H&N Publications INTERNATIONAL

ISSN(e): 2789-4231 & ISSN (p): 2789-4223

International Journal for Asian Contemporary Research

www.ijacr.net

Research Article

Open Access

Performance of Different Arbuscular Mycorrhizae Species on The Productivity of Rice Under Field Condition

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Article info

Received: 30 July, 2024
Accepted: 03 September, 2024
Published: 15 September, 2024
Available in online: 15 September, 2024

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A b s t r a c t

This study evaluates the impact of four arbuscular mycorrhizal fungi (AMF) species *Funneliformis mosseae, Rhizophagus irregularis, Claroideoglomus etunicatum*, and *Claroideoglomus claroideum* on the growth and yield of BRRI Dhan 28 rice. Conducted at the Agronomy Field Laboratory, University of Rajshahi, Bangladesh, the experiment utilized sandy loam soil with a pH of 6.8 to 8.6 and was influenced by a subtropical climate. The research employed a randomized complete block design with three replications. Rice plants were subjected to various treatments and grown under standard agronomic practices. Parameters such as plant height, tiller number, chlorophyll content, panicle length, grain number per panicle, 1000-grain weight, and yield metrics were assessed at different growth stages. Statistical analysis using analysis of variance and Duncan's Multiple Range Test evaluated the effects of the AMF treatments. Results demonstrated that *Funneliformis mosseae* consistently outperformed the other AMF species, showing the highest plant height of 89.52 cm at 120 days after transplanting (DAT), the greatest number of tillers per hill at 18.7, and the highest number of effective tillers per hill at 14.62. It also resulted in the highest grain yield of 6.5 tons per hectare and the highest biological yield of 15.21 tons per hectare. *Rhizophagus irregularis* showed significant improvements but was less effective than *Funneliformis mosseae*. *Claroideoglomus etunicatum* and *Claroideoglomus claroideum* provided variable results, with *Claroideoglomus etunicatum* showing reduced grain and straw yields compared to the control. This study highlights the superior benefits of *Funneliformis mosseae* in enhancing rice productivity.

Keywords: Arbuscular Mycorrhizal Fungi, rice, BRRI Dhan 28, chlorophyll content, subtropical climate and agronomy.

Introduction

Arbuscular mycorrhizal fungi (AMF) form a symbiotic relationship with plant roots, enhancing nutrient and water uptake, which can significantly impact crop productivity. This relationship is particularly valuable in sust ainable agriculture, where minimizing chemical inputs while maximizing yield is crucial. Mycorrhizal fungi improve plant growth by extending the root system through their hyphal networks, which increases the soil volume explored for nutrients, particularly phosphorus, and enhances resistance to soil-borne pathogens (Adedayo and Babalola 2023; Bello and Fabiyi 2024; Wahab et al. 2023). Rice (*Oryza sativa* L.) is a staple food for more than half of the global population, making improvements in its productivity a high priority for food security. Additionally, Rice is a cornerstone of Bangladesh's food security, economy, and cultural identity. As the primary staple food, it constitutes around 70% of the population's caloric intake, making its consistent and increased production vital to meeting the nutritional needs of the growing population (Bin Rahman and Zhang 2023). Economically, rice cultivation supports a significant portion of the rural workforce and contributes substantially to the national GDP (Rayhan, Rahman, and Lyu 2023). Despite advances in rice cultivation, the challenge of enhancing yield under varying environmental conditions remains. AMF have shown potential in addressing this challenge by improving nutrient availability and promoting healthier root systems, which can translate into increased rice yield and better crop quality (Deepika, Goswami, and Kothamasi 2023; Iqbal

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et al. 2021; Yang et al. 2024). Previous studies have demonstrated the effectiveness of AMF in various crops, including wheat and maize, by increasing growth parameters and yield components (Slimani et al. 2024). However, the specific impact of different AMF species on rice productivity, particularly under field conditions, requires further investigation. Different AMF species can have varying effects on plant growth and yield, and their efficiency can be influenced by environmental factors and soil conditions (Han et al. 2023; Jia et al. 2023). In Bangladesh, where rice is a primary crop, understanding how different AMF species affect rice productivity can help develop more effective and sustainable agricultural practices. This research aims to evaluate the role of four AMF species—*Funneliformis mosseae, Rhizophagus irregularis, Claroideoglomus etunicatum*, and *Claroideoglomus claroideum* in enhancing rice growth and yield parameters under field conditions. By comparing these AMF species, this study seeks to identify the most effective strains for improving rice production, contributing to the development of sustainable farming practices in rice cultivation.

