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Role of Arbuscular Mycorrhizal Fungi in Alleviating Salinity Stress and Improving Physiological Parameters of Wheat (*Triticum aestivum* L.): A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Salinity stress poses a significant threat to global wheat production, impacting crop yield and food security. In recent years, Arbuscular Mycorrhizal Fungi (AMF) have gained attention as potential bioinoculants capable of mitigating salinity-induced stress and improving plant physiological parameters. This review provides a comprehensive examination of the role of AMF in alleviating salinity stress and enhancing physiological parameters in wheat (Triticum aestivum L.). Through a systematic analysis of relevant literature, we explore the mechanisms underlying the beneficial interactions between AMF and wheat under saline conditions. Key findings from various studies demonstrate that AMF colonization enhances wheat growth, nutrient uptake, and antioxidant enzyme activities, while reducing the adverse effects of salinity stress. However, challenges such as variability in AMF effectiveness and compatibility with modern agricultural practices persist. Future research directions should focus on refining AMF inoculation techniques and developing strains with enhanced salt tolerance to maximize their potential in sustainable agriculture. Overall, this review underscores the promising role of AMF in revolutionizing wheat cultivation in saline environments, offering insights for enhancing crop productivity and resilience to salinity stress.

Keywords: Salinity; AMF; wheat; antioxidants; proline.

1. INTRODUCTION

Food security is a critical concern for societies worldwide, particularly in the face of environmental degradation and climate change. Wheat (*Triticum aestivum* L.) stands out as a vital staple food for a significant portion of the global population, providing approximately 20% of calories and 55% of carbohydrates consumed worldwide. Despite its importance, wheat productivity faces significant challenges, especially from environmental stresses such as salinity [1-4].

Salinity stress is a major environmental constraint affecting wheat growth and development. More than 20% of cultivated and 33% of irrigated agricultural lands globally are severely affected by salinity. Industrialization, anthropogenic activities, and the excessive use of saline water for irrigation have exacerbated this issue, converting fertile soils into salt-affected soils. Salinity stress affects plants by limiting water availability, causing osmotic imbalance, oxidative stress, nutrient imbalance, and ion toxicity, ultimately leading to symptoms such as reduced leaf area, thickness, and succulence, as well as necrosis of roots and shoots [5-8].

Wheat, classified as moderately salt-tolerant, experiences yield losses with increasing salinity levels. To mitigate the adverse effects of salinity, plants employ various adaptive strategies, including morphological and developmental changes, accumulation of compatible osmolytes, ion homeostasis, regulation of water uptake, enhanced photosynthesis, and detoxification of reactive oxygen species (ROS) through antioxidant enzymes and phytohormone induction. However, these adaptive mechanisms may not suffice to counteract rapidly increasing salinity levels, necessitating the exploration of new approaches to enhance plant tolerance [9-10].

Recent research has highlighted the potential of microorganisms in mitigating salt stress in plants. Specifically, arbuscular mycorrhizal fungi (AMF) have emerged as promising candidates for enhancing plant tolerance to salinity stress. AMF colonization in plant roots has been shown to improve nutrient and water uptake, increase photosynthetic rates, regulate hormonal levels, and upregulate antioxidant systems to alleviate salt-induced damage [11]. However, the effectiveness of AMF in enhancing plant salinity tolerance varies among different studies, influenced by factors such as salinity levels, host plants, mycorrhizal partners, and environmental conditions [12].

Given the importance of understanding these mechanisms, this review aims to analyze the effects of different AMF isolates on the growth and stress-associated parameters of wheat plants under varying salinity gradients. By elucidating the stress tolerance mechanisms of AM fungi, this study seeks to contribute to the development of strategies for enhancing wheat productivity in saline environments [13-14].

This review will delve into recent advances in the application of cereal crop residues in green concrete technology for environmental sustainability. Green concrete, also known as sustainable or eco-friendly concrete, is an innovative approach to construction that aims to minimize its environmental impact by utilizing renewable resources and reducing carbon emissions. Cereal crop residues, such as rice husk ash, wheat straw ash, and sugarcane bagasse ash, have garnered significant attention as supplementary cementitious materials in green concrete production. These agricultural by-products offer several advantages, including their abundance, low cost, and potential to improve concrete properties such as durability, workability, and strength. The review will explore the various methods of incorporating cereal crop residues into concrete mixtures, including as partial replacements for cement or aggregates, and the effects of these additions on the performance of green concrete. Additionally, it will examine the environmental benefits of using cereal crop residues in concrete production, such as reducing the demand for natural resources, lowering carbon emissions, and promoting sustainable agricultural practices, the review will discuss the limitations and challenges associated with the use of cereal crop residues in green concrete technology, such as concerns regarding material consistency, compatibility with cementitious binders, and long-term durability. It will also highlight areas for future research and development to overcome these challenges and optimize the utilization of cereal crop residues in green concrete production the review aims to provide a comprehensive overview of the current state of research on the application of cereal crop residues in green concrete technology, with a focus on its potential to contribute to environmental sustainability in the construction industry [15-17].

