Fungal Genomics & Biology
ISSN: 2165-8056
OPEN ACCESS Freely available online
Research Article

Native Arbuscular Mycorrhizal Fungi Improves Growth and Quality of Exotic *Swietenia Macrophylla* King Seedlings in Nursery

R. Ajeesh[1], N. K. Binu[1*], A.V. Santhosh kumar[1], S. Gopal[1]

[1]*College of Forestry, Kerala Agricultural University, Thrissur, Kerala, India*

ABSTRACT

Aim: Exotic tree species to get established outside their place of origin have to form new associations with the local Arbuscular Mycorrhizal Fungi (AMF) species that are sufficient to compensate the gap that the native AM fungal symbionts provide to them in their place of origin. The present study throws some aspects on the efficacy of three native species of AMF on growth and seedling quality of *Swietenia macrophylla*, an exotic to peninsular India.

Methods: Polybag raised seedlings were inoculated with (*Funelliformis mosseae*, *Rhizophagus intraradices*, *Rhizophagus proliferus*) at different levels (10, 20 and 50 g inoculum per seedling).

Results: Among the AMF species, seedlings treated with *Funelliformis mosseae* showed improved growth. The physiological parameters of these seedlings were also good. The Mycorrhizal Efficiency Index (MEI) of seedlings inoculated with *Funelliformis mosseae* was 58.28%. Root colonization (35.33%) and total pore count was also found to be higher for this mycorrhizal symbiosis. The experiment showed that mycorrhizal association also helped to reduce the nursery period of the inoculated seedlings.

Conclusions: It was demonstrated that the native AM fungal community can be efficiently used for improving the growth and nutrient status of AM-inoculated mahogany seedlings. *Funneliformis mosseae* proved to be one such native species of AMF. It also contributed to the increase in the physiological aspects of the mahogany seedlings. If properly managed, the nursery time of the seedlings can be substantially reduced which can bring down the cost of production to a greater extent.

Keywords: Arbuscular mycorrhizal fungi; *Swietenia macrophylla*; *Funelliformis mosseae*; *Rhizophagus intraradices*; *Rhizophagus proliferus*; Tree physiology

INTRODUCTION

Arbuscular Mycorrhizal Fungi (AMF), a group of obligate bio trophic fungi belonging to the Phylum Glomeromycota, are among the oldest fungi in terrestrial systems on earth. The symbiotic relationship of these fungi with plants which appeared 400-460 million years ago is assumed to have played an essential role in the establishment of pre-vascular plants on the land [1,2]. Around 230 morphospecies of these fungi has been identified and described [3]. Symbiotic associations of AMF and plant roots are widespread in the natural environment and can provide a range of benefits to the host plant. Its presence can significantly increase root surface area by the production of extensive hyphae, increase transpiration, reduce leaf temperature and restrain the decomposition of chlorophyll [4]. This helps in improved nutrition absorption, especially phosphorus, enhanced resistance to soil-borne pests and disease, improved resistance to drought, tolerance to heavy metals and better soil structure [5-7]. The AMF host obtains maximum benefit when the mineral nutrient regime is least favorable for growth [8]. In turn, plants direct four per cent to 20 percent of photo assimilate to mycorrhizas [9]. Hyphae work as conduits that transport carbon from plant roots to other soil organisms involved in nutrient cycling processes. Though the AMF association can offer multiple benefits to the host plant, it may not be mutualistic at all points in time and it is possible under some conditions, host plants lose C with no apparent benefit, sometimes resulting in the decline in plant growth [10]. Hence appropriate selection of the AMF species and standardization of application is crucial.

Mahogany (*Swietenia marcophylla* King.) is one of the most

Correspondence to: N. K. Binu, College of Forestry, Kerala Agricultural University, Thrissur, Kerala, India, E-mail: binu.nk@kau.in

Received: 02-Dec-2023, Manuscript No. FGB-23-28275; **Editor assigned:** 04-Dec-2023, Pre QC No. FGB-23-28275 (PQ); **Reviewed:** 18-Dec-2023, QC No. FGB-23-28275; **Revised:** 26-Dec-2023, Manuscript No FGB-23-28275 (R); **Published:** 03-Jan-2024, DOI: 10.35248/2165-8056.23.13.235

Citation: Ajeesh R, Binu N.K, Santosh kumar A.V, Gopal S (2023) Native Arbuscular Mycorrhizal Fungi Improves Growth and Quality of Exotic *Swietenia Macrophylla* King Seedlings in Nursery. Fungal Genom Biol. 13.235

important tree species that is widely used for raising plantations and afforestation in the tropics [11]. Recent years have seen a higher demand for this species motivating the farmers to grow this species in homesteads of tropical areas like peninsular India [12,13]. However, being an exotic tree, the species do have limitations in the absence of pre-adaptation strategies, which includes an ideal AMF partner to tide over the stress factors in the new locality. The success of exotic plantations also depends on the use of potential microbiological inoculants. This is more pronounced in the nursery stages, where the goal is to produce high quality seedlings. Studies have shown that exotic plant species commonly form symbioses with AMF in low host specificity that in turn improves water and nutrient uptake and increases the invasion success [14,15]. In many tree seedlings, the inoculation of AMF was found beneficial resulting in seedlings of higher quality [16,17]. The high percentage of root colonization in AMF treated seedlings is found to be directly correlated with improved growth and physiology. Despite these, AMF is an unexploited potential bio-fertilizer in forest nurseries that can be utilized for quality tree seedling production.

