Original Article
DOI: https://doi.org/10.70749/ijbr.v3i5.1288

INDUS JOURNAL OF BIOSCIENCE RESEARCH
https://induspublishers.com/IJBR
ISSN: 2960-2793/ 2960-2807

Arbuscular Mycorrhizal Fungi (AMF) Helps in Mitigating the Growth and Enzymatic Changes in Potato (*Solanum tuberosum*) Seedlings under Salinity Stress Conditions

Khaliq Dad[1], Sumiyya Iftikhar[2], Faryal Siddique[2], Fakhra Asad[2], Aleeza Hasnain[2], Fatimah Bint-e-Usman[2], Faizan Khaliq[1], Muhammad Nawaz[2]

[1]Department of Botany, Government Graduate College, Shah Saddar Din, D.G.Khan, Pakistan
[2]Department of Environmental Sciences, Bahauddin Zakariya University, Multan, Pakistan

ARTICLE INFO

Keywords: Potato (*Solanum tuberosum*), Arbuscular mycorrhizal fungi (AMF), Growth parameters, Enzymatic parameters.

Correspondence to: Muhammad Nawaz, Department of Environmental Sciences, Bahauddin Zakariya University, Multan, Pakistan
Email: mnawaz@bzu.edu.pk

Declaration
Authors' Contribution: All authors equally contributed to the study and approved the final manuscript.
Conflict of Interest: No conflict of interest.
Funding: No funding received by the authors.

Article History
Received: 11-02-2025 Revised: 21-04-2025
Accepted: 05-05-2025 Published: 15-05-2025

ABSTRACT

Salinity stress is a major problem that limits the growth and yield of crops worldwide. Arbuscular mycorrhizal fungi (AMF) are known to improve plant growth by enhancing nutrient uptake and stress tolerance. A pot experiment was conducted by using *Funneliformis mosseae* and salinity levels of 150 mM & 200 mM NaCl, arranged in a completely randomized block design manner in order to examine the potential of mycorrhizal fungi in mitigating the adverse impacts of salinity. The results showed that inoculation markedly enhanced growth parameters i.e. root length increased by 88.25%, shoot length by 220.1%, root fresh weight by 98.7%, and shoot fresh weight by 77.2% as compared to control. Chlorophyll contents were also affected under salt stress by 23.2% and 9.2%, while found improved with AMF. Superoxide Dismutase (SOD) activity was observed increased by 28.9%, Peroxidase (POD) activity increased to 36.4%, and Ascorbate Peroxidase (APX) activity by 56.25% as compared to the control. In the presence of 200 mM NaCl, AMF-treated plants exhibited SOD activity at 8.5 µmol/g fw and POD activity at 1.35 µmol/g fw, reflecting improved oxidative stress tolerance. Catalase (CAT) activity was enhanced by 50% in AMF-treated plants under salt stress. These results demonstrated that AMF played a crucial role in enhancing antioxidant defense mechanisms and mitigating oxidative damage in potato plants under salt stress conditions. So it can be concluded that AMF inoculation possesses potential in mitigating the salt stress and induce changes in growth and physiological attributes of plants.

INTRODUCTION

Soil is a vital, non-renewable resource, meaning that once it's degraded, it cannot be restored. Salinity is a major factor in soil degradation, ranking as the second leading cause. Every day, approximately 2,000 hectares of arable land are lost globally due to salinization. This issue can reduce crop yields by 10-25% and, in severe cases, can halt cropping entirely, contributing to desertification. Addressing soil salinization is crucial for maintaining food security and preventing further desertification (Shahid et al.2018). Salinity impacts plants by introducing several constraints. The first is osmotic stress, where a drop in external water potential makes it harder for plants to absorb water. This immediately triggers changes inside the plant: most noticeably, the growth of both roots and shoots slows down sharply because the cells lose turgor pressure, which is essential for expansion. The second problem is ionic imbalance, often referred to as ionic stress or ion toxicity. This happens when too much sodium (Na^+) and chloride (Cl^-) build up inside the plant's active cells. Although high levels of sodium can damage plant metabolism and even kill the plant (Zhange et al. 2020), the exact mechanisms behind this toxicity are still not fully understood. Among major crops, potatoes, which are the fourth most important food source worldwide, are especially sensitive to soil salinity (Gebrechristos and Chen 2028).

