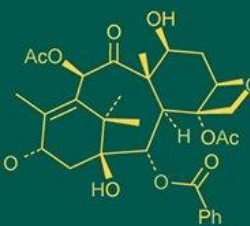
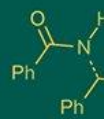


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Enhancement of growth and yield performance of kharif rice (*Oryza sativa* L.) through mycorrhizal biofertilizer application

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Abstract

Arbuscular Mycorrhizal Fungi (AMF) are capable of colonizing the roots of a wide range of terrestrial and aquatic plant species. However, most of the research works have focused on terrestrial systems, while submerged conditions have received limited attention. Numerous studies have demonstrated the positive relationship between mycorrhizal fungi and the roots of submerged rice plants. Keeping this in view, a field experiment was conducted to analyze the effect of AMF on various growth and yield parameters of the rice variety 'Satabdi' (IET 4786) under submerged conditions in the New Alluvial Zone of West Bengal during the kharif season of 2023. The experiment was laid out in a randomized block design (RBD) comprising 3 replications and 7 treatments. The treatments were - T₁ - 100% RDF, T₂ - 100% RDF + RhizoMyx @ 2.5 kg ha⁻¹ at basal, T₃ - 100% RDF + RhizoMyx @ 5 kg ha⁻¹ at basal, T₄ - 100% RDF + RhizoMyx @ 7.5 kg ha⁻¹ at basal, T₅ - 100% RDF + RhizoMyx @ 10 kg ha⁻¹ at basal, T₆ - 100% RDF + RhizoMyx @ 12.5 kg ha⁻¹ at basal, T₇ - 100% RDF + RhizoMyx @ 15 kg ha⁻¹ at basal. Mycorrhiza-treated plots performed better in terms of growth and yield-attributing characters as compared to the control plot (T₁). Treatment 100% RDF + RhizoMyx @ 10 kg ha⁻¹ at basal recorded the maximum plant height (116.67 cm), leaf area index (2.20), root volume (33.23 cc hill⁻¹), grain yield (4.95 t ha⁻¹) and straw yield (6.34 t ha⁻¹).

Keywords: Arbuscular mycorrhizal fungi, rice, submerged condition, mycorrhizal biofertilizer

Introduction

Rice is the major staple food crop consumed by people around the world, particularly in South and Southeast Asia (Bandumula, 2018) [2]. It is probably the first domesticated crop by the human beings (about 13,000 years ago) in the Yangtze River Basin (Lu *et al.*, 2002) [22]. Rice constitutes a major component of the staple diet of approximately 4 billion people and contributes 21% of per-capita energy intake globally (Mishra *et al.*, 2022) [24]. Global rice production reached 551.5 million tonnes in 2025 (FAO-Food Outlook Report, 2025) [11]. India has the largest rice-growing area worldwide and ranks second in production after China. During 2024-25, rice occupied approximately 51.4 million hectares in India, producing 150.18 million tonnes at an average productivity of 4.3-4.4 t ha⁻¹ (Government of India, 2025) [16]. West Bengal is the leading rice-producing state in the country, contributing 15.7 million tonnes from 5.7 million hectares, with an average productivity of 3.1 t ha⁻¹ (Government of West Bengal, 2025) [17].

Arbuscular Mycorrhizal Fungi (AMF) belong to the phylum Glomeromycota and subphylum Glomeromycotina, with fossil evidence dating back approximately 450 million years (Spatofora *et al.*, 2016) [34], and form symbiosis with most of the vascular plants. They perform some crucial ecological functions in the movement of nutrients (Roth and Paszkowski), improving disease resistance (Campo *et al.*, 2020) [5], helping the plant to withstand adverse climatic conditions and reduce heavy metal toxicity (Amir *et al.*, 2019) [42]. In the present scenario, mycorrhizal products are the major components in crop production in a more eco-friendly manner.