Evolving appropriate nursery management strategies to enhance productivity and thereby reducing the long nursery period has remained a basic challenge for successful exotic species establishment. The use of AMF in the nursery has been a boon to forest nursery managers in the context of producing quality seedlings cost effectively. Being exotic in India, mahogany seedlings are poorly studied about their physiological responses to AMF applications. A preliminary screening of the suitability of some of the native strains of AMF on this important exotic tree species was found to enhance the stress tolerance levels in the nursery. The present study has been designed to assess the symbiotic efficiency of selected native strains of AMF on the growth and quality of *Swietenia macrophylla* seedlings. The hypothesis to be tested was that different strains of native AMF at varying inoculation strengths help in the establishment of the seedlings and also how it influences the quality of seedlings in the nursery.

MATERIALS AND METHODS

The present investigation was conducted in a nursery at the College of Forestry (COF), Kerala Agricultural University, Vellanikkara, Thrissur, Kerala during the period 2013 to 2015 (10°32'N latitude and 76°26'E longitude). The area experiences a warm and humid climate with distinct rainy seasons and a total rainfall of 3000 mm.

The experiment was laid out as a 32 factorial Completely Randomized Design (CRD) with the three species of AMF *viz*., *Funneliformes mosseae, Rhizophagus intraradices* and *R. proliferus* as the first factor and three levels of inoculation *viz*., 10 g, 25 g and 50 g of inoculum as the second factor. The three AMF strains were selected after a preliminary screening experiment to select the most suitable species for the local edaphic conditions. The experiment had nine treatment combinations, each of which was replicated five times with 30 seedlings per replication. A separate set of materials without inoculation served as the control.

Vermi-paste (1000 spores in 100 g) containing pure cultures of these native species were obtained from The Energy Research Institute, New Delhi (TERI) and stored in refrigerated condition. Mass multiplication of the AMF was done in grow bags filled with autoclaved soil as a medium and *Zea mays* as a host. The plants were irrigated daily using sterile water. Each plant was supplied with 50 ml of hoagland's solution at an interval of 10 days [18]. The maize roots were checked for colonization frequently [19]. The shoot portion of the maize was removed when the root colonization was more than 80 per cent and the soil containing the roots were thoroughly mixed to obtain inoculum and stored in 4°C for inoculating the seedlings. The spore count obtained at this stage was 10 per g of soil. The mahogany seeds were collected locally from good mother trees. Mature mahogany pods were collected from the tree and kept in shade for after-ripening. The seeds were dewinged and treated with 100 ppm Benzyl Adenine (BA) for 12 hours before sowing. The pretreated mahogany seeds were surface sterilized (0.01 per cent sodium hypo-chloride for 10 min), washed in sterile water and sown in sterilized sand in trays. The trays were irrigated daily to ensure moisture for the seeds to germinate.

Potting media containing soil (sieved in 0.5 mm mesh) and sand mixture (1:1) was sterilized by solarization (8 days) and fumigation with 0.5 per cent formaldehyde for 20 days. The potting media was kept in open and then mixed repeatedly to remove the formaldehyde residues. The fumigated mixture was then transferred to the greenhouse and polythene bags (11.43 × 15.24 cm, gauge 75 micron) were filled with potting media, leaving 4 cm space at the top. The inoculums of the three different mycorrhizae at three different concentrations as per the treatments were placed in polybags (Table 1). These were covered with 1:1 homogenous mixture of sterile soil and sand up to 2 cm. Thirty days old seedlings obtained from the sand beds were transplanted to these polybags and maintained under open condition. These seedlings were arranged in three blocks of 30 seedlings each and grown in open condition throughout the experimental period and irrigated well.

Observations were taken after 150 days of inoculation of seedlings with AMF. For the seedling height and collar diameter 12 plants per replication were taken. Another set of 12 seedlings were destructively sampled simultaneously to determine root measurements, biometric and growth observations. The vigour index I and vigour Index II, quality index and bio-volume index were also estimated at the end of the study period [20]. Chlorophyll content (SPAD-502, Minolta), photosynthetic and transpiration rate (LI-6400, LICOR Inc., Nebraska), the pre-dawn water potential (Scholanders pressure bomb, Plant Moisture Stress (PMS) instruments, Oregon) and Relative Water Content (RWC) of seedlings were measured.