Potatoes, one of the world's most important food crops, are particularly vulnerable to soil salinity. Ranked as the fourth most vital staple globally, potatoes are rich in carbohydrates, protein, fiber, vitamin C, riboflavin, and essential minerals. With the global population expected to reach between 8.8 and 10 billion by 2050 (Shahid et al.2018), potatoes will be increasingly important in ensuring food and nutrition security, especially in developing nations. Excessive salinity, on the other hand, throws this equilibrium off and causes more activity of antioxidant enzymes such superoxide dismutase (SOD), peroxidase (POD), and catalase

(CAT). Often, the activity of these enzymes is used to evaluate a plant's salt tolerance; they are also rather important in detoxifying ROS and free radicals. High salt levels cause a reduction in potassium in the plant, which compromises the activity of these antioxidant enzymes (Boorboori and Lackóová 2025) This not only causes ROS buildup but also interferes with vital activities, including photosynthesis, especially the carbon dioxide (CO_2) fixation. While increased chloride levels lower chlorophyll content, high amounts of ROS can harm cellular components like proteins, lipids, and DNA. Salinity decreases the water potential of the soil as well, therefore increasing the difficulty for plants to absorb water. Plants then suffer osmotic stress, which results in lower turgor pressure in the leaves, stomatal closure, and a further drop in photosynthesis and growth (Han et al.2023).

Among the visible consequences of salt stress are fewer leaves, yellowing, curling, wilting, and finally leaf drop (Chourasia et al. 2021). The accumulation of sodium ions also disrupts potassium absorption a vital nutrient for many enzyme activities in the plant (Wang et al. 2013). Naturally, plants support a great range of microorganisms affecting their structure, metabolism, and resistance (Ruiz-Lozano et al. 2012). Among the most advantageous are arbuscular mycorrhizal (AM) fungi, which create symbiotic interactions with plant roots. Under stress situations, these fungi are very useful as they enable plants to develop more strongly and provide more output (Smith, 2008). About 80% of terrestrial plants, including many important crops, can create these links (Willis et al.2013). Managing salt stress using biological agents such as mycorrhizal fungi is turning out to be an optimistic approach. By improving nitrogen uptake and affecting both physiological and biochemical processes, AM fungi help plants manage salt. Much research has demonstrated that even in saline settings, inoculating crops with AM fungus results in enhancements in plant health and production (Kapoor et al.2013). Consequently, these fungi provide a quick, durable way to restore saline soils and increase the yield and quality of several economically significant crops (Dar etl.2013). Given the sensitivity of potatoes to soil salinity, this study aims to explore the role of AMF inoculants in mitigating salt-induced stress and enhancing potato growth. While many studies have explored the role of AMF in salt stress mitigation, there remains a need for in-depth analysis of how different NaCl concentrations affect enzymatic activities and nutrient uptake in potato seedlings.

MATERIALS AND METHODS

Experimental set up

A completely randomized block design (CRBD) pot experiment was conducted at the Department of Environmental Sciences, BZU Multan to observe the effects of salt stress and the role of AMF in alleviating the growth and enzymatic activities of potato seedlings. Pots were filled with sandy loamy soil collected from the upper layer (0-30 cm depth) of the lawn of university botanical garden having nitrogen, phosphorus, and potassium contents 30, 15 and 1.36 mg/kg of soil respectively. The collected soil was sterilized at 60°C for 48 hours and homogenized in order to avoid contamination. High-quality potato seeds (*Solanum tuberosum*) were obtained from Harral Seed Corporation (Pvt) Ltd., Multan, and used for the experiment. Five healthy and equal sized potato seeds were sown in pots inoculated with *Funneliformis mosseae.*

Isolation of AMF from Plant Roots

The Wet Sieving and Decanting method was used to isolate AMF spores from plant roots. Roots were cleaned, chopped into tiny bits, and soaked in sterile water to release spores. Spore separation from root fragments was accomplished by passing the mixture through sieves measuring 100 µm and 50 µm. Centrifuge tubes were used to gather the spores and combine them with a sucrose solution. After centrifugation, the spores floated to the top, and the liquid was carefully poured out. The spores were washed with sterile water and examined under a microscope using Trypan blue stain for clarity. About 0.8 grams of soil containing 40 spores per gram of *Funneliformis mosseae* was mixed with sterile soil and added to each 1 kg pot for the experiment.

Application of NaCl Concentrations

After being surface sterilized for three minutes with 0.5% sodium hypochlorite, the potato seeds were rinsed with distilled water and allowed to germinate in sandy soil. Healthy seedlings were moved into 20 cm by 20 cm pots with 0.8 g of *Funneliformis mosseae* (AMF) 3 cm below the soil's surface and 6.0 g of soil. There were six groups of treatment: control (No AMF, No NaCl), AMF only (0.8 g AMF, No NaCl), 150 mM NaCl + AMF, 150 mM NaCl, 200 mM NaCl + AMF, and 200 mM NaCl.