Materials and Methods

Experimental location and soil: The experimental location was the Agronomy Field Laboratory, Department of Agronomy and Agricultural Extension, University of Rajshahi, Bangladesh. It is located at 24°22′36″N latitude and 88°38′27″ E longitude.The experimental site featured sandy loam textured soil with a pH level of between 6.8 and 8.6.

Table 1. Main feature of BRRI Dhan 28.

Accession no.	Genotypes	Origin	Year of release	Main characteristics	Yield (t/ha)	Maturity (days)
G25	BRRI Dhan 28	BR 601-3-3-4-2-5	1994	Plant height 90 cm, clean rice medium slender and white	5.5- 6.0	140

Source: (Chakma et al. 2012)

Climate: The experimental field was situated within a subtropical climate, distinguished by moderately high temperatures and substantial rainfall throughout the kharif season (November-March). Conversely, during the Rabi season (November to March), the region experienced sparse rainfall coupled with moderately low temperatures.

Experimental host plant: The BRRI Dhan 28 rice variety was used as a rice testing plant. The BRRI Dhan 28, a high yielding rice variety having yield potential of 5.5 to 6.0 t ha-1 was released by National Seed Board (NSB) in 1994 and was developed by Bangladesh Rice Research Institute (BRRI) for commercial cultivation in Boro season (December to February). This variety is popularly known by its life cycle, yield, insects and disease resistance. Although Bangladesh Rice Research Institute (BRRI) has recommended this variety to be grown in Boro season but farmers are cultivating the variety during all three rice growing seasons in Bangladesh successfully. It is resistant to the important disease like blast. The BRRI Dhan 28 is a cross parents of BR6 and Purbachi a Chinese rice variety. Its life cycle is about 140 days. It has medium slender grain. The main feature of BRRI Dhan 28 rice variety is shown in Table 1**.**

Source and specification of collected AMF inocula for this experiment: Four mycorrhizae species were used for wheat plant productivity in the pot experiment. These are *Funneliformis mosseae* (formerly *Glomus mosseae*), *Rhizophagus irregularis* (formerly *Rhizophagus irregularis*), *Claroideoglomus etunicatum, and Claroideoglomus claroideum*. These fungi penetrate cells of the root where they form the characteristic tree-like structured (arbuscular) organs for the exchange of sugars and nutrients with the host plant. Most of them also form bulb-like structures in and between root-cells. From the colonized roots outwards mycelia grow into the ground acting as a kind of extension of the root system. *Funneliformis mosseae*, a local isolate obtained from the rhizosphere of Leucaena leucocephala, maintained as pot culture in sterilized sand: soil (1:1 v/ v) mixture on Rhodes grass (Chloris gayana) was used as the AMF in the present study. The air-dried inoculum contained AM hyphae, spores and root pieces. About 12,500 infective propagules based on the most probable number estimation was added as a layer to the soil 3 cm below the surface before sowing pre-germinated rice seed. All of these species were easily propagated in pot culture in association with different host plants. The other properties of these AMF species are also shown in Table 2.

Table 2. List of isolates used in this study and their origin.

AM Fungus	AMF spores /10 g soil	BEG Code	Local code	Source	Country of Origin
Funneliformis mosseae (formerly Glomus mosseae)	68	BEG 185	HAU B19	B. Zhao	PR China
Rhizophagus irregularis (formerly Rhizophagus irregularis)	105	BEG 145	SAMP7	J.C. Dodd	United Kingdom
Claroideoglomus etunicatum (formerly Glomus etunicatum)	204	BEG137	NPI	J.C. Dodd	United States
Claroideoglomus claroideum (formerly Glomus claroideum)	102	BEG3	PC1014	J.C. Dodd	Denmark

