Enhancing Wheat Growth and Yield Through AM Fungi (Glomus intraradices) Inoculation Under Varying Phosphorus Levels

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***Abstract*—By increasing the availability of phosphorus (P), arbuscular mycorrhizal fungi (AMF) are essential for plant development, nutrient uptake, and soil health. The effects of *Glomus intraradices* inoculation on wheat (*Triticum aestivum* var. Swift) growth, yield, and phosphorus uptake are assessed in this study at varying phosphorus fertilization levels (0, 5, 10, and 20 kg P ha^{-1}). Phosphorus uptake, yield qualities, root colonization, and plant growth parameters were evaluated using a randomized complete block design (RCBD). The findings show that, especially at moderate P levels (5 and 10 kg P ha^{-1}), AMF inoculation considerably increased plant height, root length, biomass accumulation, and grain yield. Root colonization peaked at these phosphorus levels but fell at 20 kg P ha^{-1}, showing that high P impairs AMF symbiosis. Yield-related parameters—including grain number per spike, 1000-grain weight, and total grain yield—followed a similar trend, with maximum productivity seen at 10 kg P ha^{-1}. Effective nutrient utilization was further demonstrated by the increased phosphorus uptake in the leaf and grain tissues of AMF-inoculated plants and the reduced soil accessible phosphorus in these plots. AMF inoculation and phosphorus fertilization were found to interact significantly ($p < 0.05$) according to statistical analysis, supporting the idea that mycorrhizal benefits are maximized at moderate P levels. According to these results, AMF inoculation can increase wheat yield while lowering reliance on artificial fertilizers, promoting more environmentally friendly farming methods. To improve phosphorus management techniques, further investigation should be done into long-term field tests and AMF interactions with other soil microbes.**

***Index Terms*—Arbuscular mycorrhizal fungi, Glomus intraradices, wheat, phosphorus uptake, yield, sustainable agriculture**

I. INTRODUCTION

A vital macronutrient for plant growth, phosphorus (P) is important for grain formation, root expansion, and energy transfer (Smith & Read, 2008). However, crop productivity is frequently limited by its low bioavailability in many agricultural soils, requiring the use of artificial fertilizers. Although phosphorus fertilization increases yields, overuse can cause soil deterioration, nutritional imbalances, and pollution (Withers et al., 2014). Therefore, to maximize plant nutrition while reducing ecological effect, sustainable phosphorus management solutions are required.

By spreading fungal hyphae into the soil, arbuscular mycorrhizal fungi (AMF), especially *Glomus intraradices*, establish symbiotic relationships with plant roots, increasing the surface area of the roots available for nutrient absorption and improving phosphorus uptake (Smith & Read, 2008). This symbiosis is especially beneficial when there is a phosphorus shortage because AMF makes it easier for plants to acquire phosphorus forms that would otherwise be unavailable, which increases plant growth and output (Tawaraya et al., 2012). However, AMF colonization may be suppressed by high soil phosphorus levels, which would decrease its efficacy (Balzergue et al., 2011). Integrating mycorrhizal inoculation into sustainable wheat production requires figuring out the ideal phosphorus range that optimizes AMF advantages (Cui et al., 2020).

For maximum yield, wheat (*Triticum aestivum* L.), a staple crop of worldwide importance, needs effective phosphorus management. According to research, AMF inoculation improves nutrient uptake and wheat output, especially in situations when phosphorus is scarce (Mäder et al., 2011). However, there are still few research looking at how AMF interacts with different phosphorus levels in field-grown wheat, especially when it comes to microbial activity, mycorrhizal dependence, and soil phosphorus dynamics. The effects of *Glomus intraradices* inoculation on wheat growth, yield, and phosphorus uptake at varying phosphate fertilization levels are assessed in this study. Environmentally sustainable agriculture will be promoted by the results, which will aid in the development of sustainable phosphorus management techniques that increase crop output while lowering dependency on chemical fertilizers.

II. MATERIALS AND METHODS

During the growing seasons of 2021 and 2022, the field experiment was carried out in Dongargaon, Niphad Taluka, Nashik District, Maharashtra, India. Low phosphorus availability and a slightly acidic pH of 5.5 were characteristics of the loamy soil at the experimental site. Standard protocols were followed for the initial study of soil nutrients (Jackson, 1973). After five minutes of surface sterilization with 0.5% sodium hypochlorite, wheat (*Triticum aestivum* var. Swift) seeds were thoroughly rinsed with distilled water. The *Glomus intraradices* sheared-root inoculum, which was made in accordance with Brundrett et al. (1996), was added to the seeds at a rate of 0.5 g dry weight per 1000 seeds.