Assessments of parameters

Fresh and dry weights of roots, shoots of both AMF-treated and non-inoculated plants were assessed by using digital balance while method of Arnon 1949, which involves acetone extraction, centrifugation, and absorbance readings at particular wavelengths, was used to measure the amounts of chlorophyll contents of the leaves using the formula:

For Chlorophyll a (Chl a):

Chl a (µg/g fw)= $12.7 x A_{663} - 2.69 x A_{645}$

For Chlorophyll b (Chl b):

Chl b (µg/g fw)= $22.9 x A_{645} - 4.68 x A_{663}$

For Total Chlorophyll (Chl a + Chl b):

Total Chlorophyll Content (µg/g fw)= $20.2 x A_{663} + 8.02 x A_{645}$

Shoot samples were homogenized with Tris-HCl buffer, centrifuged at 10,000 rpm, and stored at -20°C. Fresh leaf samples were frozen in liquid nitrogen, crushed in phosphate buffer (pH 7), and centrifuged for protein extraction, with protein content measured using Bradford's method. SOD activity was assessed by measuring the reduction of nitroblue tetrazolium (NBT) at 560 nm, following the method described by Giannopolitis and Ries (1977). POD activity was determined by measuring the increase in absorbance at 470 nm using guaiacol as the substrate by using the method of Chance and Maehly (1955). Hydrogen peroxide, CAT, and APX activities were measured at 390 nm, 240 nm, and 290 nm, respectively. A BSA standard curve was used to estimate total protein.

Data Analysis

MS Excel was used for the calculation of mean and standard deviation while Two Way ANOVA was carried out by using Statistix 8.0 software. The significant difference between the treatments was analyzed by using Tukey's HSD post hoc test denoted by letters at ($p \leq 0.05$).

RESULTS

Effect of AMF and salt stress on growth Parameters.

As shown in Table 1, root length of AMF treated plant group was observed maximum of 88.25% as compared to control while reduction of 55.20% with AMF and 61.3% without AMF under 150 mM NaCl stress was also recorded. Root length further decreased to 25.1% without AMF and 35.48% with AMF at 200 mM NaCl compared to control while, in AMF treated plant, shoot length increased from 220.1% in control plants to 240.13%. Under 150 mM NaCl + AMF, shoot length was improved by 160.1%, and 120.3% under 200 mM NaCl + AMF, compared to 98.5% and 73.21% without AMF, respectively. The root fresh weight of AMF treated plants was increased to 138.2% while at 150 mM NaCl stress, root fresh weight dropped to 38.89% without AMF and 22.2% with AMF. Shoot fresh weight also improved with AMF alone, reaching 177.2%, but dropped under salt stress to 41.1% (NaCl + AMF) and 82% (NaCl + no AMF) as compared to the control. The chlorophyll content, including chlorophyll a and chlorophyll b, exhibited significant variations across different treatments. In the control group, chlorophyll a was measured at 19.28 µg/g, while chlorophyll b was 6.43 µg/g, indicating healthy photosynthetic activity. AMF inoculation without NaCl showed a notable increase in both chlorophyll a (27.23 µg/g) and chlorophyll b (9.08 µg/g), suggesting that AMF enhanced photosynthesis and chlorophyll production. However, under 150 mM NaCl + AMF, chlorophyll a and chlorophyll b decreased to 15.45 µg/g and 5.15 µg/g, respectively, indicating a decline in photosynthetic efficiency due to salt stress. In the absence of AMF under 150 mM NaCl, both chlorophyll a (13.35 µg/g) and chlorophyll b (4.45 µg/g) were further reduced, highlighting the detrimental effect of salinity on chlorophyll synthesis. A pronounced reduction was observed under 200 mM NaCl + AMF, with chlorophyll a at 7.13 µg/g and chlorophyll b at 2.38 µg/g, demonstrating a significant decline in chlorophyll content due to increased salinity, despite AMF inoculation. The most severe reduction occurred in the 200 mM NaCl + No AMF treatment, where chlorophyll a and chlorophyll b were the lowest at 2.78 µg/g and 0.93 µg/g, respectively, confirming the negative impact of high salt concentrations on chlorophyll contents.

Table 1

Effect of AMF and Salt stress on the growth parameters of the potato plant (Solanum tuberosum) at ($p<0.05$).