Cultivation techniques: Healthy seeds were soaked for 24 hours, sprouted in darkness, and sown in a prepared seedbed in January 2019. The seedbed was maintained with weeding, irrigation, and pest protection. For transplanting, the field was initially flooded to rot weeds, then ploughed and leveled. The final preparation for transplanting occurred on 26 February 2019, with randomized complete block design (RCBD) with three replications on 15 February. NPK fertilizers (urea, TSP, MP) were applied as recommended by BARI during the growth stage. Seedlings were uprooted and transplanted on 26 February using conventional methods. Intercultural operations included gap filling, manual weeding, herbicide application, flood irrigation, and pest control. Infestations by rice stem borers and green leafhoppers were managed with Furadan and Sumithion. Regular observations ensured the plants grew healthily, showing vigorous tiller growth without lodging. Data were collected from three randomly selected hills per plot at 30-day intervals until harvest. The crop was harvested on 1 June at full maturity. Post-harvest, each plot's crop was bundled, tagged, and threshed separately. The grains and straw were sun-dried, adjusted to 14% moisture, and yields were converted to tons per hectare. The field appeared healthy throughout the growing period, with no major disease incidences.

Collection of experimental data: The data recording procedure involved measuring plant height from three randomly selected plants in each plot at different stages (30, 60, 90, and 120 DAT) and at maturity. Total tillers, including both productive and unproductive, were counted from the same plants. Chlorophyll levels were measured using a SPAD-502 meter. At maturity, yield data were collected by uprooting three hills per plot, excluding border rows, and harvesting the crop from a 1m² area. Yield parameters recorded included plant height, effective, non-effective and total tillers per hill, panicle length, number of grains per panicle, 1000-grain weight, grain yield, straw yield, biological yield, and harvest index. Grain and straw yields were measured, dried, and converted to tons per hectare. Biological yield was calculated by summing grain and straw yields, and the harvest index was determined as the ratio of grain yield to biological yield.

Statistical analysis: The collected data were analyzed statistically using the analysis of variance technique and the mean differences were adjudged by Duncan's Multiple Range Test ($P \leq 0.05$) with the help of SPSS software.

Results

Plant height: In the experiment investigating the role of mycorrhizae species in rice productivity under field conditions, plant height was measured at 30, 60, 90, and 120 days after transplanting (DAT). Statistically significant results were noted regarding the influence of various AMF on rice plant height in all observation of plant height (Table 3). At 30 DAT, the control group, which did not receive any arbuscular mycorrhizal fungi (AMF), had a plant height of 34.53 cm. Plants treated with *Funneliformis mosseae* showed the greatest height at 39.83 cm, which is approximately 15.4% taller than the control. *Rhizophagus irregularis* treated plants had a height of 38.22 cm, 10.7% taller than the control. *Claroideoglomus etunicatum* resulted in a plant height of 36.71 cm, 6.3% taller than the control. *Claroideoglomus claroideum* treated plants had a height of 34.62 cm, almost identical to the control (Table 3). At 60 DAT, the control group's plant height was 62.36 cm. Plants treated with *Funneliformis mosseae* showed the greatest height at 65.29 cm, 4.7% taller than the control. *Rhizophagus irregularis* treated plants had a height of 64.59 cm, 3.6% taller than the control. *Claroideoglomus etunicatum* resulted in a height of 63.82 cm, 2.3% taller than the control. *Claroideoglomus claroideum* treated plants had a height of 62.57 cm, 0.3% taller than the control (Table 1). At 90 DAT, the control group's plant height was 73.82 cm. Plants treated with *Funneliformis mosseae* had the greatest height at 81.86 cm, 10.9% taller than the control. *Rhizophagus irregularis* treated plants showed a height of 80.56 cm, 9.1% taller than the control. *Claroideoglomus etunicatum* resulted in a height of 77.5 cm, 5.0% taller than the control. *Claroideoglomus claroideum* treated plants had a height of 74.77 cm, 1.3% taller than the control (Table 3). At 120 DAT, the control group's plant height was 80.9 cm. Plants treated with *Funneliformis mosseae* had the greatest height at 89.52 cm, 10.7% taller than the control. *Rhizophagus irregularis* treated plants showed a height of 87.71 cm, 8.4% taller than the control. *Claroideoglomus etunicatum* resulted in a height of 84.61 cm, 4.6% taller than the control. *Claroideoglomus claroideum* treated plants had a height of 81.12 cm, 0.3% taller than the control (Table 3).