1.1 Preparation of Arbuscular Mycorrhizal Inoculum

The preparation of arbuscular mycorrhizal (AM) inoculum involves several steps to ensure the successful colonization of host plant roots. Here's a general outline of the process:

1. Isolation of AM Fungi: AM fungi can be isolated from soil samples collected from areas where AM symbiosis is prevalent. These fungi form characteristic structures called spores, which can be extracted from the soil using wet sieving and sucrose centrifugation techniques.

2. Propagation of AM Fungi: The isolated AM fungal spores are then propagated in a suitable growth medium. This medium typically contains a source of carbohydrates (e.g., glucose), nutrients (e.g., phosphorus, potassium), and a host plant or host plant root exudates to stimulate fungal growth. The propagation can be carried out in pots or trays under controlled environmental conditions (e.g., temperature, humidity, light).

3. Multiplication of Spores: Once the AM fungi have colonized the growth medium and produced sufficient spores, the spores are harvested and multiplied. This can be achieved by transferring spores to fresh growth medium and allowing them to proliferate under optimal conditions.

4. Inoculum Production: The harvested spores are then mixed with a carrier material to create the final inoculum product. Common carrier materials include vermiculite, perlite, sand, or compost. The carrier serves as a substrate for the spores and provides physical support during storage and application.

5. Quality Control: Before the inoculum is used for plant inoculation, it undergoes quality control checks to ensure viability and purity. This may involve assessing spore density, viability, and contamination levels using microscopy or molecular techniques.

6. Application: The prepared AM inoculum is applied to the rhizosphere of host plants either directly to the soil or via seed coating or root dipping methods. The inoculum should be applied at the appropriate time during the plant's growth cycle to maximize colonization and symbiotic benefits.

7. Monitoring and Maintenance: Once applied, the establishment and colonization of AM fungi in the plant roots are monitored over time. Regular maintenance, including irrigation, fertilization, and pest control, may be necessary to support optimal growth and colonization of host plants by AM fungi.

By following these steps, a high-quality AM inoculum can be prepared for use in promoting plant growth and enhancing plant resilience to environmental stressors.

1.2 Plant and Growth Conditions with Salt and AMF Treatments

The plant and growth conditions with salt and arbuscular mycorrhizal fungi (AMF) treatments play a crucial role in understanding the interactions between plants, soil salinity, and beneficial soil microorganisms.

1. Salt Stress Levels: Different studies have used varying levels of salt stress to assess the response of plants to salinity. These levels often range from mild to severe salt stress, with concentrations measured in terms of electrical conductivity (EC) or sodium chloride (NaCl) concentration. Commonly used stress levels include 50, 100, 150, and 200 mM NaCl, which represent mild to severe salt stress conditions.

2. AMF Inoculation Methods: Studies employ different methods for inoculating plants with AMF, including pre-inoculation of seeds, soil inoculation, and root dipping. Pre-inoculation involves coating seeds with AMF spores or inoculum before planting, while soil inoculation entails adding AMF inoculum directly to the soil around plant roots. Root dipping involves immersing plant roots in AMF suspension before transplanting them into the soil.

3. Plant Species and Growth Conditions: Various plant species have been studied under salt stress and AMF treatments, including wheat (Triticum aestivum), tomato (Solanum lycopersicum), maize (Zea mays), soybean (Glycine max), and alfalfa (Medicago sativa). Growth conditions such as temperature, humidity, photoperiod, and soil type can also influence plant responses to salt stress and AMF inoculation.

4. Experimental Design and Duration: Experimental designs vary among studies and may include randomized complete block designs, factorial designs, or pot experiments. The duration of experiments can range from a few weeks to several months, depending on the plant species and objectives of the study. Long-term studies are essential for assessing the sustained effects of salt stress and AMF inoculation on plant growth and performance.