Treatments	Control	AMF, no NaCl	150mM NaCl + AMF	150mM NaCl + No AMF	200mM NaCl + AMF	200mM NaCl + No AMF
Root length (cm)	17.5±0.03^{d}	32.6±0.05^{a}	28.2±0.04^{b}	19.4±0.03^{c}	9.6±0.02^{e}	4.3±0.02^{f}
Shoot length(cm)	22.5±0.03^{c}	49.2±0.08^{a}	30.2±0.04^{b}	20.70.03^{c}	12.2±0.03^{d}	8.7±0.04^{e}
Shoot fresh weight (g)	34.6±0.05^{c}	74.3±1.6^{a}	51.4±1.2^{b}	35.7±0.08^{cd}	21.8±0.05^{e}	15±0.04^{f}
Root fresh weight (g)	30.1±0.04^{d}	55.8±0.9^{a}	48.3±0.06^{b}	33.5±0.9^{c}	16.5±0.02^{e}	7.5±0.08^{f}
Shoot dry weight (g)	13.5±0.05^{c}	23.6±0.5^{a}	15.7±0.07^{b}	9.3±0.05^{d}	5.2±0.04^{de}	4.1±0.05^{f}
Root dry weight (g)	8.5±0.06^{c}	15.4±0.04^{a}	11.8±0.04^{b}	7.3±0.03^{cd}	4.9±0.01^{e}	2.3±0.01^{f}
Chlorophyll a	19.2 ± 0.05^{b}	27.2± 0.6^{a}	15.4± 0.04^{c}	13.3 ± 0.02^{d}	7.1± 0.04^{e}	2.7 ± 0.02^{f}
Chlorophyll b	6.43 ± 0.02^{b}	9.0 ± 0.23^{a}	5.1± 0.01^{c}	4.4± 0.01^{de}	2.38 ±0.01^{f}	0.9 ±0.01^{g}
Total chlorophyll content (µg/g)	25.7±0.07^{b}	36.3±0.9^{a}	20.6±0.05^{c}	17.8 ±0.03^{d}	9.5 ±0.05^{e}	3.7 ±0.02^{f}

Effect of AMF and salt stress on enzymatic parameters

Total soluble protein content was significantly reduced under salt stress but was enhanced by AMF inoculation. The control plants had a total soluble protein content of 2.2 mg/g fw. AMF inoculation without salt stress increased protein content by 41%. Under 150 mM NaCl + AMF, protein content was 1.7 mg/g fw, a 22.7% reduction compared to the control. The 150 mM NaCl + No AMF treatment exhibited 1.1 mg/g fw, a 50%

reduction was observed as compared to control while under 200 mM NaCl + AMF, protein content was 1.3 mg/g fw, showing a 52.9% reduction from the control, while the 200 mM NaCl + No AMF treatment had the lowest protein content at 0.9 mg/g fw, a 59.1% reduction recorded as compared to control as shown in Fig. 1-6. SOD activity showed a significant increase under salt stress and was further enhanced by AMF inoculation as it helps improve the plant's antioxidant defense mechanisms. In the control group, the SOD activity was 4.5 µmol/g fw. however, AMF treatment without salt stress increased SOD activity by 28.9%, due to improvement in nutrient uptake. Under 150 mM NaCl + AMF, SOD activity increased by 62.2% but without AMF, SOD activity further increased by 79.1% compared to the control. With 200 mM NaCl + AMF, SOD activity reached to 88.9%, while the non-AMF treatment under 200 mM NaCl exhibited the highest SOD activity i.e. 96.4% increase compared to the control. POD activity also showed an increase with salt stress and AMF inoculation. Under AMF inoculation without NaCl, POD activity increased by 36.4%. while with 150 mM NaCl + AMF treatment, POD activity increased by 90.9%, but without AMF treatment under 150 mM NaCl exhibited a 127.3% increase. With 200 mM NaCl + AMF, POD activity was 1.35 µmol/g fw, reflecting a 145.5% increase, and the highest increase in POD activity was observed under 200 mM NaCl + No AMF, where POD activity reached to 181.8% increase as compared to control (Fig. 1-6). CAT activity also increased under salt stress, but AMF inoculation helped mitigating the extreme rise in CAT levels. AMF inoculation without salt stress resulted in a 25% increase in CAT activity and with 150 mM NaCl + AMF, CAT activity was observed 17% less compared to non-AMF treatment under 150 mM NaCl, 41.7% more than the control. The highest CAT activity was observed under 200 mM NaCl + No AMF, where CAT activity increased by 66.7%, reaching 40.0 µmol/g fw. Similarly, APX activity exhibited an increase under salt stress, but AMF inoculation resulted in a lower APX activity, indicating that AMF reduces oxidative damage by improving plant stress tolerance. AMF inoculation without salt stress resulted in a 56.25% increase to 12.5 µmol/g fw. Under 150 mM NaCl + AMF, APX activity increased by 150%, while 150 mM NaCl + No AMF exhibited 25.0 µmol/g fw, a 212.5% increase from the control. Under 200 mM NaCl + AMF, APX activity was 25% less compared to without AMF with 200 mM salt stress. Moreover, H_2O_2 levels were significantly enhanced under salt stress and were reduced by AMF inoculation. The control plants had H_2O_2 levels of 12.0 µM/g fw. AMF inoculation without salt stress reduced H_2O_2 levels by 16.7%, bringing the level to 10.0 µM/g fw. Under 150 mM NaCl + AMF, H_2O_2 levels were 22.0 µM/g fw, a 83.3% increase compared to the control.