Table 3. Effect of different Arbuscular Mycorrhizae Fungi (AMF) species at difference stage on plant height

Treatment	Plant Height			
	30DAT	60DAT	90DAT	120DAT
Control	34.53±0.48c	62.36±0.37d	73.82±0.5b	80.9±1.08c
Funnelifomis mosseae	39.83±1.38a	65.29±0.32a	81.86±2.24a	89.52±1.84a
Rhizophagus irregularis	38.22±0.94ab	64.59±0.47ab	80.56±1.7a	87.71±1.75ab
Claroideoglomus etunicatum	36.71±1.02bc	63.82±0.61bc	77.5±1.86ab	84.61±1.37bc
Claroideoglomus claroideum	34.62±0.5c	62.57±0.31cd	74.77±0.67b	81.12±1.01c
LS	0.05	0.05	0.05	0.05
CV(%)	4.37	1.18	3.46	2.96

Data are means of three replicates. Mean values in a column having a different letter (s) differed significantly, NS= Non-significant, CV= Co-efficient of variation, LS= Level of significance.

Total number of tillers per hill: Significant statistical results were recorded for how different AMF affect the total number of tillers per hill. The control group, which did not receive any arbuscular mycorrhizal fungi (AMF), had an average of 14.85 tillers per hill. Among the treatments, rice plants inoculated with *Funneliformis mosseae* had the highest number of tillers per hill, averaging 18.7, representing an increase of approximately 25.9% compared to the control. Plants treated with *Rhizophagus irregularis* also showed a significant increase in the number of tillers, with an average of 18.02, which is about 21.3% higher than the control. *Claroideoglomus etunicatum* treatment resulted in an average of 16.66 tillers per hill, 12.2% higher than the control. *Claroideoglomus claroideum* treated plants had a similar performance to the control, with an average of 14.96 tillers per hill, showing only a slight increase of 0.7% (Table 4).

Number of effective tillers per hill: The impact of different AMF on the number of effective tillers per hill was statistically significant. The control group, had an average of 9.41 effective tillers per hill. Among the treatments, rice plants inoculated with *Funneliformis mosseae* had the highest number of effective tillers per hill, averaging 14.62, which is approximately 55.3% higher than the control. Plants treated with *Rhizophagus irregularis* also showed a significant increase in the number of effective tillers, with an average of 13.83, about 47.0% higher than the control.

Claroideoglomus etunicatum treatment resulted in an average of 11.79 effective tillers per hill, 25.3% higher than the control. *Claroideoglomus claroideum* treated plants had a similar performance to the control, with an average of 9.41 effective tillers per hill, indicating no significant difference (Table 4).

The non-effective number of tillers per hill: Variations in AMF showed statistically significant effects on the number of non-effective tillers per hill. The control group, which did not receive any arbuscular mycorrhizal fungi (AMF), had an average of 5.44 non-effective tillers per hill. Among the treatments, rice plants inoculated with had the lowest number of non-effective tillers per hill, averaging 4.08, representing a decrease of approximately 25.0% compared to the control. Plants treated with *Rhizophagus irregularis* had an average of 4.19 non-effective tillers per hill, which is about 23.0% lower than the control. *Claroideoglomus etunicatum* treatment resulted in an average of 4.87 non-effective tillers per hill, 10.5% lower than the control. *Claroideoglomus claroideum*-treated plants had an average of 5.55 non-effective tillers per hill, showing a slight increase of 2.0% compared to the control (Table 4).

Chlorophyll content of rice: Results revealed a statistically significant effect of various AMF on the chlorophyll content (µmol m^{-2}) at 30 and 60 days after transplanting (DAT). At 30 DAT, the control group, which did not receive any arbuscular mycorrhizal fungi (AMF), had a chlorophyll content of 35.33 µmol m^{-2}. Among the treatments, plants inoculated with *Funneliformis mosseae* exhibited the highest chlorophyll content at 48.62 µmol m^{-2}, which is approximately 37.7% higher than the control. Plants treated with *Rhizophagus irregularis* also showed a significant increase in chlorophyll content, with a value of 47.25 µmol m^{-2}, about 33.7% higher than the control. *Claroideoglomus etunicatum* treatment resulted in a chlorophyll content of 45.2 µmol m^{-2}, 28.0% higher than the control. *Claroideoglomus claroideum* treated plants had a chlorophyll content of 38.87 µmol m^{-2}, 10.0% higher than the control (Table 2). At 60 DAT, the control group's chlorophyll content was 38.82 µmol m^{-2}. *Funneliformis mosseae* treated plants again showed the highest chlorophyll content at 51.66 µmol m^{-2}, approximately 33.1% higher than the control. *Rhizophagus irregularis*-treated plants had a chlorophyll content of 49.66 µmol m^{-2}, 27.9% higher than the control. *Claroideoglomus etunicatum* treatment resulted in a chlorophyll content of 49.36 µmol m^{-2}, 27.1% higher than the control. *Claroideoglomus claroideum* treated plants had a chlorophyll content of 42.32 µmol m^{-2}, 9.0% higher than the control (Table 4).

