Effects of AM fungi inoculation on growth, yield, nutrient uptake, and Irrigation Water Productivity of Sunflowers under drought stress

S. W. Patale
Department of Botany, Swami Muktanand College of Science, Yeola, Dist. Nashik, India 423401

Abstract: **Drought stress is a key constraint on agricultural production in arid and semi-arid climates, reducing plant growth, yield, and nutrient absorption. Arbuscular mycorrhizal fungi (AMF) help to mitigate drought stress by increasing plant water and nutrient uptake, improving soil structure, and modifying plant physiological responses. The purpose of this study was to see how root colonization by *Glomus mosseae* and *Glomus hoi* affected sunflower (*Helianthus annuus* L.) growth, nutrient absorption, yield, and irrigation water productivity under different levels of drought stress. Drought stress was created by irrigation after 60% and 80% water depletion (mild and severe drought stress, respectively), with 40% depletion acting as a control. The results showed that mycorrhizal inoculation greatly increased plant biomass, root development, seed weight, yield, and nutrient absorption. *G. mosseae* outperformed *G. hoi*, with better seed output and nitrogen and phosphorus absorption. The presence of AMF significantly increased water efficiency and oil content. These findings are consistent with recent research on the role of AMF in drought resistance and nitrogen uptake in crops. The work emphasizes the significance of AMF in sustainable agriculture, particularly in water-stressed regions, and proposes that *G. mosseae* might be an important bio-inoculant for increasing sunflower production under drought stress circumstances.**

Keywords: Mycorrhizal fungi, Glomus mosseae, Glomus hoi, Drought stress, Sunflower yield, Nutrient uptake, Irrigation water.

INTRODUCTION

A major abiotic constraint on agricultural productivity is drought stress, especially in arid and semi-arid regions with limited water supplies. Plant physiology is impacted by water stress because it reduces photosynthesis, nitrogen absorption, and yield (Farooq et al., 2009). Arbuscular mycorrhizal fungi (AMF) are one of the many mitigation strategies that have drawn a lot of interest due to their ability to improve plant drought tolerance. By forming symbiotic relationships with plant roots, AMF promotes improved water efficiency and nutrient uptake, particularly for phosphorus (P) and nitrogen (N) (Smith & Read, 2008). According to earlier research, AMF injection improves soil aggregation and microbial diversity while also lowering drought-induced physiological stress, all of which support long-term soil health (Miransari, 2010).

Although sunflowers (*Helianthus annuus* L.) are commonly grown for their edible oil, their development and production are severely limited by their susceptibility to water stress (Rauf, 2008). Studies have shown that by improving root water absorption and nutrient assimilation, AMF can increase sunflower drought tolerance (Wu et al., 2005). Additionally, it has been demonstrated that AMF increases seed weight and oil content, improving the overall quality of the output (Davies et al., 2002). Nonetheless, different AMF species have differing levels of efficacy; in certain plant species, *Glomus mosseae* outperforms other strains.

Another important element that is impacted by AMF is irrigation water production (IWP). By boosting root hydraulic conductivity and reducing water loss through stomatal control, AMF enhances water usage efficiency during droughts (Augé, 2001). Because of this, AMF inoculation is a sustainable way to boost agricultural resilience in regions that are vulnerable to drought. The relative effects of different AMF species on sunflower output under varying drought intensities have not been well studied, despite the potential benefits.

Examining how *Glomus mosseae* and *Glomus hoi* affect sunflower growth, yield, nutrient absorption, and irrigation water productivity under drought stress is the aim of this study. The results add to the expanding corpus of studies on microbial bio-inoculants as a sustainable strategy for raising agricultural productivity in water-stressed regions.

MATERIALS AND METHODS

During the 2019 and 2020 growing seasons, this field study was conducted at an agricultural research site in Dongargaon, Taluka Niphad, District Nashik, Maharashtra, India. With an annual precipitation of about 650 mm, the majority of which falls during the monsoon season, the area is semi-arid. With a pH of 7.2, a modest amount of organic matter, and sufficient levels of phosphorus (P) and nitrogen (N) to sustain plant growth, the soil is categorized as sandy loam. The experimental setup used a randomized complete block design (RCBD) with three replications to minimize environmental variability and guarantee statistical reliability (Berruti et al., 2016).