5. Physiological and Biochemical Parameters: Researchers measure various physiological and biochemical parameters to evaluate the response of plants to salt stress and AMF treatments. These parameters may include plant biomass, chlorophyll content, photosynthetic rate, antioxidant enzyme activity, osmolyte accumulation, ion uptake, and nutrient status. Assessing these parameters provides insights into the mechanisms underlying plant tolerance to salinity and the role of AMF in enhancing stress resilience.

2. SALINITY STRESS AND ITS IMPACT ON WHEAT

Salinity stress is a significant environmental factor that affects wheat cultivation worldwide, posing challenges to crop growth, yield, and overall agricultural productivity. This section delves into the concept of salinity stress and explores its profound impact on wheat plants.

Soil salinity refers to the accumulation of soluble salts in the soil, primarily sodium chloride (NaCl), calcium sulfate ($CaSO_4$), and magnesium sulfate ($MgSO_4$), beyond levels tolerable by most crops. These salts can accumulate naturally through processes like weathering of minerals, or through human activities such as irrigation with saline water, excessive fertilizer use, and poor drainage systems [18].

The effects of salinity stress on wheat are multifaceted and can manifest at various stages of the plant's life cycle. During germination and seedling establishment, high salt concentrations in the soil inhibit water uptake by seeds, leading to reduced germination rates and poor seedling vigor. As the plants grow, salinity stress continues to impede growth and development, resulting in stunted growth, reduced leaf area, and diminished biomass accumulation. Furthermore, salinity stress adversely affects reproductive development in wheat, leading to decreased fertility, lower grain set, and ultimately reduced yield potential.

The mechanisms underlying the detrimental effects of salinity stress on wheat physiology are complex and multifaceted. One key mechanism involves the disruption of cellular osmotic balance, as high soil salinity leads to the accumulation of salts in plant tissues, causing water loss and dehydration. Additionally, salt stress disrupts ion homeostasis within plant cells, leading to toxic ion accumulation, particularly sodium ions (Na^+) and chloride ions (Cl^-), which can disrupt cellular metabolism and enzyme function.

To cope with salinity stress, wheat plants activate various physiological and biochemical mechanisms aimed at mitigating the harmful effects of salt accumulation. These include osmotic adjustment mechanisms to maintain cellular water balance, ion exclusion mechanisms to prevent the uptake of toxic ions, activation of antioxidant defense systems to scavenge reactive oxygen species (ROS), and modulation of hormonal pathways to regulate stress responses [19-23].

Despite the plant's ability to deploy adaptive mechanisms, salinity stress remains a significant challenge in wheat cultivation, leading to economic losses, reduced crop yields, and environmental degradation. Addressing salinity stress in wheat requires a multifaceted approach, including the development of salt-tolerant wheat varieties through conventional breeding and biotechnological approaches, improvement of soil management practices, and the exploration of innovative agronomic strategies to mitigate the effects of salinity on crop productivity.

3. ROLE OF ARBUSCULAR MYCORRHIZAL FUNGI (AMF) IN PLANT-MICROBE INTERACTIONS

Arbuscular mycorrhizal fungi (AMF) are symbiotic fungi that form mutualistic associations with the roots of the majority of land plants, including wheat (*Triticum aestivum* L.). This section explores the pivotal role of AMF in facilitating plant-microbe interactions, particularly in the context of wheat cultivation [24-27].

1. Symbiotic Relationship: AMF establish a symbiotic association with wheat roots, forming specialized structures called arbuscules and vesicles within the root cortical cells. These structures serve as sites for nutrient exchange between the fungus and the plant host, facilitating the uptake of essential nutrients such as phosphorus (P) and nitrogen (N) from the soil. In return, the plant provides the fungus with a source of carbohydrates produced through photosynthesis.

2. Nutrient Acquisition: One of the primary benefits of AMF colonization for wheat plants is enhanced nutrient acquisition, particularly phosphorus. Phosphorus is often limited in soil environments, and AMF play a crucial role in increasing the availability and uptake of phosphorus by wheat roots through their extensive hyphal network, which can explore a larger soil volume than plant roots alone.

3. Improved Stress Tolerance: AMF colonization has been shown to enhance the tolerance of wheat plants to various environmental stresses, including salinity. By promoting the accumulation of osmolytes, such as proline and glycine betaine, and enhancing antioxidant enzyme activities, AMF help mitigate the negative effects of salinity stress on wheat physiology. Additionally, AMF-mediated improvements in soil structure and water retention can help alleviate drought stress in wheat plants.

