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A Comprehensive Review on Arbuscular Mycorrhizal Fungi: Impact on Plant Growth and Nutrient Acquisition

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Abstract

Arbuscular Mycorrhizal Fungi (AMF) are helpful for plants to grow and get nutrients from soil. Climate change and excessive pesticide and fertilizer use have exacerbated crop yield pressures, causing environmental damage. AMFs are an environmentally beneficial management approach for increasing agricultural yield. AMF inoculation provides plant resistance to various stressors, including heat, salt, drought, metals, and extreme temperatures. This review paper examines the impact of AMF efficiency on plant physiology, including nutrient uptake and development. This publication provides a comprehensive overview of the complex interactions between AMF and plants, drawing on recent research. The article discusses the obstacles and future prospects in AMF research, emphasizing the necessity for a comprehensive approach to fully utilize these fungi for improved plant productivity and nutrient absorption.

Keywords: *Arbuscular Mycorrhizal Fungi (AMF), plant growth, exacerbated, stressors, nutrient absorption*

1. Introduction

Plant science has emerged as an emerging subject in response to concerns about food security. Researchers are exploring new ways to increase crop yields. Food shortages are produced by biotic and abiotic conditions that limit global agricultural productivity including salt, drought, floods, plant diseases, nutritional deficiencies, and toxicity. Regulating and utilizing beneficial microbes are crucial for reducing environmental impact and achieving long-term objectives [1]. Arbuscular Mycorrhizal Fungi have symbiotic connections with most plant species impacting their growth and nutrient intake. Beneficial fungi create symbiotic relationships with plant roots, extending the root system and increasing nutrient absorption surface area [2]. This symbiotic relationship helps both fungi and plants [3]. Fungi obtain carbohydrates from plants, while plants gain access to nutrients like phosphate and nitrogen [4]. Arbuscular mycorrhizal fungi can enhance plant resistance to abiotic stressors such as drought, salt, and heavy metal toxicity [5, 6]. Numerous studies have examined how arbuscular mycorrhizal fungi increase plant growth and nutrient uptake [7]. Research repeatedly shows that arbuscular mycorrhizal fungi promote plant growth and nutrient absorption [8]. Arbuscular mycorrhizal fungi promote plant development and nutrient uptake and protect against diseases and toxic stressors [9]. Arbuscular mycorrhizal fungus can protect plants from infections and harmful stressors. For instance, [10] discovered that arbuscular mycorrhizal fungus improved the development and production of essential oil in *Ocimum basilicum* plants. The study suggests that using the symbiotic link between arbuscular mycorrhizal fungi and plants can lead to sustainable agriculture and improved plant health management. Research on arbuscular mycorrhizal fungi's impact on plant development and nutrient uptake has consistently shown good results. Arbuscular mycorrhizal fungi can enhance plant tolerance to abiotic stressors such as drought, salt, and heavy metal toxicity [11]. Arbuscular mycorrhizal fungi have been shown in studies to improve plant tolerance and lessen the negative impact of heavy metals on growth. AM fungi have been shown to improve nutrient uptake by plants [12]. They improve plant access to phosphorus, a limiting nutrient in many soils. AM fungi are widely recognized for enhancing plant growth and nutrient uptake. Arbuscular mycorrhizal fungi have improved soil structure and stability, promoted organic matter decomposition, and improved nutrient uptake. They also have direct effects on plant development and nutrient uptake (Fig. 1).

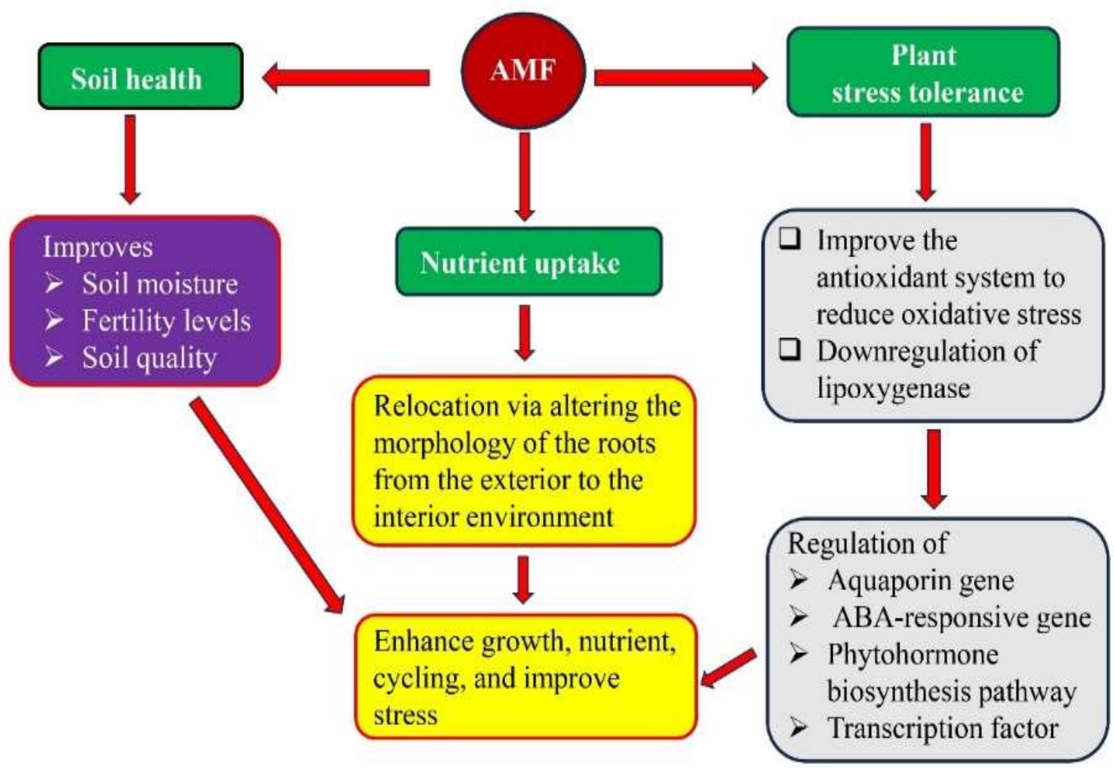

Fig. 1. An illustration showing the role of mycorrhizal fungi in regulating several ecological processes and promoting plant development and nutrient uptake under stressful circumstances.