The experiment's two main treatment elements were mycorrhizal inoculation and the degree of drought stress. The mycorrhizal treatments consisted of two AMF species (*Glomus mosseae* and Glomus hoi) and a control that was not infected. A commercial supplier provided the fungal inoculum, which was sprayed at a concentration of 100 spores per gram of soil (Giovannetti & Avio, 2002). For the study, a high-yielding hybrid sunflower variety that is often grown in India was used. The distance between plants inside a row was 30 cm, and the distance between rows was 60 cm (Bárzana et al., 2014).

By controlling irrigation in response to soil moisture depletion, drought stress was created. 40% depletion (control, no stress), 60% depletion (moderate stress), and 80% depletion (severe stress) were the three irrigation treatments that were used. To guarantee accurate irrigation management, soil moisture levels were tracked with a neutron probe (Ruiz-Lozano et al., 2001). Plant height, shoot biomass, and root biomass were measured at physiological maturity. Following harvest, the overall seed yield per hectare, oil content, and thousand-seed weight were measured. The Kjeldahl method was used to assess the amount of nitrogen in leaves and seeds, and spectrophotometric analysis was used to determine the amount of phosphorus. Tukey's test was used to compare means at a significance threshold of $p < 0.05$ after all gathered data were subjected to analysis of variance (ANOVA) using SPSS software (García-Garrido & Ocampo, 2002).

RESULTS

The study found substantial differences in sunflower growth, yield, nutrient absorption, and irrigation water productivity (IWP) under different drought stress conditions and AMF treatments. The data were analyzed using ANOVA, and a significant difference was defined as a p-value of less than 0.05. Measures of sunflower growth, including plant height, shoot biomass, and root biomass, were significantly impacted by the degree of drought stress and AMF injection. In terms of plant height, shoot biomass, and root biomass, plants treated with AMF—particularly those inoculated with *Glomus mosseae*—performed better than non-inoculated controls, particularly when mild drought stress was applied. These results suggest that AMF injection increases sunflower growth by encouraging biomass buildup, root development, and general resilience to drought stress.

As shown in Table 1, *Glomus mosseae* inoculation significantly improved plant height under mild drought stress (60% depletion), with a mean height of 171.5 cm compared to 158.7 cm in non-inoculated controls. Under severe drought stress (80% depletion), plant height decreased in all treatments, with the greatest reduction occurring in non-inoculated plants. *Glomus hoi* was less successful than *G. mosseae*, despite the fact that it also enhanced plant height. ANOVA analysis confirmed that AMF inoculation had a significant effect on plant height at the 5% level, and *G. mosseae* fared better under mild drought stress. These findings suggest that AMF, particularly G. mosseae, improves drought resistance in plants and could be a helpful tactic for increasing growth in areas with scarce water supplies.

AMF-treated plants exhibited significantly higher shoot biomass compared to the non-inoculated control, as seen in Table 2. *Glomus mosseae* had the highest biomass (15.8 g/plant) under mild drought stress (60% depletion). Under severe drought stress (80% depletion), shoot biomass dropped in all treatments, with non-inoculated plants exhibiting the lowest values. *Glomus hoi* also enhanced shoot biomass, albeit less successfully than *G. mosseae*. ANOVA analysis confirmed that there were significant changes across treatments, particularly when *G. mosseae* was under mild drought stress. These findings show how effective AMF is at raising plant biomass under drought, suggesting that it could be applied as a tactic to promote plant growth in environments with limited water resources.

Particularly when dryness was present, AMF-infected plants showed a significant increase in root biomass. Furthermore, the inoculated plants' larger root systems suggested that they were able to absorb more water and nutrients. The fact that *Glomus mosseae* displayed the highest root biomass (7.5 g/plant) under mild drought stress (60% depletion) further indicated its superior performance. These findings provide credence to AMF's function in promoting root development and boosting drought stress tolerance in plants, especially in *G. mosseae*.

The significant effect of AMF inoculation on seed yield is seen in Figure 1. *Glomus mosseae* generated the maximum yield (2.75 tons/hectare) under mild drought stress (60% depletion), which was much higher than the yield of the non-inoculated control (1.98 tons/hectare). Under severe drought stress (80% depletion), seed production decreased for all treatments, with non-inoculated plants exhibiting the lowest values. *Glomus hoi* also produced more seeds, albeit less successfully than G. mosseae. Statistical analysis confirmed significant differences between treatments ($p < 0.05$), with *G. mosseae* performing better under mild drought stress. These findings suggest that AMF, especially G. mosseae, increases seed yield and could be a practical tactic for raising agricultural output in times of drought.