The percentage AMF colonization in the root samples of different treatments at the end of the study was determined following the procedure of. The extrametrical chlamydospores produced by the AMF were estimated following the wet sieving and decanting technique [21]. Mycorrhizal use Efficiency Index (MEI) or mycorrhizal dependency allows assessment of the growth improvement produced by inoculation of plants with a mycorrhizal fungus. MEI were estimated for the seedlings from all the treatments [22].

The data were subjected to One-Way Analysis of Variance (ANOVA) using R-agricolae package [23]. Based on the outcome of ANOVA on all data, posthoc analysis was performed to separate the means.

RESULTS

There were significant differences in the growth, physiology and quality of mahogany seedlings produced due to inoculations (Table 1-4). For all the biometric characters, except the leaf area, the inoculated seedlings showed a significant difference when compared to the un-inoculated seedlings. Among the inoculated seedlings those treated with *Funneliformis mosseae* showed the best performance for all

the characters. The different concentrations of the mycorrhizae tried in this experiment did not show any significant difference for any of the growth characters of the seedlings. Inoculating the seedlings with AMF also influenced the growth parameters of the seedlings. Vigour index 1 and 2, were higher for the seedlings treated with *Funneliformis mosseae*. The interaction effect was also found to be significant for vigour index 1, vigour index 2 and relative growth rate. The relative growth rate was highest for the combination *Funneliformis mosseae* at 25 g. The net assimilation rate was highest for the seedlings when the combination was *Rhizopahagus proliferus* at 25 g. The values for all the other combinations were at par. The physiology of mahogany seedlings, influenced by different treatments, were also studied (Table 2). The photosynthesis rate was significantly different for inoculated seedlings when compared to the un-inoculated seedlings of mahogany. The photosynthesis rate of the seedlings inoculated with the two species of *Rhizophagus* was at par and it was observed that the values (5.87 µ mol CO_2 m^{-2} s^{-1}) were higher when compared for the seedlings treated with *Funneliformis mosseae* (3.96 µ mol CO_2 m^{-2} s^{-1}). The difference in the concentration of the mycorrhizal treatment did not influence the photosynthetic rate. No significant difference in stomatal conductance and rate of transpiration was observed between different AMF treatments, however, the un-inoculated seedlings showed higher values for both stomatal conductance (0.93 mol H_2O m^{-2} s^{-1}) and rate of transpiration (1.61µmol H_2O m^{-2} s^{-1}), when compared to the inoculated seedlings. The AMF × concentration interaction had a significant influence on the stomatal conductance and rate of transpiration of the seedlings. The stomatal conductance and the rate of transpiration were significantly higher for all the treatment combination except for the seedlings treated with Funneliformes mosseae at 10 g, the lowest value obtained were (0.01 mol H_2O m^{-2} s^{-1}) and (1.48 61 µ mol H_2O m^{-2} s^{-1}) respectively for stomatal conductance and rate of transpiration. The seedlings treated with *Funneliformis mosseae* showed the lowest leaf temperature (30.42°C). It was also observed that the seedlings treated with different concentrations of AMF showed a significant difference in the leaf temperature. Seedlings inoculated with 10 g of AMF showed the lowest value (30.74°C) when compared to other treatments. The AMF × concentration interaction effect was not significant. inoculated with different species of chlorophyll content of the seedlings AMF did not vary significantly. However, the different concentrations of AMF had a significant effect on the chlorophyll content of the seedlings. The highest value 51.03 and 49.26 (Soil Plant Analysis Development (SPAD) units), were observed when the concentrations of AMF were 25 g and 50 g respectively. The AMF × concentration interaction effect was not significant. The plant water potential of the seedlings inoculated with different species of AMF did not vary significantly, whereas the concentrations of AMF had a significant effect on the plant water potential of the seedlings. The highest plant water potential (0.57 megapascal) was observed for the seedlings when the concentrations of AMF were 50 g, whereas the plant water potential of the seedlings for the other two concentrations was at par. The AMF × concentration interaction effect was not significant for the treatments compared. The relative water content of the seedlings treated with different AMF showed significant differences with the species of the AMF. The seedlings treated with *Funneliformis mosseae* showed the highest relative content (72.32 %) when compared to other AMF species. Similarly, it was observed that the relative water content of the seedlings increased as the concentration of the AMF increased. However, the AMF × concentration interaction effect was not significant for various treatments that were compared. The root colonization percent of mahogany seedlings as influenced by different mycorrhizal treatments revealed that the AMF and concentration effect on the seedlings were significant (Table 3). The total spore content and colonization percentage were highest for the seedlings treated with *Funneliformis mosseae*. The effect of the concentration on both the total spore count and colonization was found to have a linear relationship. The interaction effect was also found to be significant. The total spore count of the soil and colonization percentage was highest for the treatment combination of the AMF *Funneliformis mosseae* at 50 g. The lowest spore count was observed for the treatment combination *Rhizophagus sp*. at 10 g concentration. The difference in the quality of the seedlings subjected to different mycorrhizal treatments (Table 4). The result showed that the bio-volume of the seedlings treated with *Funneliformis mosseae* was the highest. For the other two *Rhizophagus sp*. the value for the bio-volume was at par. The mycorrhizal efficiency index of the seedlings treated with *Funneliformis mosseae* too was the highest. For the other two *Rhizophagus* sp. the value for the mycorrhizal efficiency index was again at par. The concentration of the AMF did not show any significant difference for the bio-volume index, quality index and mycorrhizal efficiency index. The AMF × concentration interaction was significant for the bio-volume index, quality index and mycorrhizal efficiency index. The highest bio-volume was observed for the treatment combination *Rhizophagus intraradices* at 10 g and the lowest value was observed for the treatment combination *Rhizophagus proliferus* at 10 g. The lowest value for the quality index of the seedlings was observed for the combination *Rhizophagus intraradices* at 10 g. The mycorrhizal efficiency index of the seedlings was at par for the seedlings treated with *Funneliformis mosseae* irrespective of the concentration level and for the treatment combination *Rhizophagus intraradices* at 10 g and *Rhizophagus proliferus* at 50 g.