Rice is one of the model plants for studies on the symbiosis of arbuscular mycorrhizal fungi (Wang *et al.*, 2021) [36]. Production of rice is generally practised in wetland condition with

submerged ecosystem (FAO, 2011) ^[10]. Several studies have revealed the absence or less activity of AMF in flooded condition (Lumini *et al.*, 2011) ^[23] while other studies revealed the presence and effectiveness of AMF in flooded condition (Chen *et al.*, 2017; Bernaola *et al.*, 2018) ^[4, 6] although the mechanism is unknown till date. Several experiments reported the positive influence of AMF on rice plant biomass, grain yield and nutrient uptake (Gewaily, 2019) ^[14] under submerged ecosystems. The present experiment was conducted to evaluate the influence of different doses of mycorrhizal biofertilizer on the growth and yield characteristics of kharif rice grown under submerged conditions. This study can provide a guideline for the application of AMF in rice under a submerged ecosystem and further application of mycorrhizal products in different crops under different ecosystems.

Materials and Methods

Site Description

The experiment was conducted during the kharif (rainy) season of 2023 at the C Block of the Incheck Farm, Kalyani, under Bidhan Chandra Krishi Viswavidyalaya (B.C.K.V.), Mohanpur, Nadia, West Bengal, India. The experimental site lies in the New Alluvial Zone (NAZ) of West Bengal, situated at 22°57' N latitude and 88°20' E longitude, with an elevation of 9.75 meters above mean sea level, and characterized by lowland topography. The area typically experiences hot summers, uneven rainfall, high humidity and a short, mild winter season. The cropping seasons are generally classified into: dry and warm or *pre-kharif* (during March-May), wet and warm or kharif (during June-October) and dry and cool or *rabi* (during November-February). The region receives an average annual rainfall of nearly 1396 mm, with 70-80% contributed by the southwest monsoon, which typically begins in the second week of June. The soil at the experimental site was sandy clay loam in texture, neutral in reaction (pH 7.04), with medium organic carbon content (0.51%), low available nitrogen (188.9 kg ha⁻¹), medium level of potassium (184.70 kg ha⁻¹) and high available phosphorus (39.35 kg ha⁻¹).

Experimental design and crop management

The experiment followed a Randomised Block Design (RBD) with 3 replications and 7 treatments using plots of 5 m × 3 m. Plant spacing was maintained at 20 cm × 20 cm (row-to-row and plant-to-plant). A full recommended dose of chemical fertilizers @ 60 kg N, 30 kg P₂O₅ and 30 kg K₂O ha⁻¹ in the form of Urea, SSP and MOP was applied to the designated plots, respectively. One-third of the total nitrogen (N) and the full recommended doses of P₂O₅ and K₂O were applied as basal dressing, and the remaining N was top-dressed in two equal splits at tillering and panicle initiation stages. Different doses of RhizoMyx were uniformly broadcast and thoroughly incorporated into the top 5-10 cm soil layer of the respective plots immediately before transplanting 22-day-old rice seedlings. To promote AMF establishment and root colonization, the soil was kept at about field capacity (without standing water) for the first five to seven days after transplantation. After then, additional irrigation was applied as needed to adjust for evapotranspiration and rainfall variability, maintaining a standing water depth of 5 ± 2 cm throughout the crop

growth phase (until 10 days before physiological maturity). The treatments were as follows - T₁ - 100% RDF, T₂ - 100% RDF + RhizoMyx @ 2.5 kg ha⁻¹ at basal, T₃ - 100% RDF + RhizoMyx @ 5 kg ha⁻¹ at basal, T₄ - 100% RDF + RhizoMyx @ 7.5 kg ha⁻¹ at basal, T₅ - 100% RDF + RhizoMyx @ 10 kg ha⁻¹ at basal, T₆ - 100% RDF + RhizoMyx @ 12.5 kg ha⁻¹ at basal, T₇ - 100% RDF + RhizoMyx @ 15 kg ha⁻¹ at basal. The variety used in this experiment was 'Satabdi' (IET 4786), a high-yielding, semi-dwarf indica rice variety released in 2000 for irrigated ecosystems in West Bengal.