Figure 1

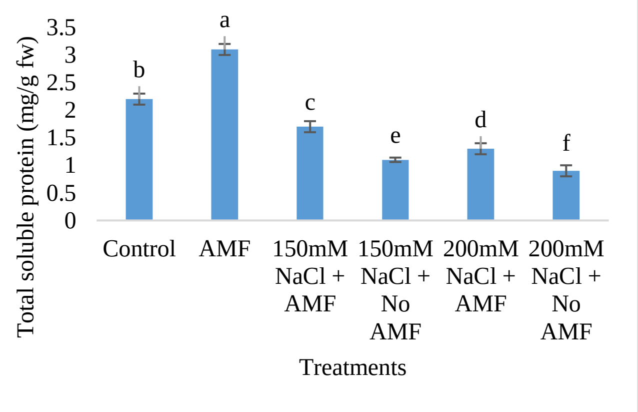

Figure 2

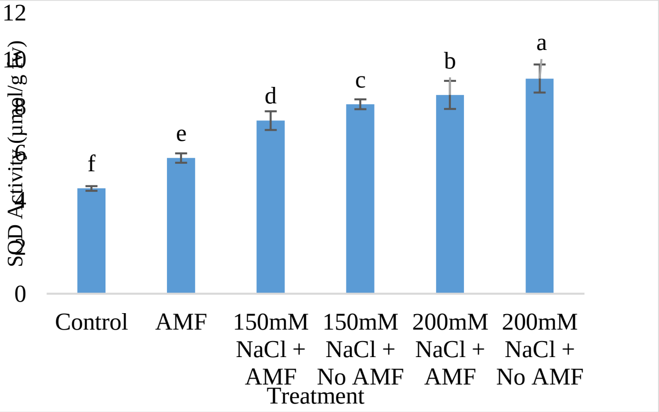

Figure 3

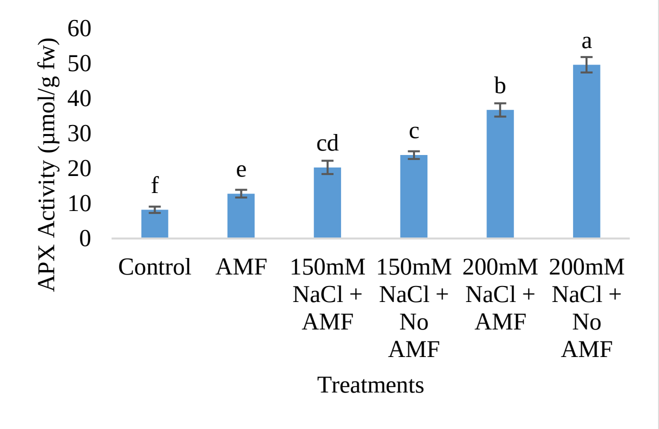

Figure 4

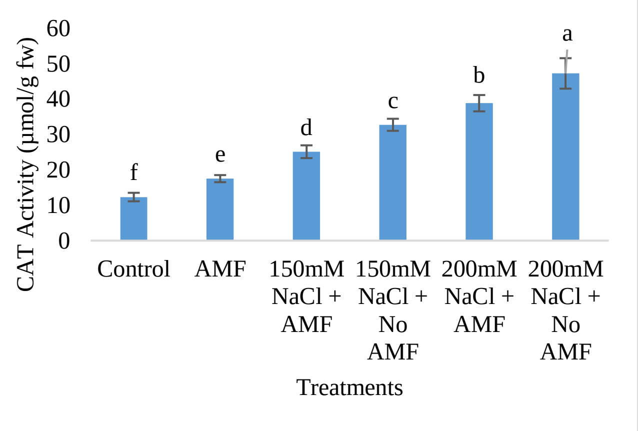

Figure 5

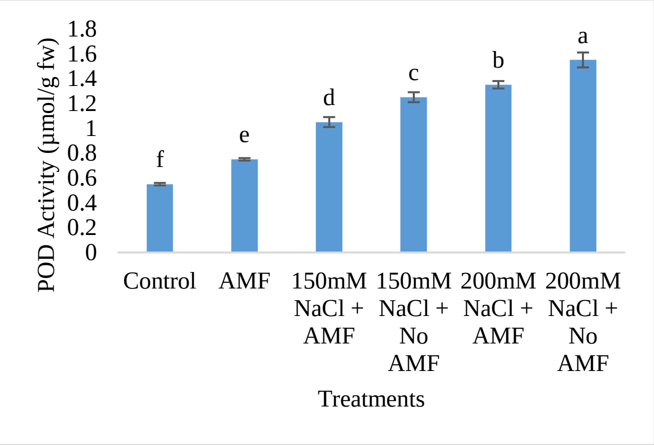

Figure 6

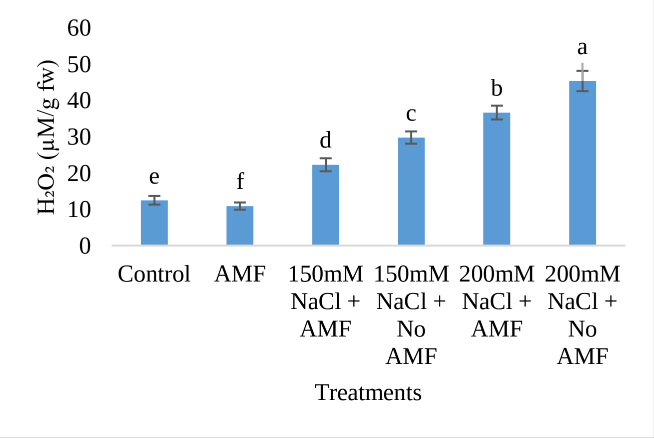

Figure 1-6

Effect of Salt stress and AMF inoculation on Total Soluble protein content (mg/g fw), SOD Activity (µmol/g fw), POD Activity (µmol/g fw), CAT Activity (µmol/g fw), APX Activity (µmol/g fw) and H_2O_2 (µM/g fw) on potato seedlings at significant level ($p<0.05$).

DISCUSSION

Soil salinization is a major cause of soil degradation worldwide, posing a serious threat to crop production, particularly in dry and semi-dry regions. In salt-affected and poorly drained soils, frequent surface salt buildup hinders plant growth. As researched by Nie et al. (2024), salinity negatively impacts plant health by disrupting key physiological processes such as growth, photosynthesis, and water balance. This is primarily due to the osmotic stress that impairs water absorption, ion toxicity caused by excessive sodium ions, and oxidative damage resulting from an increase in reactive oxygen species (ROS). The damage caused by salinity manifests as poor seed germination, reduced nutrient absorption, and degradation of cellular structures like membranes, proteins, and DNA (Arif et al.2020). An important approach for enabling plants to handle salt stress is by adding arbuscular mycorrhizal fungus (AMF) into the soil. AMF form symbiotic relationships with plant roots, where they extend their hyphal networks into the soil, enhancing nutrient uptake, especially phosphorus and nitrogen. Additionally, AMF contribute to maintaining ion balance and improving water absorption, which is critical under salt stress conditions (Saboor et al.2021). AMF are particularly vital in organic farming and have been shown to boost plant growth, with productivity increases ranging from 16% to 78% (Ebbisa et al. 2022). Furthermore, AMF helps preserve soil enzymes and organic matter, thus promoting healthier and more productive soils (Janah et al.2021). Research has demonstrated that AMF can improve plant tolerance to salinity by alleviating the negative effects of salt stress. This aligns with findings from Nie et al. (2024), who showed that plants inoculated with AMF exhibit better growth (46.3%) and survival under saline conditions compared to those without AMF. In potatoes, previous studies have also confirmed that AMF inoculation can enhance tuber yield and improve nutritional quality, particularly under salt stress (Douds et al.2007; Carrara et al.2023). Salt stress impedes water absorption, generates ion toxicity, and induces oxidative stress, all of which reduce plant biomass and hinder growth, as also reported by Han et al. (2023). The results of the present study reinforce these findings. Results showed that salinity significantly inhibited the growth of potato plants, as evidenced by reductions in both fresh and dry weights and a decrease in chlorophyll content. These findings confirm that potatoes are particularly sensitive to even low salinity levels. However, AMF-treated plants showed better growth parameters, including increased root and shoot length, as well as higher fresh and dry weights under salt stress AMF significantly enhanced the growth of potato plants, confirming the beneficial role of AMF in enhancing plant resilience under saline conditions. AMF inoculation improved root length