Table 1: Effect of different Arbuscular Mycorrhizal Fungi (AMF) treatments on the biometric and growth parameters of *Swietenia macrophylla* seedlings.

	Treatments	Shoot height (cm)	Collar diameter (mm)	Leaf area (cm^2)	Shoot dry weight (g)	Root Dry weight (g)	Shoot-root biomass ratio	Vigour index 1	Vigour index 2	Relative growth rate
Arbuscular mycorrhizal fungi	*Funneliformis mosseae*	42.61	6.92	410.16	3.88	2.56	3.12	9.13	1.5	55.2
	Rhizophagus intraradices	34.92	6.28	289.2	3.01	2.33	2.32	6.77	1.48	45.5
	Rhizophagus proliferus	30.8	5.86	474.35	2.28	2.6	2.5	7.15	1.41	48.32
Concentration	10 gm	37.81	6.38	351.3	3.42	2.43	2.73	7.89	1.5	50.93
	25 gm	35.03	6.15	334.24	2.62	2.39	2.38	6.64	1.45	48.33
	50 gm	35.49	6.53	488.17	3.13	2.67	2.83	8.52	1.44	49.76

Control	22.00*	5.50*	120.44	1.15	2.09*	1.16*	35.40*	3.65*	1.38*
SEM	2.19	0.34	90.07	0.48	0.32	0.43	2.04	0.99	0.03
LSD	4.41	0.68	181.04	0.97	0.64	0.86	4.1	1.99	0.05
df	20	20	20	20	20	20	20	20	20

Note: (*): With control indicate significant differences between AMF inoculated seedlings; SEM: Scanning Electron Microscopy; LSD: Lysergic Acid Diethylamine; df: Degrees of Freedom applicable only to the AMF treatments.

Table 2: Effect of different treatments on the physiology of *Swietenia macrophylla* seedling.

Treatments		Chlorophyll (SPAD units)	Photosynthesis (µmol CO_2 m^{-2} s^{-1})	Transpiration (µmol H_2O m^{-2} s^{-1})	Leaf temperature (°C)	Stomatal conductance (mol H_2O m^{-2} s^{-1})	Relative water content (%)	Plant water potential (Mpa)
Main effects								
Arbuscular mycorrhizal fungi	*Funneliformis mosseae*	46.33	3.96	1.08	30.42	0.07	72.32	0.49
	Rhizophagus intraradices	50.51	5.87	1.4	30.99	0.08	71.08	0.5
	Rhizophagus proliferus	46.03	5.12	1.24	31.46	0.07	70.54	0.52
Concentration	10 gm	42.59	4.32	1.04	30.74	0.06	67.7	0.46
	25 gm	51.03	4.82	1.26	30.9	0.08	72.22	0.48
	50 gm	49.26	5.81	1.43	31.22	0.08	74.02	0.57
Control		34.63*	7.45*	1.61*	31.63*	0.93*	63.80*	0.42*
SEM		1.99	0.68	0.23	0.05	0.02	2.6	0.03
LSD		3.99	1.37	0.45	0.1	0.03	5.23	0.06

Note: (*): With control indicate significant differences between Arbuscular Mycorrhizal Fungi (AMF) inoculated seedlings; SEM: Scanning Electron Microscopy; LSD: Lysergic Acid Diethylamine; df: Degrees of Freedom applicable only to the AMF treatments.

Table 3: Effect of different treatments on the root colonization percentage of *Swietenia macrophylla* seedling.