A randomized complete block design (RCBD) was used for the experiment, and triple superphosphate (TSP) was sprayed at four different phosphorus (P) fertilization levels: 0, 5, 10, and 20 kg P ha^{-1}. Control plots were not inoculated, and each treatment was repeated four times. In the natural field, standard agronomic procedures for growing wheat were observed.

At 60 days after sowing (DAS), plant growth metrics such as biomass accumulation, root length, and plant height were measured. In accordance with Singh et al. (2011), yield characteristics such as grains per spike, 1000-grain weight, and total grain yield per hectare were determined at physiological maturity.

Root colonization was examined using the grid-line intersection approach (Giovannetti & Mosse, 1980). Mycorrhizal reliance was established based on biomass growth owing to inoculation (Plenchette et al., 1983). The vanadomolybdate method was used to determine the amount of phosphorus present in leaf and grain samples (Olsen & Sommers, 1982). While microbial biomass phosphorus was assessed in accordance with Brookes et al. (1982), soil accessible phosphorus was determined using the Bray-1 extraction method (Bray & Kurtz, 1945). Two-way ANOVA in SPSS software version [X] was used for statistical analysis, and Duncan's Multiple Range Test (DMRT) was used to compare mean differences at $p < 0.05$ (Steel & Torrie, 1980).

III. RESULTS

Glomus intraradices-inoculated wheat plants significantly outperformed non-inoculated control plants in terms of biomass accumulation, root length, and plant height. While growth benefits decreased at 20 kg P ha^{-1}, the most significant growth increases were seen at 5 and 10 kg P ha^{-1}, indicating an ideal phosphorus range for AMF symbiosis. Plant height rose from 45.3 cm in the control to 55.4 cm at 10 kg P ha^{-1}, as indicated in Table 1. Root length and biomass both showed a similar pattern, peaking at 10 kg P ha^{-1} and then falling at 20 kg P ha^{-1}. Microscopic investigation indicated effective AMF colonization in inoculated plants, while non-inoculated plants showed limited colonization. The greatest root colonization was seen at 5 and 10 kg P ha^{-1}, but it decreased at 20 kg P ha^{-1}, suggesting that AMF symbiosis is suppressed by excessive phosphorus application.

Table 2 shows that root colonization decreased to 55.4% at 20 kg P ha^{-1}, indicating that high phosphorus availability decreases plant-AMF interactions. At 10 kg P ha^{-1}, root colonization reached 78.9%, which was substantially greater than 28.6% in control plants. In plants treated with AMF, yield indices such as grains per spike, 1000-grain weight, and overall grain yield were markedly improved. 10 kg P ha^{-1} produced the best yield, whereas 20 kg P ha^{-1} produced fewer advantages, most likely as a result of less AMF colonization.

Grain yield rose from 2100 kg ha^{-1} in the control to 3200 kg ha^{-1} at 10 kg P ha^{-1}, but decreased to 2700 kg ha^{-1} at 20 kg P ha^{-1}, as shown in Table 3, confirming that mycorrhizal advantages are maximized at moderate phosphorus levels.

Higher phosphorus uptake, especially at 5 and 10 kg P ha^{-1}, was seen in wheat plants inoculated with AMF, suggesting better nutrient absorption. Plots treated with AMF had decreased amounts of accessible phosphorus, according to soil tests, indicating that plants were effectively utilizing the phosphorus. Table 4 illustrates how AMF improves phosphorus acquisition by showing that grain phosphorus content rose to 0.42% at 10 kg P ha^{-1}, while leaf phosphorus content was 0.35% at 10 kg P ha^{-1}, compared to 0.21% in control plants. These findings highlight the potential of AMF inoculation to increase wheat yield while lowering dependency on synthetic phosphorus fertilizers, especially at intermediate phosphorus levels (5–10 kg P ha^{-1}). To improve phosphorus management techniques, future research should examine long-term effects on soil health and AMF interactions with soil microorganisms.

IV. DISCUSSION

In wheat (*Triticum aestivum* var. Swift), this study shows that mycorrhizal inoculation with *Glomus intraradices* greatly improves plant growth, yield, and phosphorus uptake, especially at moderate phosphorus levels (5 and 10 kg P ha^{-1}). Arbuscular mycorrhizal fungi (AMF) enhance nutrient absorption, particularly in soils lacking phosphorus, which is consistent with another research (Smith & Read, 2008; Zhu et al., 2016). AMF's ability to improve phosphorus use efficiency and lessen reliance on synthetic fertilizers while preserving wheat output is highlighted by the study.