by 86.25% and shoot length by 120.3% in the presence of 200 mM NaCl, while the control group showed a root length of 17.5 cm and a shoot length of 22.5 cm. In contrast, AMF-treated plants under salt stress had root lengths of 28.2 cm (150 mM NaCl + AMF) and 9.6 cm (200 mM NaCl + AMF). AMF also showed an increase in shoot fresh weight, with AMF-treated plants showing an increase of 177.2% under non-saline conditions, which aligns with the study by Wahab et al. (2023). An important consequence of salinity stress is the excessive generation of reactive oxygen species (ROS), which leads to oxidative stress and damage to plant cellular components. Under salt stress, plants often experience disruption in cellular integrity, leading to damage in key structures such as membranes, proteins, and DNA. AMF plays a crucial role in mitigating this oxidative stress by enhancing the plant's antioxidant defense system, effectively neutralizing ROS. AMF-inoculated plants have been shown to exhibit increased activities of antioxidant enzymes, including total soluble protein,ln CAT, APX, SOD, and peroxidase (POD), all of which work synergistically to reduce oxidative damage and protect cellular structures from deterioration. In this study, AMF-inoculated potato plants showed a significant increase in SOD and POD activity under salt stress, with SOD activity increasing by 28.9% and POD activity rising by 36.4% compared to non-inoculated. This increase in SOD and POD is consistent with Latef et al. (2011), who observed that AMF-inoculated plants exhibited higher levels of SOD and POD, contributing to enhanced oxidative stress tolerance. Additionally, CAT and APX activities were also elevated in AMF-treated plants under salinity, further supporting the protective role of AMF in managing ROS. The AMF treatment resulted in a 50% increase in CAT activity and a 56.25% increase in APX activity compared to the control group. This finding aligns with Pooja et al. (2025), who reported similar increases in antioxidant enzyme activities in AMF-treated plants exposed to salinity, enhancing their ability to neutralize H_2O_2 and other harmful ROS. The increase in SOD, POD, CAT, and APX activity under AMF inoculation demonstrates a robust defense mechanism against the oxidative damage caused by salinity. The AMF symbiosis likely improves the plant's nutrient uptake, particularly potassium, which is essential for the function of these enzymes. Furthermore, AMF improves the nutrient availability and water absorption capacity of plants, thus enhancing their overall stress tolerance. In contrast, non-AMF plants under salt stress showed significantly lower levels of these antioxidant enzymes, confirming that AMF inoculation offers a clear advantage in enhancing the plant's resilience to oxidative stress. This research highlights the importance of AMF inoculation in promoting growth and stress tolerance in potato plants under salt stress. While AMF inoculation showed positive effects on growth and chlorophyll content, the protective effect diminished at higher salinity concentrations, particularly at 200 mM NaCl. This suggests that while AMF can mitigate some of the detrimental effects of salinity, the intensity of the stress may eventually overwhelm the benefits of mycorrhizal symbiosis. These results are consistent with previous studies, such as Wahab et al. (2023), who found that AMF inoculation significantly improved plant growth under salinity stress but noted a diminishing effect at higher salt concentrations.

