https://doi.org/10.21273/hortsci.28.11.1129

Tomazelli, D. (2022, April 20). *Inoculation of Arbuscular Mycorrhizal Fungi Improves Growth and Photosynthesis of Ilex paraguariensis (St. Hil) Seedlings*. https://www.scielo.br/j/babt/a/PGVqknMdCLbD5cTSN9QVwtC/?lang=en

Wei, M., Zhang, M., Huang, G., Yuan, Y., Fu, C., & Yu, L. (2020). Coculture with two *Bacillus velezensis* strains enhances the growth of *Anoectochilus* plants via promoting nutrient assimilation and regulating rhizosphere microbial community. *Industrial Crops and Products*, *154*, 112697. https://doi.org/10.1016/j.indcrop.2020.112697

Wu, J., & Guo, Y. (2014). An integrated method for quantifying root architecture of field-grown maize. *Annals of Botany*, *114*(4), 841–851. https://doi.org/10.1093/aob/mcu009

Wu, Q., Srivastava, A. K., & Zou, Y. (2013). AMF-induced tolerance to drought stress in citrus: A review. *Scientia Horticulturae*, *164*, 77–87. https://doi.org/10.1016/j.scienta.2013.09.010

Yao, Q., Wang, L., Zhu, H., & Chen, J. C. (2009). Effect of arbuscular mycorrhizal fungal inoculation on root system architecture of trifoliate orange (*Poncirus trifoliata* L. Raf.) seedlings. *Scientia Horticulturae*, *121*(4), 458–461. https://doi.org/10.1016/j.scienta.2009.03.013