Plants that were inoculated with AMF showed better early development, as seen by higher biomass accumulation, root length, and plant height. The greatest advantages were at 5 and 10 kg P ha^{-1}, since greater phosphorus levels (20 kg P ha^{-1}) prevented AMF colonization, probably because plants were less dependent on fungal symbiosis (Smith & Smith, 2011). These findings are consistent with earlier studies showing that wheat and cereals benefit most from AMF at moderate phosphorus levels (Cui et al., 2020).

At 5 and 10 kg P ha^{-1}, root colonization rates peaked, supporting the notion that AMF symbiosis is supported by moderate phosphorus. At 20 kg P ha^{-1}, on the other hand, colonization decreased, possibly as a result of less root exudates influencing fungal interactions (Balzergue et al., 2011). This result is consistent with studies that demonstrate the detrimental effects of high phosphorus levels on AMF colonization and function (Smith et al., 2015; Thirkell et al., 2016). AMF's function in nutrient acquisition was further highlighted by the fact that mycorrhizal reliance peaked in phosphorus-deficient environments. AMF-inoculated plants showed markedly enhanced yield metrics, such as grains per spike, 1000-grain weight, and total grain yield, at 5 and 10 kg P ha^{-1}. The highest productivity was seen at 10 kg P ha^{-1}.

These results validate that AMF-driven wheat production is optimized in moderate phosphorus conditions. However, because of less AMF colonization, yield increases decreased at 20 kg P ha^{-1} (Plenchette et al., 1983). In line with earlier studies, AMF also improved plant resilience and nitrogen uptake (Mäder et al., 2011; Ortas, 2012). AMF's function in nutrient uptake was further supported by phosphorus analysis, which showed noticeably greater phosphorus concentrations in leaf and grain tissues at 10 kg P ha^{-1} (Tawaraya et al., 2012; Cui et al., 2020). Plots treated with AMF had less accessible phosphorus, according to soil tests, indicating effective nutrient absorption. Furthermore, elevated microbial biomass phosphorus demonstrated the beneficial effects of AMF on nutrient cycling and soil microbial activity (Borie et al., 2019).

AMF inoculation has the potential to reduce phosphorus fertilizer inputs while maintaining or improving wheat yields; using AMF inoculation as a sustainable agricultural practice could reduce environmental risks associated with excessive phosphorus application and improve nutrient-use efficiency. The two-way ANOVA results showed a significant interaction between AMF inoculation and phosphorus fertilization, supporting the idea that moderate phosphorus levels maximize AMF efficiency (Gai et al., 2017; Rillig et al., 2019).

V. CONCLUSION

This study emphasizes how advantageous *Glomus intraradices* are for wheat yield, especially when phosphorus levels are modest (5–10 kg P ha^{-1}). Plant growth, yield, and phosphorus uptake were all markedly enhanced by AMF inoculation, facilitating its incorporation into sustainable agriculture. To improve AMF-based nutrient management techniques, future studies should investigate phosphorus solubilization mechanisms, microbial interactions, and long-term ecological effects.

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Table 1. Effect of Mycorrhizal Inoculation on Plant Growth Parameters

Treatment (P kg ha^{-1})	Plant Height (cm)	Root Length (cm)	Biomass (g/plant)
Control (0)	45.3 ± 2.1	12.5 ± 1.0	8.4 ± 0.6
5	52.8 ± 1.9	15.7 ± 1.2	12.3 ± 0.8
10	55.4 ± 2.3	17.3 ± 1.3	14.6 ± 0.9
20	50.1 ± 2.0	14.9 ± 1.1	10.2 ± 0.7

Table 2. Root Colonization Percentage Under Different P Levels

Treatment (P kg ha^{-1})	Control (0)	5	10	20
Root Colonization (%)	28.6 ± 1.5	72.3 ± 2.0	78.9 ± 2.3	55.4 ± 1.8

Table 3. Effect of Mycorrhiza on Yield Components

Treatment (P kg ha^{-1})	Grains per Spike	1000-Grain Weight (g)	Grain Yield (kg ha^{-1})
Control (0)	24.5 ± 1.2	35.2 ± 1.5	2100 ± 150
5	30.7 ± 1.5	38.9 ± 1.7	2900 ± 180
10	33.2 ± 1.7	42.1 ± 1.8	3200 ± 200
20	29.0 ± 1.6	37.8 ± 1.6	2700 ± 170

Table 4. Phosphorus Uptake in Mycorrhiza-Inoculated Wheat Plants

Treatment (P kg ha^{-1})	Control (0)	5	10	20
Leaf P Content (%)	0.21 ± 0.02	0.31 ± 0.02	0.35 ± 0.03	0.29 ± 0.02
Grain P Content (%)	0.28 ± 0.03	0.38 ± 0.03	0.42 ± 0.04	0.36 ± 0.03