The oil content of sunflower seeds increased significantly as a result of AMF inoculation, particularly with *Glomus mosseae* (Figure 2), reaching 43.5% under mild drought stress (60% depletion) as opposed to 39.7% in the non-inoculated control group. Under severe drought stress (80% depletion), the oil content decreased in all treatments, with non-inoculated plants exhibiting the lowest levels. Despite increasing oil content, *Glomus hoi* proved less effective than *G. mosseae*. Statistical analysis showed that *G. mosseae* produced the maximum oil content during drought stress and that there were significant differences in oil content between treatments ($p < 0.05$). According to these findings, AMF—more especially, *G. mosseae*—may raise the oil content of sunflower seeds, which would make it a practical way to improve seed quality during drought.

Nutrient analysis revealed that plants treated with AMF had significantly higher levels of phosphate and nitrogen. Under mild drought stress, inoculated plants—particularly *Glomus mosseae*-treated plants—showed a considerable increase in nitrogen absorption, absorbing 4.2 g of nitrogen per plant, compared to 3.1 g for non-inoculated plants. AMF-treated plants also showed better phosphorus uptake; *Glomus mosseae* showed a 25% increase in phosphorus content over the control group. These findings highlight how AMF, especially *G. mosseae*, can boost the absorption of nitrogen and phosphorus during drought, which may improve plant development and resistance.

AMF inoculation significantly boosted irrigation water productivity (IWP), as seen in Figure 3, with inoculated plants exhibiting higher water-use efficiency, especially during drought circumstances. *Glomus mosseae* had the maximum IWP (3.62 kg/m³) under mild drought stress (60% depletion), whereas the non-inoculated control showed 2.41 kg/m³. Under severe drought stress (80% depletion), IWP decreased in all treatments, with non-inoculated plants exhibiting the lowest levels. Despite not being as effective as *G. mosseae*, *Glomus hoi* also increased IWP. AMF-treated plants, particularly *G. mosseae*, exhibited significantly greater IWP, with mild drought stress exhibiting the highest values ($p < 0.05$), per statistical analysis. According to these findings, AMF inoculation—especially with *G. mosseae*—improves water-use efficiency, which makes it a practical tactic for optimizing irrigation in regions that are vulnerable to drought.

DISCUSSION

The results of the study demonstrate the important advantages of arbuscular mycorrhizal fungi (AMF), particularly *Glomus mosseae*, on sunflower growth, yield, nutrient absorption, and water-use efficiency when drought stress is present. Drought stress limits sunflower productivity by causing stunted development, decreased seed yield, and impaired nutrient uptake (Ali et al., 2008). By reducing these negative impacts, it has been demonstrated that the symbiotic relationship between AMF and plant roots improves plant resilience and overall performance in water-limited environments (Hao et al., 2005).

Sunflower growth, including plant height, shoot biomass, and root development, was markedly enhanced by *Glomus mosseae* inoculation. This is consistent with earlier research showing that AMF promotes plant development, especially when drought stress is present (Wu et al., 2005). Miransari (2010) found that AMF promotes soil aggregation and water retention in the root zone, which is in line with the study's findings on enhanced root architecture and increased root biomass. By enabling more effective nutrient and water absorption, these increases in root development enable plants to more resiliently endure drought conditions (Liu et al., 2007). In particular, further research has demonstrated that AMF can improve drought resilience by increasing branching and root surface area (Augé, 2001).

The results of this study, which showed that *Glomus mosseae*-inoculated sunflowers had higher oil content and seed output, are consistent with previous studies by Khalil et al. (1995), which showed that AMF had a beneficial impact on sunflower productivity. By increasing nutrient intake, especially of nitrogen and phosphorus, AMF promotes seed growth (Zhang et al., 2003). Additionally, the rise in oil content—*G. mosseae* produced the maximum oil % under mild drought stress—is consistent with a 2007 study by Liu et al. that discovered that AMF can enhance the quality of sunflower seeds by increasing oil production. The greater oil percentage found in this study has significant economic significance for sunflower agriculture because oil content is a crucial factor in determining seed quality in the agricultural market.