Characteristics of the Biofertilizer

RhizoMyx is a commercial mycorrhizal biofertilizer product containing AMF propagules and unspecified biostimulant compounds. This unique formulation increases the uptake of nutrients and enhances root growth. It supports root development in several crops including cereals, pulses and vegetables for improvement in nutrient and water availability, resulting in improved growth potential.

Recorded Observations

Different growth and yield parameters were recorded during the crop growth period and after harvest. The growth parameters included plant height, leaf area index (LAI), root length, root volume and dry matter accumulation (DMA), whereas the yield attributes comprised the number of panicles m⁻², number of filled grains panicle⁻¹, grain yield and straw yield. Plant height was measured from the base of the plant to the tip of the tallest leaf, with the leaf held upright, using a measuring scale. The LAI was calculated using Watson's formula (Watson, 1947) ^[37] of total leaf area of the plant per unit ground area. For dry matter accumulation, leaves and stems were separated, placed in brown paper bags, shade-dried, then oven-dried, and the results were expressed in g m⁻². Root length was measured from the collar region to the root tip. Root volume was measured by the water displacement (volumetric) method. Fresh root samples collected from each plot were thoroughly washed under running tap water to remove adhering soil particles and blotted dry with absorbent paper. The cleaned roots were then gently submerged in a graduated measuring cylinder filled with a known volume of water. The increase in water level (displaced volume) was recorded and expressed as cm³ hill⁻¹. The number of panicles m⁻² was determined by counting panicles within a randomly selected 1 m² area from each plot. Filled grains were separated, counted and averaged to estimate the number of filled grains per panicle. After drying and threshing, seed weight was recorded and converted to kg ha⁻¹ to obtain grain yield. Straw yield was measured by weighing the straw bundles and expressed in kg ha⁻¹.

Statistical Analysis

The collected data was statistically analyzed using the Analysis of Variance (ANOVA) method (Cochran and Cox, 1967; Gomez and Gomez, 1984; Panse and Sukhatme, 1985) ^[7, 15, 26]. The significance of variation sources was tested through the error mean square using Fisher-Snedecor's 'F' test at a 0.05 probability level. For comparing F values and determining the critical difference (CD) at the 5% significance level, Fisher and Yates tables were used.

Results

Growth attributes

Application of 100% RDF + RhizoMyx @ 10 kg ha⁻¹ (T₅) recorded the highest plant height (116.67 cm) followed by T₄ and T₃ (Table 1). Dry matter accumulation (DMA) was higher in inoculated plots in comparison with the control (T₁). T₅ recorded highest dry matter, which was significant with all other treatments. Arbuscular mycorrhiza on growth attributing characters of lowland rice. Dry matter increased with the increasing of crop age and recorded maximum at harvest. Leaf area index increased almost linearly and decreased towards maturity. Among the treatments, T₅, T₄, T₃ and T₂ recorded higher values but no significant variation was found in these treatments.

Mycorrhizal biofertilizer improved the yield attributing characters and thereby increased yield of transplanted kharif

rice (Table 2). Number of panicles m⁻² was highest in T₅. Number of panicles ranged from 224.33 to 265.00 among the different treatments with a variation of 18.12%. Number of filled grains panicle⁻¹ was recorded highest in T₅ (125.67) followed by treatments T₄ (123.67), T₃ (118.00) and T₂ (112.67). Both grain and straw yields showed a significant increase in mycorrhiza-treated plots compared to the control. Grain yield varied between 3.61 and 4.95 t ha⁻¹, reflecting a 37.12% difference. The maximum grain yield (4.95 t ha⁻¹) was achieved with the application of 100% RDF + RhizoMyx @ 10 kg ha⁻¹ at basal, which was statistically at par with T₄ and T₃ but significantly higher than the other treatments. Straw yield ranged from 4.70 to 6.34 t ha⁻¹, with a variation of 34.89%. The highest straw yields were observed in T₅ (6.34 t ha⁻¹), followed by T₄ (6.23 t ha⁻¹), T₃ (5.56 t ha⁻¹) and T₂ (5.43 t ha⁻¹).