Treatments		Total spore count	Colonization percentage
Main effects			
Arbuscular mycorrhizal fungi	*Funneliformis mosseae*	85.44	35.33
	Rhizophagus intraradices	62.33	34.11
	Rhizophagus proliferus	48.11	24.78
Concentration	10 gm	39.56	20.44
	25 gm	60.78	29.78
	50 gm	95.56	44
Scanning electron microscopy		3.38	1.79
Lysergic acid diethylamine		6.79	3.59
Degrees of freedom		20	20

Table 4: Effect of different treatments on the quality indices of *Swietenia macrophylla* seedling.

Treatments		Bio-volume index	Quality index	Mycorrhizal efficiency index
Main effects				
Arbuscular mycorrhizal fungi	*Funneliformis mosseae*	298.2	0.774	58.28
	Rhizophagus intraradices	228.1	0.682	29.65
	Rhizophagus proliferus	184.1	0.734	39.62
Concentration	10 gm	250.8	0.723	44.33
	25 gm	222.3	0.694	35.44
	50 gm	237.3	0.772	47.78
Control		121.16*	0.703*	0.00*
SEM		26.18	0.05	9.87
LSD		52.61	0.1	19.84
df		20	20	20

Note: (*): With control indicate significant differences between Arbuscular Mycorrhizal Fungi (AMF) inoculated seedlings; SEM: Scanning Electron Microscopy; LSD: Lysergic Acid Diethylamine; df: Degrees of Freedom applicable only to the AMF treatments.

DISCUSSION

Raising exotic tropical tree seedlings particularly for the plantations is still challenging and knowledge on the interaction of AMF with the nursery substrate appears to be an important step for AMF-dependent tree species like mahogany. The knowledge on the AMF specificity for a beneficial interaction is necessary for the early establishment and growth of mahogany seedlings. However, concerning the use of native or non-native AMF as inoculum it is argued that besides the higher costs involved, the application of commercially available AMF inoculum is not favorable when compared to the local inoculum production and application for reforestation. The main arguments are that when inoculated seedlings with non-native fungi are planted into the field, exotic fungi often have difficulty in establishing within the pre-existing fungal community and if they do establish, they may become fast spreading invaders out-competing the local fungal community as reviewed [24]. A study has shown that local fungi were found to be finally more effective in colonization [25]. In the Southern part of India, studies have shown that the predominant genus of AMF is *Rhizophagus, Funelliformis* [26,27]. This was the reason behind the selection of this native AMF species in this experiment. Three native species of AMF (*Funneliformis mosseae, Rhizopahagus intraradices* and *Rhizopahagus proliferus*) were selected at different levels (10, 25 and 50 g inoculum per seedling). The data shows that exotic mahogany seedlings are a mycorrhizal dependent species as the results show that inoculated seedlings performed better than the uninoculated seedlings. Besides this, however, it is revealed that they preferred the mycorrhizae as shown by the difference in their response to the difference in mycorrhizal species and quantity of the inoculum used in the experiment (Table 1-4). Many other studies also indicated clear colonization of vesicles and arbuscules in the secondary roots of seedling and mahogany trees in natural areas, in young plantations [28,29]. It is reported that about twenty-three AMF species belonging to genera *Acaulospora, Glomus, Gigaspora* and *Rhizophagus* were found to have a symbiosis with mahogany trees growing in its natural habitat. Mahogany plants grown in the presence of AMF showed a general increase in plant growth parameters like plant height, stem girth, leaf area and total dry weight as against those grown in soils uninoculated with AMF. The seedlings inoculated with *Funneliformis mosseae* responded better for all the growth characters of the seedlings. One of the reasons for this may be since besides higher photosynthetic rate the plant water status of the seedlings treated with *Funneliformis mosseae* was at a higher level as exemplified with high values for the relative water content and lower leaf temperature.

Higher water potential of AMF inoculated plants would help to increase photosynthetic assimilation and in turn meet the carbon demands of the AMF as reported [30]. It is also documented that the symbiosis with AMF also helps the plants through improvement in absorption of soil water in addition to the nutrient absorption and enhancing the conductivity of roots and regulating the concentration of cellular osmolytes [31,32]. Thus, it can be concluded that physiologically these seedlings were sound. A similar result was observed for inoculated mahogany seedlings under stressed conditions in the nursery. Studies on *Tectona grandis, Azadirachta indica, Acacia mangium, Anacardium occidentale* and *Santalum album* also confirmed our results [33-35]. There are many reports on the host preference among AMF [36]. Several authors have also stressed the need for selecting efficient AMF strains that can be used for inoculating different mycotrophic plants [37,38]. There are many reports, where indigenous AMF were found to be ineffective or less effective when compared with exotics [39,40]. For example, unsuitable AMF did not affect the growth of sandal seedlings. So, it becomes inevitable to select the best performing mycorrhizae for the establishment of exotic like mahogany. The present investigation indicated that the photosynthetic rate of the seedlings inoculated with both the species of *Rhizophagus* were higher when compared to the *Funneliformis mosseae* inoculated seedlings, but this was not transformed to the increased growth of the plants and thus the quality of seedlings was not good compared to those treated with *Funneliformis mosseae*. This might be due to the utilization of the photosynthate for the maintenance respiration and also for higher root respiration. Higher root respiration resulting in the loss of the photosynthate was observed for *Plantago major* for AMF inoculated seedlings [41]. There may be another possibility that the carbon flux out of the plant in