Panicle length: The panicle length of rice plants showed significant statistical results in response to different AMF. The control group, had an average panicle length of 19.6 cm. Among the treatments, rice plants inoculated with *Funneliformis mosseae* exhibited the greatest panicle length, averaging 21.45 cm, which is approximately 9.4% longer than the control. Plants treated with *Rhizophagus irregularis* also showed a significant increase in panicle length, with an average of 21.14 cm, about 7.9% longer than the control. *Claroideoglomus etunicatum* treatment resulted in an average panicle length of 20.62 cm, 5.2% longer than the control. *Claroideoglomus claroideum* treated plants had a similar performance to the control, with an average panicle length of 19.69 cm, indicating only a slight increase of 0.5% (Table 4).

Number of grains per panicle: In the experiment, rice number of grains per panicle was statistically significantly affected by the four type of AMF used. The control group, which did not receive any arbuscular mycorrhizal fungi (AMF), had an average of 148.81 grains per panicle. Among the treatments, rice plants inoculated with *Funneliformis mosseae* had the highest number of grains per panicle, averaging 180.43, which is approximately 21.2% higher than the control. Plants treated with *Rhizophagus irregularis* also showed a significant increase, with an average of 178.16 grains per panicle, about 19.7% higher than the control. *Claroideoglomus etunicatum* treatment resulted in an average of 164.9 grains per panicle, 10.8% higher than the control. *Claroideoglomus claroideum* treated plants had a similar performance to the control, with an average of 149.03 grains per panicle, indicating no significant difference (Table 5).

Thousand grain weight of rice: The impact of different AMF on the weight of 1000 grains was statistically non-significant. the was measured. The control group, which did not receive any arbuscular mycorrhizal fungi (AMF), had an average 1000 grain weight of 23.16 grams. Among the treatments, rice plants inoculated with *Funneliformis mosseae* had the highest 1000 grain weight at 23.99 grams, representing an increase of approximately 3.6% compared to the control. Plants treated with *Rhizophagus irregularis* showed a slight increase with an average 1000 grain weight of 23.51 grams, about 1.5% higher than the control. *Claroideoglomus etunicatum* treatment resulted in an average 1000 grain weight of 23.48 grams, 1.4% higher than the control. *Claroideoglomus claroideum* treated plants had a 1000 grain weight of 23.91 grams, indicating an increase of approximately 3.2% compared to the control (Table 5).

Grain yield: Statistical analysis indicated significant effects of various AMF on rice grain yield (t ha^{-1}). The control group, had an average grain yield of 4.98 t ha^{-1}. Among the treatments, rice plants inoculated with *Funneliformis mosseae* had the highest grain yield at 6.5 t ha^{-1}, representing an increase of approximately 30.5% compared to the control. Plants treated with *Rhizophagus*

Table 4. Influence of different Arbuscular Mycorrhizae Fungi (AMF) species on total number of tiller $hill^{-1}$, no of effective tiller $hill^{-1}$, no of non-effective tiller $hill^{-1}$ and Chlorophyll Content of rice.