Figures

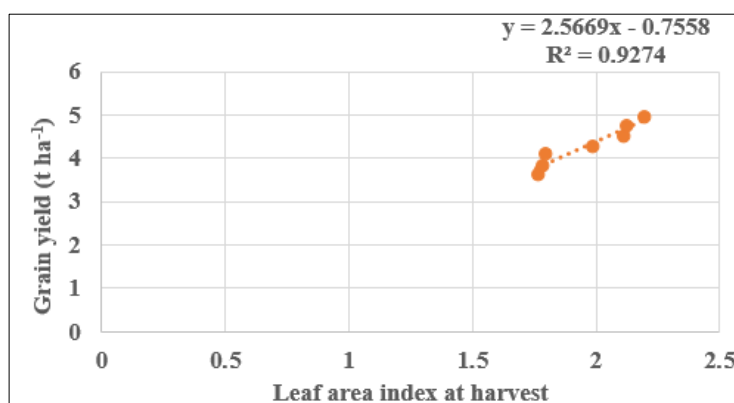


Fig 1: Relationship between leaf area index at harvest and grain yield (t ha⁻¹)

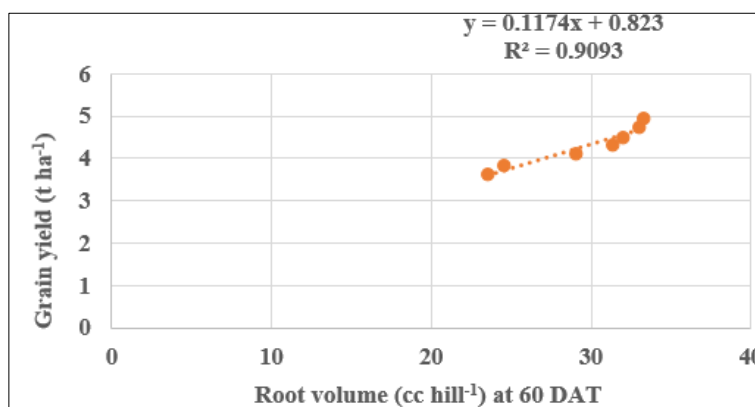


Fig 2: Relationship between root volume (cc hill⁻¹) and grain yield (t ha⁻¹)

Tables

Table 1: Effect of mycorrhizal biofertilizer on different growth attributes of transplanted kharif rice

Treatments	Plant height (cm)	Dry matter accumulation (g m ⁻²)	Leaf area Index	Root length (cm)		Root volume (cc hill ⁻¹)	
				30 DAT	60 DAT	30 DAT	60 DAT
T ₁	93.67 ^c	828.55 ^a	1.76 ^b	12.74 ^c	20.42 ^d	15.91 ^b	23.52 ^c
T ₂	106.03 ^{abc}	850.253 ^a	1.99 ^{ab}	14.84 ^{abc}	26.2 ^{bc}	17.69 ^a	31.36 ^{ab}
T ₃	110.68 ^{ab}	860.66 ^a	2.11 ^a	15.56 ^{ab}	27.91 ^{ab}	17.77 ^a	32.02 ^{ab}
T ₄	112.33 ^{ab}	864.63 ^a	2.12 ^a	15.67 ^{ab}	28.45 ^{ab}	18.16 ^a	32.98 ^a
T ₅	116.67 ^a	876.22 ^a	2.2 ^a	16.27 ^a	29.48 ^a	17.52 ^a	33.23 ^a
T ₆	103.80 ^{abc}	838.88 ^a	1.8 ^b	14.67 ^{abc}	24.29 ^c	17.59 ^a	29.09 ^{abc}
T ₇	102.33 ^{bc}	835.38 ^a	1.78 ^b	14.04 ^{bc}	23.56 ^c	17.13 ^{ab}	24.59 ^{bc}