4. Induced Systemic Resistance: AMF can also induce systemic resistance in wheat plants against various biotic stresses, such as pathogen infections. Through the activation of plant defense mechanisms, including the production of antimicrobial compounds and the upregulation of defense-related genes, AMF confer enhanced protection against fungal pathogens and other pests.

5. Hormonal Regulation: AMF colonization influences the hormonal balance within wheat plants, modulating the levels of phytohormones such as auxins, cytokinins, and abscisic acid (ABA). These hormonal changes can regulate various aspects of plant growth and development, including root architecture, shoot growth, and stress responses.

Overall, the symbiotic association between wheat plants and AMF plays a crucial role in enhancing nutrient acquisition, improving stress tolerance, and conferring resistance to biotic stresses. Understanding the mechanisms underlying AMF-mediated plant-microbe interactions is essential for harnessing the full potential of these beneficial fungi in sustainable wheat cultivation practices.

4. PHYSIOLOGICAL PARAMETERS AFFECTED BY SALINITY STRESS AND AMF INOCULATION IN WHEAT

Salinity stress imposes significant physiological changes on wheat plants, affecting various growth and developmental processes. This section examines the impact of salinity stress and arbuscular mycorrhizal fungi (AMF) inoculation on key physiological parameters in wheat.

1. Photosynthetic Efficiency: Salinity stress disrupts the photosynthetic machinery of wheat plants, leading to a decline in photosynthetic efficiency. Reduced chlorophyll content, stomatal closure, and decreased photosynthetic rates are common responses to salinity stress. However, AMF inoculation has been shown to mitigate these negative effects by maintaining optimal chlorophyll levels, promoting stomatal conductance, and enhancing photosynthetic activity. AMF-mediated improvements in nutrient uptake and water status contribute to maintaining photosynthetic efficiency under saline conditions.

2. Water Relations: Salinity stress disrupts the water balance in wheat plants, leading to osmotic stress and reduced water uptake. As a result, plants experience water deficit symptoms such as wilting, leaf rolling, and decreased turgor pressure. AMF colonization enhances the water relations of wheat plants by increasing root hydraulic conductivity, improving water uptake efficiency, and regulating stomatal behavior. These mechanisms help alleviate the negative effects of salinity stress on plant water status, ensuring adequate hydration and turgor pressure.

3. Ion Homeostasis: Salinity stress results in the accumulation of toxic ions, such as sodium (Na+) and chloride (Cl-), in wheat tissues, disrupting ion homeostasis and cellular integrity. Excessive Na+ uptake leads to ion toxicity, osmotic imbalance, and membrane damage, adversely affecting plant growth and metabolism. AMF inoculation plays a crucial role in maintaining ion homeostasis by restricting Na+ uptake, promoting the sequestration of toxic ions in vacuoles, and enhancing the expression of ion transporters involved in ion exclusion and compartmentalization. These mechanisms help mitigate the detrimental effects of salinity stress on wheat ion balance and cellular functioning [28-32].

4. Antioxidant Defense System: Salinity stress induces the production of reactive oxygen species (ROS) in wheat plants, leading to oxidative stress and cellular damage. To counteract ROS-mediated damage, plants activate antioxidant defense mechanisms, including enzymatic and non-enzymatic antioxidants. AMF colonization enhances the antioxidant capacity of wheat plants by upregulating the activities of antioxidant enzymes, such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), and increasing the accumulation of non-enzymatic antioxidants, such as glutathione and ascorbate. These antioxidative responses help protect wheat plants from oxidative stress-induced injuries and maintain cellular redox balance under saline conditions [33-35].

5. Growth and Yield Parameters: Salinity stress negatively impacts the growth and yield of wheat plants, resulting in reduced biomass accumulation, impaired reproductive development, and decreased grain yield. However, AMF inoculation has been shown to alleviate these adverse effects by promoting root and shoot growth, enhancing nutrient uptake, and improving reproductive performance. AMF-mediated improvements in physiological parameters, such as photosynthesis, water relations, ion homeostasis, and antioxidant defense, contribute to enhanced growth and productivity in saline environments [36].

Overall, the interaction between salinity stress and AMF inoculation influences multiple physiological parameters in wheat, ultimately determining plant performance and productivity under challenging environmental conditions. Understanding the mechanisms underlying these physiological responses is essential for developing effective strategies to enhance the salinity tolerance of wheat through AMF-mediated mechanisms.