Treatment	Total no of tiller $hill^{-1}$	No of effective tiller $hill^{-1}$	No of non-effective tiller $hill^{-1}$	Chlorophyll Content (µmol m^{-2})	
				30DAT	60DAT
Control	14.85±0.41c	9.41±0.6b	5.44±0.2ab	35.33±2.03c	38.82±1.71b
Funnelifomis mosseae	18.7±0.59a	14.62±1.09a	4.08±0.52b	48.62±2.21a	51.66±2.58a
Rhizophagus irregularis	18.02±0.52ab	13.83±1.08a	4.19±0.6ab	47.25±2.24a	49.66±2.44a
Claroideoglomus etunicatum	16.66±0.79bc	11.79±1.18ab	4.87±0.41ab	45.2±2.53ab	49.36±2.48a
Claroideoglomus claroideum	14.96±0.39c	9.41±0.6b	5.55±0.23a	38.87±2.59bc	42.32±1.75b
LS	0.05	0.05	0.05	0.05	0.05
CV(%)	5.81	13.89	15.11	9.37	8.32

Data are means of three replicates. Mean values in a column having a different letter (s) differed significantly, NS= Non-significant, CV= Co-efficient of variation, LS= Level of significance.

Table 5. The role of different Arbuscular Mycorrhizae Fungi (AMF) species on yield and yield contributing characters.

Treatment	Panicle Length (cm)	No of Grain panicle^{-1}	1000 Grain Weight (g)	Grain Yield (t ha^{-1})	Straw Yield (t ha^{-1})	Biological Yield (t ha^{-1})	Harvest Index(%)
Control	19.6±0.25b	148.81±3.27b	23.16±0.71	4.98±0.43b	6.11±0.14b	11.09±0.56b	44.73±1.56
Funnelifomis mosseae	21.45±0.22a	180.43±8.15a	23.99±0.14	6.5±0.35a	8.7±0.64a	15.21±0.98a	42.83±0.55
Rhizophagus irregularis	21.14±0.45a	178.16±7.54a	23.51±0.53	5.87±0.47ab	7.35±0.72ab	13.22±1.18ab	44.48±0.52
Claroideoglomus etunicatum	20.62±0.47ab	164.9±8.03ab	23.48±0.71	4.62±0.31b	5.89±0.24b	10.51±0.55b	43.91±0.64
Claroideoglomus claroideum	19.69±0.19b	149.03±3.05b	23.91±0.26	4.77±0.38b	6.05±0.13b	10.82±0.51b	43.96±1.47
LS	0.05	0.05	NS	0.05	0.05	0.05	NS
CV(%)	2.86	6.8	3.85	12.72	11.44	11.47	4.15

Data are means of three replicates. Mean values in a column having a different letter (s) differed significantly, NS= Non-significant, CV= Co-efficient of variation, LS= Level of significance.

irregularis also showed a significant increase in grain yield, with an average of 5.87 t ha^{-1}, about 17.8% higher than the control. *Claroideoglomus etunicatum* treated plants had a lower grain yield of 4.62 t ha^{-1}, 7.2% lower than the control. *Claroideoglomus claroideum* treated plants had a grain yield of 4.77 t ha^{-1}, indicating a slight decrease of approximately 4.2% compared to the control (Table 5).

Straw yield: Differences in AMF caused significant statistical changes in rice straw yield (t ha^{-1}). The control group, which did not receive any arbuscular mycorrhizal fungi (AMF), had an average straw yield of 6.11 t ha^{-1}. Among the treatments, rice plants inoculated with *Funneliformis mosseae* had the highest straw yield at 8.7 t ha^{-1}, representing an increase of approximately 42.4% compared to the control. Plants treated with *Rhizophagus irregularis* also showed a significant increase in straw yield, with an average of 7.35 t ha^{-1}, about 20.4% higher than the control. *Claroideoglomus etunicatum* treatment resulted in a lower straw yield of 5.89 t ha^{-1}, 3.6% lower than the control. *Claroideoglomus claroideum* treated plants had a straw yield of 6.05 t ha^{-1}, indicating a slight decrease of approximately 1.0% compared to the control (Table 5).

Biological produced: The biological yield (t ha^{-1}) of rice showed significant statistical results in response to different AMF. The control group, had an average biological yield of 11.09 t ha^{-1}. Among the treatments, rice plants inoculated with *Funneliformis mosseae* achieved the highest biological yield at 15.21 t ha^{-1}, representing an increase of approximately 37.8% compared to the control. Plants treated with *Rhizophagus irregularis* also showed a significant increase in biological yield, with an average of 13.22 t ha^{-1}, about 19.8% higher than the control. *Claroideoglomus etunicatum* treatment resulted in a biological yield of 10.51 t ha^{-1}, which is 5.3% lower than the control. *Claroideoglomus claroideum* treated plants had a biological yield of 10.82 t ha^{-1}, showing a slight decrease of approximately 2.4% compared to the control (Table 5).