the plant-AMF continuum was more for this particular mycorrhizal association resulting in the higher energetic cost of the symbiosis that can be high enough to cause growth decrease in mycorrhizal plants [42,43]. A positive dose response relation was not observed for the growth characters of the mahogany as it is usually observed with other species. However, a positive relation was observed for some of the physiological characteristics of the seedlings such as chlorophyll content, leaf temperature, water potential and relative water content and for the parameters like total spore count and the colonization percentage. This positive linear relation is usually attributed to better colonization of the rhizosphere by the introduced microorganisms and increased plant protection [44,45].

Some detrimental effects on root growth were also observed with high inoculation doses [46]. The critical level of spores for the mycorrhizal inoculation to cause an increase in the plant height, dry matter yield, root length and per cent root infection in *Prosopis cineraria* seedling was found to be 400 germinable spores per polybag (1 kg soil) [47]. In *Tecomella undulata* the best dose of AMF for better seedling performance was found to be 100 g rhizosphere soil (500 germinable spores) [48].

Further, seedlings raised in the presence of *F. mosseae* showed a greater bio-volume index, quality index and mycorrhizal efficiency index compared to all other treatments and this increase was to an extent of 146.00 per cent, 10 per cent and 58 per cent, respectively, over those uninoculated seedlings. Such high values of bio-volume index and quality index indicate a sturdier stem and a proportionate top dry weight compared to the seedling dry weight, qualities which are desirable among nursery seedlings. The positive growth effect seen in the nursery can be significantly used to improve the tree survival and field establishment of mahogany seedlings as demonstrated earlier for other species like *Acacia koa, Eucalyptus tereticornis, Ceratonia siliqua.*

Inoculating with AMF improved the physiology of seedlings (Table 2). The high percentage of root colonization in AMF treated plants is directly correlated with better nutrient uptake, increased total chlorophyll content, an increase in the rate of photosynthesis and transpiration [49-51]. The difference in photosynthetic rate could probably be due to excessive starch accumulation in leaves of seedlings inoculated with AMF. This observation was further strengthened by the present study as mycorrhizal fungi used in this study significantly improved the chlorophyll content and photosynthesis of soil compared to the uninoculated treatment (Table 2).

The interaction effect was more pronounced for the combination *R. intraradices* at 10 g. For this combination, the plant height and collar diameter were higher when compared to all other combinations. The total photosynthetic area expressed as the leaf area was significantly higher in plants with this combination. This increased leaf area and growth of the seedlings colonized by this specific combination of the mycorrhizae and doses have probably resulted in significantly higher biomass observed compared to other treatments. The enhancement in growth and physiology is also related to the higher mycorrhizal efficiency index (Table 4). The growth of mahogany seedlings was significantly high for the parameters leaf area ratio and leaf weight ratio. Further, seedlings raised in the presence of *R. intraradices* at 10 g inoculum showed a greater bio volume index, quality index and mycorrhizal index.

CONCLUSION

The current study demonstrates that the AMF specificity for a beneficial interaction is necessary for the early establishment and growth of mahogany seedlings. Furthermore, it was demonstrated that the native AM fungal community can be efficiently used for improving the growth and nutrient status of AM-inoculated mahogany seedlings. *Funneliformis mosseae* proved to be one such native species of AMF that has conferred maximum growth benefits compared to other fungi. It also contributed to the increase in the physiological aspects of the mahogany seedlings. If properly managed, the nursery time of the seedlings can be substantially reduced which can bring down the cost of production to a greater extent.

ACKNOWLEDGEMENT

The authors wish to acknowledge the research grant by Kerala Agricultural University for the conduct of the research work.