Table 2: Effect of mycorrhizal biofertilizer on yield attributes and yield of kharif rice

Treatments	No. of panicles m ⁻²	No. of filled grains panicle ⁻¹	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)
T ₁	224.33 ^e	95.33 ^c	3.61 ^e	4.70 ^d
T ₂	244 ^{bcd}	112.67 ^{abc}	4.3 ^{bcd}	5.43 ^{bc}
T ₃	250 ^{bc}	118 ^{ab}	4.52 ^{abc}	5.56 ^b
T ₄	252.33 ^b	123.67 ^{ab}	4.76 ^{ab}	6.23 ^a
T ₅	265 ^a	125.67 ^a	4.95 ^a	6.34 ^a
T ₆	240.67 ^{cd}	110.33 ^{abc}	4.09 ^{cde}	5.33 ^{bcd}
T ₇	233.33 ^{de}	106.33 ^{bc}	3.8 ^{de}	4.85 ^{cd}

[T₁ - 100% RDF, T₂ - 100% RDF + RhizoMyx @ 2.5 kg ha⁻¹ at basal, T₃ - 100% RDF + RhizoMyx @ 5 kg ha⁻¹ at basal, T₄ - 100% RDF + RhizoMyx @ 7.5 kg ha⁻¹ at basal, T₅ - 100% RDF + RhizoMyx @ 10 kg ha⁻¹ at basal, T₆ - 100% RDF + RhizoMyx @ 12.5 kg ha⁻¹ at basal, T₇ - 100% RDF + RhizoMyx @ 15 kg ha⁻¹ at basal]

Discussion

Mycorrhizal inoculation improved root characteristics in rice, which resulted in greater uptake of essential plant nutrients and enhanced plant growth. Maximum root length and root volume were observed in T₅ treatment, followed by T₄, T₃ and T₂ (Table 1). A positive influence of fungal inoculation was observed in paddy soil (Yapa *et al.*, 2020; Aziez *et al.*, 2023) [1, 39]. In the case of flooded conditions, AM symbiosis was supported by lateral roots of rice plant (Fiorilli *et al.*, 2015) [12]. Although, arbuscular mycorrhiza is obligate aerobe, the presence of certain AMF species like *Claroideoglomus etunicatum* and their equally higher colonization under submerged soil proved their positive influence on paddy (Purakayastha and Chhonkar, 2001) [27]. Colonization by arbuscular mycorrhizal fungi (AMF) supported development of root system by boosting root growth, including increased number and length of lateral roots, more fine roots and higher root dry weight. Various secondary metabolites, including 6-n-pentyl-6H-pyran-2-one (6PP), gliotoxin, viridin, harzianopyridone, harziandione and peptaibols, are produced and released by AMF into the rhizosphere, which stimulate extensive root branching and enhance root biomass (Reino *et al.*, 2007; Vinale *et al.*, 2008) [30, 35]. Enhanced root colonization improved root traits in rice, leading to greater root length and volume (Senthamizhkumaran *et al.*, 2021; Guigard *et al.*, 2023) [18, 31]. The present study revealed a highly significant positive correlation between root volume and grain yield ($R^2 = 0.9093$; $y = 0.1174x + 0.823$) (Fig. 2), which is consistent with earlier findings that vigorous root systems facilitate efficient resource acquisition and support higher grain productivity in rice (Kaysar *et al.*, 2023) [21]. A similar highly significant positive relationship was observed between LAI at harvest and grain yield ($R^2 = 0.9274$; $y = 2.5669x - 0.7558$), indicating that canopy development at the later growth stages played a pivotal role in determining yield potential (Fig. 1). This finding aligns with earlier reports emphasizing that an expanded leaf area enhances light interception, photosynthetic efficiency and assimilate translocation to the grains (Hashimoto *et al.*, 2023) [19]. A similar finding was observed by Yasodha *et al.* (2020) [40] in lowland rice.