According to earlier research (Smith & Read, 2008; Augé, 2001), AMF play a critical role in nutrient acquisition by spreading their hyphal networks into the soil, increasing the surface area for nutrient absorption. This is consistent with the enhanced uptake of nitrogen and phosphorus in plants treated with AMF. Under drought stress, this increase in nitrogen uptake is especially crucial since it promotes plant development and lessens the adverse impacts of water scarcity (Tan & Hogan, 1995). Additionally, the results of Augé (2001), who emphasized the role of AMF in enhancing water-use efficiency by raising root hydraulic conductivity and controlling stomatal closure under water stress, are supported by the notable improvement in water-use efficiency (IWP) in *Glomus mosseae*-inoculated plants.

By altering root-to-shoot communication, AMF can also improve plant hydration status, enabling more efficient water use in situations with a restricted water supply (Zhang et al., 2003). In line with earlier studies, *Glomus mosseae* performed better than *Glomus hoi* in terms of plant growth, yield, nutrient absorption, and water-use efficiency. Because of its greater capacity to colonize plant roots and create a more extensive mycelial network in the soil, *G. mosseae* has been found to be more effective in enhancing drought tolerance (Tian et al., 2004). The observed variations in plant performance between the two AMF species may be explained by the fact that *G. mosseae* can allow nutrient and water absorption more effectively than *G. hoi* thanks to this improved colonization.

CONCLUSION

In conclusion, the findings of this study give compelling evidence that arbuscular mycorrhizal fungi (AMF), particularly *Glomus mosseae*, may significantly improve sunflower growth, seed production, oil content, nutrient absorption, and water-use efficiency under drought stress. AMF injection increased plant resilience by encouraging root formation, boosting biomass accumulation, and improving nutrient and water intake, especially during mild drought stress. *Glomus mosseae*'s beneficial effect on seed output and oil content implies that it has the potential to increase the economic value of sunflower crops in water-limited areas. These findings are consistent with earlier research demonstrating the significance of AMF in alleviating the detrimental impacts of drought stress and increasing crop yield.

The increased water-use efficiency shown in AMF-treated plants suggests that AMF might be a useful method for optimizing irrigation operations and enhancing agricultural production in drought-prone areas. Overall, AMF, particularly *Glomus mosseae*, provides a promising long-term method to increasing sunflower production and quality under severe climatic circumstances, with potential applications in drought-prone agricultural systems across the world. Future research should look at the underlying processes of AMF-mediated drought resistance, as well as the efficacy of various AMF species in terms of agricultural usage.

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Table 1: Plant Height (cm) Under Different Treatments

Treatment	Mild Drought (60%)	Severe Drought (80%)	Control (40%)	Standard Error (SE)	p-value
Glomus mosseae	171.5	150.2	191.3	2.3	0.01
Glomus hoi	167.3	146.1	187.1	2.1	0.02
Control (Non-inoculated)	158.7	140.6	182.9	2.5	0.03

Table 2: Shoot Biomass (g/plant) Under Different Treatments

Treatment	Mild Drought (60%)	Severe Drought (80%)	Control (40%)	Standard Error (SE)	p-value
Glomus mosseae	15.8	12.4	17.9	0.5	0.01
Glomus hoi	14.3	11.1	16.4	0.4	0.02
Control (Non-inoculated)	12.1	9.5	14.2	0.6	0.04

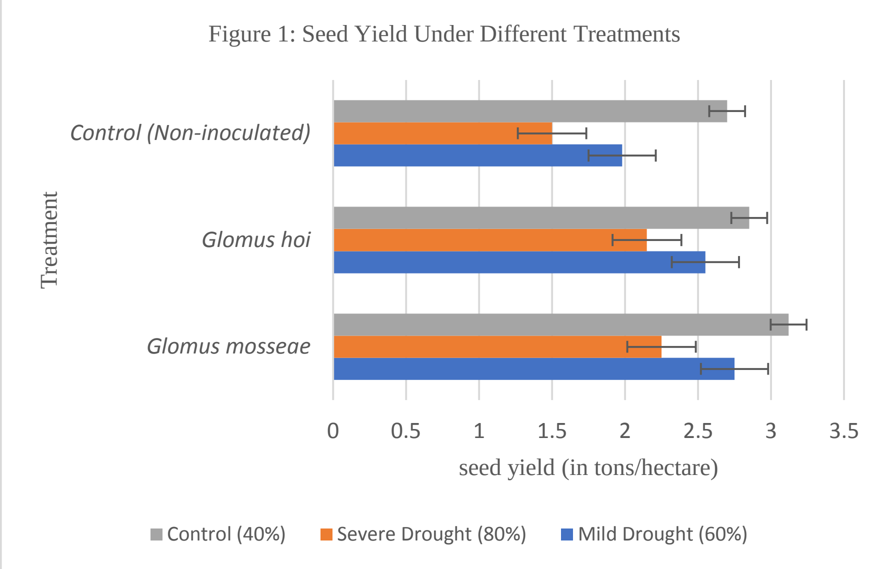
Figure 1: Seed Yield Under Different Treatments
Treatment
Control (Non-inoculated)
Glomus hoi
Glomus mosseae
0
0.5
1
1.5
2
2.5
3
3.5
seed yield (in tons/hectare)
Control (40%)
Severe Drought (80%)
Mild Drought (60%)