REFERENCES

1. Simon L, Bousquet J, Lévesque RC, Lalonde M. Origin and diversification of endomycorrhizal fungi and coincidence with vascular land plants. Nature. 1993;363(6424):67-69.
2. Remy W, Taylor TN, Hass H, Kerp H. Four hundred-million-year-old vesicular arbuscular mycorrhizae. Proc Natl Acad Sci. 1994;91(25):11841-11843.
3. Schubler A. Glomeromycota; link Taxonomy.2013
4. Abbaspour H, Saeidi-Sar S, Afshari H, Abdel-Wahhab MA. Tolerance of mycorrhiza infected *pistachio (Pistacia vera L.)* seedling to drought stress under glasshouse conditions. J Plant Physiol. 2012;169(7):704-709.
5. Shoulders E, editor. Proceedings of the Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, 1984. The Station; 1985.
6. Miller MH. Arbuscular mycorrhizae and the phosphorus nutrition of maize: A review of Guelph studies. Can J Plant Sci. 2000;80(1):47-52.
7. Gosling P, Hodge A, Goodlass G, Bending GD. Arbuscular mycorrhizal fungi and organic farming. Agric Ecosyst Environ. 2006;113(1-4):17-35.
8. Ezawa T, Smith SE, Smith FA. P metabolism and transport in AM fungi. Plant Soil. 2002;244:221-230.
9. Ruissen T. Arbuscular mycorrhizal fungi and their ecological roles: a review with a Norwegian perspective. Agarica. 2013;33:105-116.
10. Lerat S, Lapointe L, Piché Y, Vierheilig H. Variable carbon-sink strength of different *Glomus mosseae* strains colonizing barley roots. Canad J Bot. 2003;81(8):886-889.
11. Rodríguez-Morelos VH, Soto-Estrada A, Pérez-Moreno J, Franco-Ramírez A, Díaz-Rivera P. Arbuscular mycorrhizal fungi associated with the rhizosphere of seedlings and mature trees of *Swietenia macrophylla* (Magnoliophyta: Meliaceae) in Los Tuxtlas, Veracruz, Mexico. Rev Chil de Hist Nat. 2014;87(1):1-10.
12. da Silva GR, de Jesus Matos Viegas I, da Silva Júnior ML, Gama MA, Okumura RS, Frazão DA et al. Growth and mineral nutrition of mahogany ('*Swietenia macrophylla*') seedlings subjected to lime in yellow alic latosol. Aust J Crop Sci. 2017;11(10):1297-1303.
13. Rajan SK, Reddy BJ, Bagyaraj DJ. Screening of arbuscular mycorrhizal fungi for their symbiotic efficiency with *Tectona grandis*. For Ecol Manag. 2000;126(2):91-95.
14. Shah MA, Reshi ZA, Khasa D. Arbuscular mycorrhizal status of some Kashmir Himalayan alien invasive plants. Mycorrhiza. 2009;20(1):67-72.

15. Smith SE, Read D. Growth and carbon economy of arbuscular mycorrhizal symbionts. Mycorrhizal symbiosis. 2008:117-144.

16. Dutt S, Sharma SD, Kumar P. Arbuscular mycorrhizas and Zn fertilization modify growth and physiological behavior of apricot (*Prunus armeniaca L.*). Sci Hortic. 2013;155:97-104.

17. Binu NK, Ashokan PK, Balasundaran M. Influence of different arbuscular mycorrhizal fungi and shade on growth of sandal (*Santalum album*) seedlings. J Trop For Sci. 2015:158-165.

18. Hoagland DR, Arnon DI. The water-culture method for growing plants without soil. Calif Agric. 1950;347(2nd edit).

19. Phillips JM, Hayman DS. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Trans Br mycol. 1970;55(1):158-IN18.

20. Kharb RS, Lather BS, Deswal DP. Prediction of field emergence through heritability and genetic advance of vigour parameters. Seed Sci Technol. 1994;22(3):461-466.

21. Gerdemann JW, Nicolson TH. Spores of mycorrhizal endogone species extracted from soil by wet sieving and decanting. Trans Br mycol. 1963;46(2):235-244.

22. Secilia J, Bagyaraj DJ. Evaluation and first-year field testing of efficient vesicular arbuscular mycorrhizal fungi for inoculation of wetland rice seedlings. World J Microbiol Biotechnol. 1994;10(4):381-384.

23. Mendiburu FD. Agricolae: statistical procedures for agricultural research. 2019.

24. Schwartz MW, Hoeksema JD, Gehring CA, Johnson NC, Klironomos JN, Abbott LK, et al. The promise and the potential consequences of the global transport of mycorrhizal fungal inoculum. Ecol Lett. 2006;9(5):501-515.

25. Allen MF, Allen EB, Gómez-Pompa A. Effects of mycorrhizae and nontarget organisms on restoration of a seasonal tropical forest in *Quintana Roo*, Mexico: factors limiting tree establishment. Restor Ecol. 2005;13(2):325-333.

26. Harikumar VS, Potty VP. Diversity patterns of endomycorrhizal association with sweet potato in Kerala. J Mycol Pl Pathol. 1999;29(2):197-200.

27. Gopal KS, Sally KM, Kumar AN, Binimol KS. Identification of arbuscular mycorrhizal fungi from rhizosphere soils of solanaceous crops in bacterial wilt areas of Kerala. J Veg Sci. 2005;32:65-68.

28. Herrera RA, Ferrer RL. Vesicular-arbuscular mycorrhiza in Cuba. Mycorrhiza. 1980:156-162.

29. Noldt G, Bauch J. Colonization of fine roots of mahogany (*Swietenia macrophylla King*) by vesicular-arbuscular mycorrhizal fungi under plantation conditions in Central Amazon. J Appl.Bot. 2001;75(3-4):168-172.