5. FACTORS INFLUENCING THE EFFICACY OF AMF IN ALLEVIATING SALINITY STRESS

The effectiveness of arbuscular mycorrhizal fungi (AMF) in alleviating salinity stress in wheat plants can vary depending on various factors. Understanding these factors is crucial for optimizing the efficacy of AMF inoculation in improving plant tolerance to salinity stress. Several key factors that influence the efficacy of AMF in mitigating salinity stress include:

1. Mycorrhizal Symbiosis Specificity: Different AMF species exhibit varying degrees of effectiveness in conferring salinity tolerance to host plants. The selection of suitable AMF strains with high compatibility and symbiotic efficiency with wheat plants is essential for achieving optimal benefits under saline conditions.

2. Salinity Stress Severity: The severity and duration of salinity stress significantly impact the response of wheat plants to AMF inoculation. Moderate levels of salinity stress may stimulate beneficial interactions between plants and AMF, whereas severe stress conditions can limit the effectiveness of mycorrhizal symbiosis in mitigating stress-induced damage.

3. Soil Characteristics: Soil properties, such as texture, pH, organic matter content, and microbial diversity, influence the colonization and establishment of AMF in the rhizosphere. Soil conditions that favor AMF growth and activity, such as neutral pH, well-drained soil structure, and adequate organic matter, enhance the efficacy of mycorrhizal symbiosis in alleviating salinity stress.

4. Wheat Cultivar and Genotype: Variability in the salinity tolerance of wheat cultivars and genotypes can influence the responsiveness of plants to AMF inoculation. Some wheat varieties exhibit innate resistance or susceptibility to salinity stress, affecting their ability to form symbiotic associations with AMF and benefit from mycorrhizal-mediated improvements in stress tolerance.

5. AMF Inoculation Methods: The methods used for AMF inoculation, such as seed coating, soil application, or root dipping, can affect the colonization efficiency and establishment of mycorrhizal symbiosis in wheat plants. Optimal inoculation techniques that ensure uniform distribution and effective contact between AMF propagules and plant roots are essential for maximizing the benefits of mycorrhizal associations under saline conditions.

6. Environmental Conditions: Environmental factors, including temperature, moisture availability, light intensity, and atmospheric CO2 concentration, influence the growth, development, and activity of both wheat plants and AMF. Favorable environmental conditions that promote plant growth and AMF colonization facilitate the establishment of symbiotic interactions and enhance the efficacy of AMF in mitigating salinity stress.

7. Interaction with Other Soil Microorganisms: The presence of other soil microorganisms, such as rhizobacteria, fungi, and pathogens, can influence the outcome of mycorrhizal symbiosis in wheat plants under saline conditions. Interactions between AMF and beneficial microbes may synergistically enhance plant stress tolerance, while antagonistic interactions with pathogens or competitive microbes may diminish the efficacy of AMF inoculation.

Understanding the interplay between these factors is essential for harnessing the full potential of AMF-mediated mechanisms in improving the salinity tolerance of wheat plants. By optimizing the conditions conducive to mycorrhizal symbiosis and considering the multifaceted influences on AMF efficacy, researchers can develop effective strategies for sustainable agriculture in saline environments.

6. RECENT ADVANCES AND FUTURE PERSPECTIVES

Recent advancements in research on the role of arbuscular mycorrhizal fungi (AMF) in alleviating salinity stress in wheat plants have provided valuable insights into the mechanisms underlying mycorrhizal-mediated improvements in stress tolerance. These advancements have expanded our understanding of the complex interactions between plants and AMF under saline conditions and have opened up new avenues for enhancing the efficacy of AMF inoculation in agricultural practices. Some of the key recent advances and future perspectives in this field include:

1. Molecular Mechanisms of AMF-Mediated Salinity Tolerance: Advances in molecular biology techniques have enabled researchers to elucidate the molecular mechanisms underlying AMF-induced salinity tolerance in wheat plants. Transcriptomic, proteomic, and metabolomic studies have identified key genes, proteins, and metabolic pathways involved in plant responses to salinity stress in the presence of AMF. Further exploration of these molecular mechanisms will provide valuable insights into the signaling pathways and regulatory networks governing mycorrhizal-mediated stress tolerance [37].

2. Engineering Mycorrhizal Symbiosis for Enhanced Stress Tolerance: Genetic engineering approaches hold promise for enhancing the effectiveness of mycorrhizal symbiosis in improving stress tolerance in crops. Strategies aimed at modulating the expression of genes involved in AMF colonization, nutrient transport, antioxidant defense, and stress-responsive pathways could potentially enhance the resilience of wheat plants to salinity stress. Future research efforts should focus on developing genetically modified wheat varieties with enhanced compatibility and responsiveness to AMF inoculation [38-47].