CONCLUSION

In conclusion, this study demonstrated the positive effects of arbuscular mycorrhizal fungi (AMF) inoculation on potato seedlings under salinity stress. Inoculation with *Funneliformis mosseae* significantly enhanced growth, biomass, and overall plant health, improving shoot and root lengths and promoting better nutrient absorption compared to non-inoculated plants. The AMF-treated plants also exhibited increased antioxidant enzyme activities, helping them better manage oxidative stress. However, the benefits were more pronounced under moderate salinity levels, highlighting the sensitivity of AMF's effectiveness to high salt conditions. These findings suggest that AMF inoculation, particularly with *Funneliformis mosseae*, could serve as an effective, eco-friendly strategy to enhance growth, nutrient uptake, and stress tolerance in potatoes, with potential applications as a biofertilizer for crops in saline-affected agricultural regions.

REFERENCES

1. Arif Y, Singh P, Siddiqui H, Bajguz A, Hayat S. Salinity induced physiological and biochemical changes in plants: An omic approach towards salt stress tolerance. Plant Physiol Biochem. 2020;156:64–77. https://doi.org/10.1016/j.plaphy.2020.08.042
2. Boorboori MR, Lackóová L. Arbuscular mycorrhizal fungi and salinity stress mitigation in plants. Front Plant Sci. 2025;15:1504970. https://doi.org/10.3389/fpls.2024.1504970
3. Carrara JE, Reddivari L, Lehotay SJ, Wang Y, Breksa AP, Venkateshwaran M. Arbuscular mycorrhizal fungi increase the yield and nutritional quality of yellow and purple fleshed potatoes (*Solanum tuberosum*). Am J Potato Res. 2023;100(3):210–20. https://doi.org/10.1007/s12230-023-09910-w
4. Chance B, Maehly AC. Assay of catalases and peroxidases. Methods in Enzymology. 1955;2:764–775. https://doi.org/10.1016/0076-6879(55)02015-2
5. Chourasia KN, Lal MK, Tiwari RK, Dev D, Kardile HB, Patil VU, Kumar A, Vanishree G, Kumar D, Bhardwaj V, Meena JK, Mangal V, Shelake RM, Kim JY, Pramanik D. Salinity stress in potato: Understanding physiological, biochemical and molecular responses. Life (Basel). 2021;11(6):545. https://doi.org/10.3390/life11060545
6. Dar MH, Razvi SM, Singh N, Mushtaq A, Dar S, Hussain S. Arbuscular mycorrhizal fungi for salinity stress: Anti-stress role and mechanisms. Pedosphere. 2023;33(1):212–24. https://doi.org/10.1016/j.pedsph.2022.06.027
7. Douds DD Jr, Nagahashi G, Reider C, Hepperly PR. Inoculation with arbuscular mycorrhizal fungi

increases the yield of potatoes in a high P soil. Biol Agric Hortic. 2007;25(1):67–78. https://doi.org/10.1080/01448765.2007.10823209