A significant increase in yield was observed among the mycorrhizal inoculated plots. This might be due to the production of higher amount of photosynthates that eventually led to higher number of grains. These findings were supported by the experimental results of Elita *et al.* (2023) [9]. This was probably due to the expansion of rhizosphere region by the hyphal network of mycorrhizal fungi that enhanced the uptake of essential nutrients (Huey *et al.*, 2020; Franzoni *et al.*, 2021) [13, 20]. Besides,

mycorrhizal inoculation improved the uptake of glycine and glutamic acid nitrogen transport from its source to the host, and it also increased the uptake of phosphorus and potassium (Aziez *et al.*, 2023) [1]. Greater root colonization not only increased nutrient uptake in plants but also reduced disease-causing pathogens in plant roots (Spagnoletti *et al.*, 2020) [33], which eventually led to higher grain yield and straw yield. Higher yield attributes eventually led to higher grain yield. Previous studies have shown that rice plants with AMF colonization exhibit greater biomass, increased stomatal conductance, enhanced PS II activity, higher nitrogen and phosphorus uptake, elevated IAA levels, and reduced ABA production (Mitra *et al.*, 2021) [25]. Significant response of AMF + NPK fertilization to crop growth and yield was reported by previous researches (Raya-Hernández *et al.*, 2020) [29]. The present study observed a decline in growth and yield parameters of kharif rice beyond a certain mycorrhizal biofertilizer dose, indicating a shift from mutualism to a less beneficial or even parasitic-like interaction at supra-optimal inoculum levels. Although the precise mechanism driving this effect was not directly investigated, a negative mycorrhizal growth response in rice, where AMF inoculation reduced vegetative growth despite successful root colonization, remains a plausible explanation. Guigard *et al.* (2023) [18] demonstrated that symbiotic compatibility between rice cultivars and AMF genotypes strongly modulates plant responses, with certain combinations resulting in significant growth depressions (dry weight reductions up to 21% and height reductions of 14% to 19% in IR 64). The authors attributed these negative effects to an imbalance in the carbon-for-nutrient exchange, whereby the carbon demand of the fungus exceeded nutritional returns to the host. Higher doses of mycorrhizal biofertilizer led to elevated P level which masked the effect of biofertilizer in different growth and yield attributes (Zinati *et al.*, 2025) [41]. In fertilized rice systems, basal P application already provides sufficient available soil P, enabling the plant to meet its P requirement primarily through the direct root-uptake pathway. In this situation, the mycorrhizal phosphate uptake pathway was hidden by the host plant since high concentrations of phosphate in both the tissues and the soil inhibited the expression of the phosphate transporters specific to mycorrhiza and decreased the amount of carbon allocated to the fungus. As a result, the greater intensity of root colonization caused by doses of biofertilizer that were above the optimal level imposed a higher carbon cost on the host without bringing about any corresponding nutritional benefits, causing the symbiosis to change from mutualistic to neutral or even to a parasitic type and finally leading to a reduction in biomass accumulation, tillering, panicle development and grain yield.

Conclusion

The present study evaluated the impact of mycorrhizal biofertilizer on various growth and yield parameters of transplanted kharif rice in the lower Indo-Gangetic Plains of the New Alluvial Zone in West Bengal, India. The overall experiment showed that mycorrhizal inoculation improved different growth and yield attributes in lowland rice. Biofertilizer along with 100% RDF increased the different parameters as compared to the control plot. However, higher doses of biofertilizer showed negative impact on different growth and yield attributes. Hence, the study demonstrated that mycorrhizal biofertilizer is an effective and ecologically safe measure to enhance crop productivity sustainably and may serve as one component of sustainable agriculture for farmers in the New Alluvial Zone of West Bengal. Future research should quantify AMF colonization dynamics under varied flooding regimes, evaluate the economic sustainability of RhizoMyx across diverse soil P levels, and identify flood-tolerant AMF species for targeted inoculum production. Multi-season experiments are needed to determine residual effects and long-term sustainability of mycorrhizal biofertilizer in rice-based cropping systems.

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