3**. Microbial Consortia for Synergistic Stress Mitigation:** Recent studies have highlighted the potential benefits of employing microbial consortia, comprising AMF, rhizobacteria, and other beneficial microbes, for synergistically mitigating salinity stress in wheat plants. Combined inoculation with AMF and selected rhizobacterial strains has been shown to enhance plant growth, nutrient uptake, and stress tolerance compared to single inoculations. Future research should explore the interactions and mechanisms underlying the synergistic effects of microbial consortia and optimize their application for sustainable agriculture in saline environments.

4. Biotechnological Tools for AMF Inoculum Production: Advances in biotechnological approaches, such as mass production of AMF inoculum, formulation of mycorrhizal products, and development of efficient delivery systems, are essential for scaling up the application of AMF in agricultural settings. Bioreactor-based production of AMF spores, encapsulation techniques, and biofertilizer formulations can improve the viability, stability, and efficacy of mycorrhizal inoculants for field applications. Future efforts should focus on developing cost-effective and environmentally friendly methods for large-scale production and application of AMF inoculum.

5. Climate-Smart Agriculture Strategies: Integration of AMF inoculation into climate-smart agriculture strategies can contribute to enhancing the resilience and sustainability of wheat production systems in the face of climate change and increasing salinity stress. Adoption of conservation agriculture practices, agroforestry systems, and precision farming techniques in combination with AMF inoculation can promote soil health, water conservation, and crop resilience while mitigating the adverse effects of salinity stress on wheat cultivation. Future research should explore the synergies between AMF inoculation and climate-smart agricultural approaches for resilient and sustainable food production systems, recent advances in research on AMF-mediated salinity tolerance in wheat plants offer promising opportunities for addressing the challenges of salinity stress in agriculture. By harnessing the potential of AMF symbiosis and leveraging biotechnological innovations, microbial consortia, and climate-smart agricultural strategies, we can develop effective and sustainable solutions for enhancing wheat productivity and resilience in saline environments. Continued interdisciplinary research and collaborative efforts are essential for translating these advances into practical applications and promoting the adoption of AMF-based technologies for resilient and sustainable agriculture.

7. CONCLUSION

the role of arbuscular mycorrhizal fungi (AMF) in alleviating salinity stress and improving physiological parameters in wheat (*Triticum aestivum* L.) presents a promising avenue for sustainable agriculture in saline environments. Salinity stress poses a significant threat to wheat production globally, leading to reduced yields and compromised quality. However, AMF inoculation has emerged as a potential strategy to enhance the tolerance of wheat plants to salinity stress., it has been demonstrated that AMF can mitigate the adverse effects of salinity stress by improving nutrient uptake, enhancing water relations, modulating antioxidant defense mechanisms, and regulating hormonal balance in wheat plants. These beneficial effects of AMF symbiosis contribute to enhanced growth, development, and productivity of wheat under saline conditions, the considerable progress made in understanding the mechanisms underlying AMF-mediated salinity tolerance in wheat, several challenges and opportunities remain. Further research is needed to elucidate the molecular and physiological mechanisms governing the interactions between wheat plants and AMF under saline conditions. Advances in molecular biology, omics technologies, and genetic engineering hold promise for enhancing our understanding of these complex interactions and developing improved wheat varieties with enhanced salinity tolerance, there is a need for the development of cost-effective and environmentally sustainable methods for large-scale production and application of AMF inoculum in agricultural systems. Biotechnological innovations, such as bioreactor-based production, formulation of mycorrhizal products, and optimization of delivery systems, are essential for maximizing the efficacy and scalability of AMF-based technologies.

Integration of AMF inoculation into climate-smart agricultural strategies and sustainable farming practices can further enhance the resilience and productivity of wheat production systems in saline environments. By promoting soil health, conserving water resources, and mitigating the adverse effects of salinity stress, AMF-based technologies offer promising solutions for ensuring food security and environmental sustainability in the face of climate change and increasing soil salinity, continued interdisciplinary research, collaboration among scientists, policymakers, and stakeholders, and concerted efforts to translate scientific advancements into practical applications are essential for harnessing the full potential of AMF symbiosis in wheat cultivation and promoting resilient and sustainable agriculture in saline environments.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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