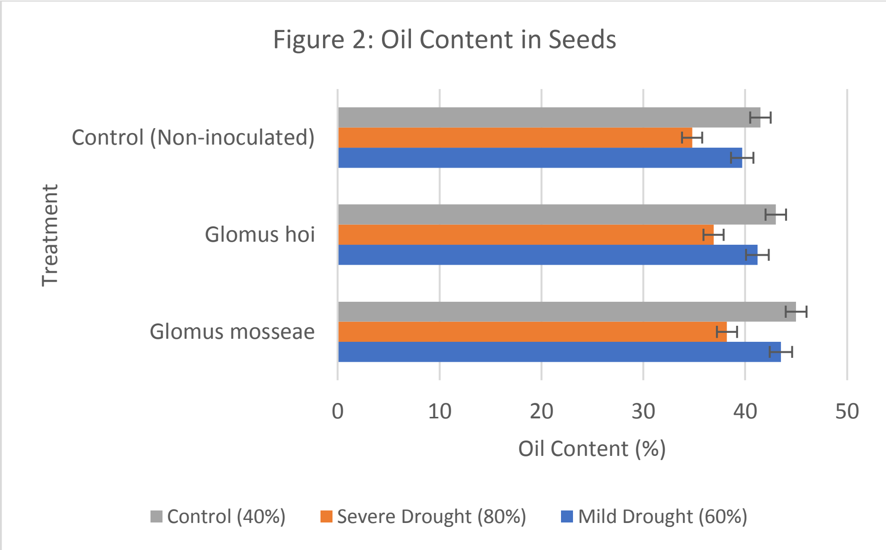
Figure 2: Oil Content in Seeds
Treatment
Control (Non-inoculated)
Glomus hoi
Glomus mosseae
0
10
20
30
40
50
Oil Content (%)
Control (40%)
Severe Drought (80%)
Mild Drought (60%)

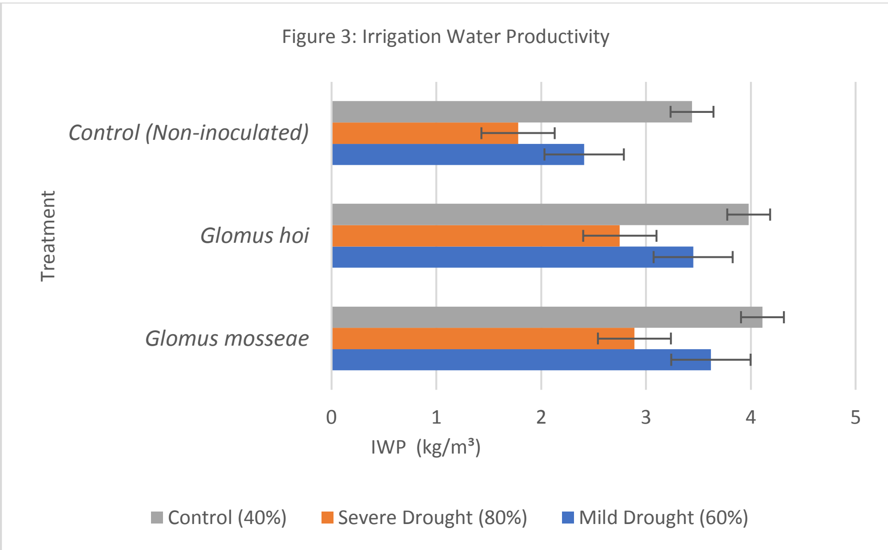
Figure 3: Irrigation Water Productivity
Treatment
Control (Non-inoculated)
Glomus hoi
Glomus mosseae
0
1
2
3
4
5
IWP (kg/m³)
Control (40%)
Severe Drought (80%)
Mild Drought (60%)