30. Poorter H, Remkes C, Lambers H. Carbon and nitrogen economy of 24 wild species differing in relative growth rate. Plant physiol. 1990;94(2):621-627.

31. Augé RM. Arbuscular mycorrhizae and soil/plant water relations. Can J Soil Sci. 2004;84(4):373-381.

32. Aroca R, Vernieri P, Ruiz-Lozano JM. Mycorrhizal and non-mycorrhizal *Lactuca sativa* plants exhibit contrasting responses to exogenous ABA during drought stress and recovery. J Exp Bot. 2008;59(8):2029-2041.

33. Sumana DA, Bagyaraj DJ. Growth stimulation of *Dalbergia sissoo* by selected VA mycorrhizal fungi. Impact of diseases and insect pests in tropical forests. Kerala Forest Research Institute Publication, Peechi. 1996:246-251.

34. Ghosh S, Verma NK. Growth and mycorrhizal dependency of *Acacia mangium Willd.* inoculated with three vesicular arbuscular mycorrhizal fungi in lateritic soil. New For. 2006;31:75-81.

35. Ananthakrishnan G, Ravikumar R, Girija S, Ganapathi A. Selection of efficient arbuscular mycorrhizal fungi in the rhizosphere of cashew and their application in the cashew nursery. Sci Hortic. 2004;100(1-4):369-375.

36. Wu QS, Li GH, Zou YN. Roles of arbuscular mycorrhizal fungi on growth and nutrient acquisition of peach (*Prunus persica L. Batsch*) seedlings. J Anim Plant Sci. 2011;21(4):746-750.

37. Jeffries P, Rhodes LH. Use of mycorrhizae in agriculture. Crit. Rev. Biotechnol. 1987;5(4):319-357.

38. Bagyaraj DJ, Varma A. Interaction between arbuscular mycorrhizal fungi and plants: their importance in sustainable agriculture in arid and semiarid tropics. Microb Ecol. 1995;119-142.

39. Bagyaraj DJ, Reddy MB, Nalini PA. Selection of an efficient inoculant VA mycorrhizal fungus for Leucaena. For Ecol Manag. 1989;27(2):81-58.

40. Reena J, Bagyaraj DJ. Response of *Acacia nilotica* and *Calliandra calothyrsus* to different VA mycorrhizal fungi. Arid Land Res Manag. 1990;4(4):261-268.

41. Baas R, Kuiper D. Effects of vesicular-arbuscular mycorrhizal infection and phosphate on Plantago major *ssp. pleiosperma* in relation to internal cytokinin concentrations. Physiol Plant. 1989;76(2):211-215.

42. Johnson NC, Graham JH, Smith FA. Functioning of mycorrhizal associations along the *mutualism–parasitism continuum*. The New Phytol. 1997;135(4):575-585.

43. Zangaro W, Torezan JM, Rostirola LV, Souza PB, Nogueira MA. Influence of mycorrhizas, organic substrates and container volumes on the growth of *Heliocarpus popayanensis Kunth*. Cerne. 2015;21:395-403.

44. Bull CT, Weller DM, Thomashow LS. Relationship between root colonization and suppression of *Gaeumannomyces graminis var. tritici* by *Pseudomonas fluorescens* strain 2-79. Phytopathology. 1991;81(9):954-959.

45. Raaijmakers JM, Leeman M, Van Oorschot MM, Van der Sluis I, Schippers B, Bakker PA. Dose-response relationships in biological control of Fusarium wilt of radish by *Pseudomonas spp*. Phytopathology. 1995;85(10):1075-1080.

46. Kapulnik Y, Okon Y, Henis Y. Changes in root morphology of wheat caused by *Azospirillum* inoculation. Can J Microbiol. 1985;31(10):881-887.

47. Verma N, Srivastava JT. Standardization of inoculum dose of an am fungus for *prosopis cinerarl*4. Seedlings. Indian J Forest. 2009;32(3):397-400.

48. Srivastava KK, Srivastava HP, Kumar S. Standardization of inoculum dose in *Tecomella undulata* seedlings. Indian J For. 2004;130(11):1316-1318.

49. Reid CP, Kidd FA, Ekwebelam SA. Nitrogen nutrition, photosynthesis and carbon allocation in ectomycorrhizal pine. Mycorrhiza. 1983:415-431.

50. Nylund JE, Unestam T. Ectomycorrhiza in semi-hydroponic scots pine: increased photosynthesis but reduced growth. Mycorrhizae. 1987;3-8.

51. Rajasekaran S, Nagarajan SM. Effect of dual inoculation (AM Fungi and Rhizobium) on chlorophyll content of *Vigna unguiculata (L.) Walp. Var. Pusa* 151. Mycorrhizae. 2005;17(1):10-11.