8. Ebbisa A. Arbuscular mycorrhizal fungi (AMF) in optimizing nutrient bioavailability and reducing agrochemicals for maintaining sustainable agroecosystems. In: de Sousa RN, editor. Arbuscular mycorrhizal fungi in agriculture - New insights. IntechOpen; 2022. p. 1–20. https://doi.org/10.5772/intechopen.106995
9. Gebrechristos HY, Chen W. Utilization of potato peel as eco-friendly products: A review. Food Sci Nutr. 2018;6(6):1352–6. https://doi.org/10.1002/fsn3.691
10. Giannopolitis CN, Ries SK. Superoxide dismutases: I. Occurrence in higher plants. Plant Physiology. 1977;59(2):309–314. https://doi.org/10.1104/pp.59.2.309
11. Gonzalez A, Bermejo V, Gimeno BS. Effect of different physiological traits on grain yield in barley grown under irrigated and terminal water deficit conditions. The Journal of Agricultural Science. 2010;148(3):319–328. https://doi.org/10.1017/S0021859610000031
12. Han X, Yang R, Zhang L, Wei Q, Zhang Y, Wang Y, Shi Y. A review of potato salt tolerance. Int J Mol Sci. 2023;24(13):10726. https://doi.org/10.3390/ijms241310726
13. Janah I, Meddich A, Elhasnaoui A, Khayat S, Anli M, Boutasknit A, Wahbi S. Arbuscular mycorrhizal fungi mitigates salt stress toxicity in Stevia rebaudiana Bertoni through the modulation of physiological and biochemical responses. J Soil Sci Plant Nutr. 2021;23(1):152–62. https://doi.org/10.1007/s42729-021-00690-y
14. Kapoor R, Evelin H, Mathur P, Giri B. Arbuscular mycorrhiza: Approaches for abiotic stress tolerance in crop plants for sustainable agriculture. In: Tuteja N, Gill SS, editors. Plant acclimation to environmental stress. Springer; 2013. p. 359–401. https://doi.org/10.1007/978-1-4614-5001-6_14
15. Latef AA, Chaoxing H. Effect of arbuscular mycorrhizal fungi on growth, mineral nutrition, antioxidant enzymes activity and fruit yield of tomato grown under salinity stress. Scientia Horticulturae. 2011 Jan 10;127(3):228-33. https://doi.org/10.1016/j.scienta.2010.09.020
16. Nie W, He Q, Guo H, Zhang W, Ma L, Li J, Wen D. Arbuscular mycorrhizal fungi: Boosting crop resilience to environmental stresses. Microorganisms. 2024;12(12):2448. https://doi.org/10.3390/microorganisms12122448
17. Pooja P, Kumar A, Sharma S, Verma R, Singh VP. Impact of AMF on photosynthesis, antioxidant enzymes, and water relations in salt-stressed chickpea plants. Agronomy. 2025;15(1):247. https://doi.org/10.3390/agronomy15010247
18. Ruiz-Lozano JM, Porcel R, Azcón C, Aroca R. Regulation by arbuscular mycorrhizae of the integrated physiological response to salinity in plants: New challenges in physiological and molecular studies. J Exp Bot. 2012;63(11):4033–44. https://doi.org/10.1093/jxb/ers126
19. Saboor A, Ali MA, Hussain S, El Enshasy HA, Hussain S, Ahmed N, Gafur A, Sayyed RZ, Fahad S, Danish S, Datta R. Zinc nutrition and arbuscular mycorrhizal symbiosis effects on maize (Zea mays L.) growth and productivity. Saudi J Biol Sci. 2021;28(11):6339–51. https://doi.org/10.1016/j.sjbs.2021.06.096
20. Shahid SA, Zaman M, Heng L. Introduction to soil salinity, sodicity and diagnostics techniques. In: Guidelines for salinity assessment, mitigation and adaptation using nuclear and related techniques. Springer; 2018. p. 1–42. https://doi.org/10.1007/978-3-319-96190-3_1
21. Smith SE, Read DJ. Mycorrhizal symbiosis. 3rd ed. Elsevier; 2008.
22. Wahab A, Muhammad M, Munir A, Abdi G, Zaman W, Ayaz A, Khizar C, Reddy SPP. Role of arbuscular mycorrhizal fungi in regulating growth and productivity under abiotic and biotic stresses. Plants. 2023;12(17):3102. https://doi.org/10.3390/plants12173102
23. Wang M, Zheng Q, Shen Q, Guo S. The critical role of potassium in plant stress response. Int J Mol Sci. 2013;14(4):7370–90. https://doi.org/10.3390/ijms14047370
24. Willis A, Rodrigues BF, Harris PJC. The ecology of arbuscular mycorrhizal fungi. Crit Rev Plant Sci. 2013;32(1):1–20. https://doi.org/10.1080/07352689.2012.683375
25. Zhang X, Li D, Wang C. The Innovation: A new journal for interdisciplinary research. The Innovation. 2020;1(1):100017. https://doi.org/10.1016/j.xinn.2020.100017