Harvest index: Statistically non-significant differences were observed in the harvest index of rice. The control group, which did not receive any arbuscular mycorrhizal fungi (AMF), had a harvest index of 44.73%. Among the treatments, rice plants inoculated with *Funneliformis mosseae* had a harvest index of 42.83%, which is slightly lower than the control by approximately 4.3%. Plants treated with *Rhizophagus irregularis* had a harvest index of 44.48%, very close to the control, showing a marginal decrease of about 0.6%. *Claroideoglomus etunicatum* resulted in a harvest index of 43.91%, a slight decrease of about 1.8% compared to the control. *Claroideoglomus claroideum* treated plants had a harvest index of 43.96%, indicating a minor decrease of about 1.7% compared to the control (Table 5).

Discussions

The results of this study elucidate the impact of different arbuscular mycorrhizal fungi (AMF) species on rice productivity under field conditions, focusing on various growth and yield parameters. Inoculation with *Funneliformis mosseae* resulted in the highest plant height (Table 3), number of effective tillers, chlorophyll content (Table 4), panicle length, grain yield, straw yield, and biological yield (Table 5) compared to other treatments and the control. This enhancement can be attributed to *Funneliformis mosseae's* ability to improve nutrient uptake, particularly phosphorus, which is critical for root and shoot development (Iqbal et al. 2021). Similar improvements were observed with *Rhizophagus irregularis*, which also significantly increased plant height, number of effective tillers, and grain yield compared to the control. This AMF species has been shown to enhance nutrient acquisition and plant growth through extensive mycelial networks (Campo et al. 2020; Iqbal et al. 2021). *Claroideoglomus etunicatum* treatment showed intermediate results across several parameters, including plant height and grain yield, indicating its moderate effectiveness. While this AMF species improved certain growth parameters, it did not achieve the same level of benefit as *Funneliformis mosseae* and *Rhizophagus irregularis*, aligning with findings from previous studies that suggest variability in the efficacy of different AMF species (Basiru, Mwanza, and Hijri 2020; Martins and Rodrigues, 2023). In contrast, *Claroideoglomus claroideum* did not significantly outperform the control in most parameters, including grain yield and straw yield. This limited effectiveness suggests that its mycorrhizal benefits in this context might be less pronounced, potentially due to species-specific interactions or environmental factors affecting its performance. The harvest index (Table 5), reflecting the efficiency of biomass conversion into grain yield, was statistically similar across all treatments, with a slight decrease in *Funneliformis mosseae*. This decrease, however, did not overshadow the significant increase in total yield components. Such observations suggest that while *Funneliformis mosseae* boosts overall productivity, it may slightly affect the allocation of resources between grain and straw, a point that warrants further investigation. Overall, the study highlights the potential of AMF, particularly *Funneliformis mosseae* and *Rhizophagus irregularis*, to significantly enhance rice productivity through improvements in growth parameters and yield components. These findings align with previous research advocating the use of AMF in sustainable agriculture for increased crop productivity and soil health (Campo et al. 2020; Iqbal et al. 2021; Zhang et al. 2023).

Conclusions

This study demonstrates that arbuscular mycorrhizal fungi (AMF) significantly influence rice productivity under field conditions. Among the AMF species tested, *Funneliformis mosseae* and *Rhizophagus irregularis* were particularly effective, enhancing plant height, number of effective tillers, chlorophyll content, panicle length, and overall grain and straw yields compared to the control. *Funneliformis mosseae* led to the highest increases in yield components, suggesting its superior potential for improving rice production. *Claroideoglomus etunicatum* showed moderate benefits, while *Claroideoglomus claroideum* provided minimal improvements. These findings underscore the importance of selecting appropriate AMF species to optimize rice productivity, with implications for sustainable agricultural practices and soil management.

Conflict of interest

There is ano any conflict of interest among the authors.

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To cite this article: Sultana, F., Momen, M.B.H., Islam, M.R and Khan, M.T.A. (2024). Performance of Different Arbuscular Mycorrhizae Species on The Productivity of Rice Under Field Condition. *International Journal for Asian Contemporary Research*, 4 (2): 48-52.