Arbuscular mycorrhizal fungi have indirect effects on ecosystem function and soil fertility. This review focuses on the role of Arbuscular Mycorrhizal Fungi in controlling plant growth and development, as well as enhancing nutrient absorption in difficult situations, given its importance in agriculture research.

2. Evolution of Mycorrhiza and Its Type

Mycorrhizae may be older than plant terrestrialization, as evidenced by fossil and genetic data. Research indicates that protomycorrhizal fungi play a crucial role in plant terrestrialization. Genetic data suggests that all land plants evolved from a common ancestor that quickly adapted to mycorrhizal symbiosis [13-14]. Fossil plants from the Rhynie chert, dating back 400 million years, have been found to have arbuscular mycorrhizae in the stems of Aglaophyton major. This suggests that late mycorrhizal symbiosis may have developed earlier [15]. Contemporary mycorrhizal groupings, such as orchids and ericoids, originated during the Cretaceous era's angiosperm radiation. However, ectomycorrhizae emerged much later, during the Jurassic period [16]. Genetic studies indicate that legume-fixing bacteria symbiosis is a variant of mycorrhizal symbiosis [17]. Mycorrhizal fungi distribution reflects the competition and complexity of root construction during the Cenozoic Era when angiosperm dominance was prevalent and species had complex ecological interactions [18]. Mycorrhiza is divided into two groups. Endomycorrhizal fungi permeate cell walls and membranes, while ectomycorrhizal fungi do not penetrate individual cells within the root. This differs between two forms of fungi [19, 20]. Arbutoid mycorrhizas are classified as ectoendomycorrhizas, while endomycorrhizas include arbuscular, ericoid, and orchid mycorrhizas. Monotropoid mycorrhizas are a separate class.

3. Mutualist Mycorrhizal Mechanisms

Most plant species have a mutualistic relationship with mycorrhizal fungi in their roots. Mycorrhizal relationships exist between plants and the fungus that lives in their roots. Although only a small number of mycorrhizal relationships between plant species and fungi have been studied, 95% of plant families are primarily mycorrhizal, either because their species benefit from mycorrhizae or because they rely entirely on them. Orchidaceae seeds require mycorrhizae to germinate [21]. Recent investigations on ectomycorrhizal plants in boreal forests suggest a complex connection between mycorrhizal fungus and plants, beyond simple mutualism. Mycorrhizal fungi were discovered to store nitrogen from plant roots amid nitrogen shortages, highlighting the importance of this relationship. Research suggests that some mycorrhizae transfer nutrients based on their surroundings and other mycorrhizae. The revised model explains why mycorrhizae do not alleviate plant nitrogen restriction. As soil nitrogen supply decreases, plants may shift from a mixed strategy with both mycorrhizal and nonmycorrhizal roots to a solely mycorrhizal approach [22]. Evolutionary and phylogenetic linkages may account for more variance in mycorrhizal mutualism intensity than ecological variables [23].

4. AMF Impact on Plant Nutrient Acquirement

4.1. Plant Growth Enhancement

Beneficial rhizospheric bacteria can improve crop quality and their nutritional value. Over the last two decades, various research on AMF has shown that it has numerous benefits for agricultural output and soil health. As a result, it is widely acknowledged that AMF may someday replace inorganic fertilizers, as mycorrhizal treatment can greatly reduce the quantity of chemical fertilizer input, particularly phosphorus [24]. AMF, which are naturally occurring root symbionts, provide essential inorganic nutrients to host plants, promoting growth and production in both stressed and unstressed settings. AMF's ability to act as a biofertilizer may help plants adapt to changing environmental conditions. Arbuscular mycorrhizal fungi (AMF) can create symbiotic relationships with the most terrestrial plants [25]. This type of symbiosis affects plant growth and yield, nutrient acquisition, resistance to biotic and abiotic stresses (e.g., salinity, drought, etc.), soil aggregation, and carbon sequestration [26–30]. AMF can change how the microbial community is organized and promote the development of additional microorganisms in the rhizosphere [31, 32]. This can impact several biological processes, including biological nitrogen fixation [33]. AMF colonization in strawberries increased secondary metabolite levels, leading to improved antioxidant capabilities [34]. AMF can enhance crop nutrition by altering the synthesis of carotenoids and volatile compounds. AMF improves tomato quality, as reported by [[35-36]. Another study [37] indicated that *Glomus versiforme* increased citrus fruit quality by increasing organic acids, sugars, vitamin C, flavonoids, and mineral content. Mycorrhizal symbiosis leads to higher levels of anthocyanin, chlorophyll, carotenoids, tocopherols, total soluble phenolics, and other minerals [38]. AMF has shown the potential to boost crop yield in extensive field production of potatoes [39], yam [40], and maize [41]. According to [42] and [43], AMF enhances the production of important phytochemicals in edible plants, allowing them to operate effectively in the food production chain. Maintaining soil pH can protect AMF from abiotic stress and preserve its horticultural usefulness. AMF can help plants to develop resistance against different adverse conditions.

4.2. Nutrient Uptake and Cycling

Excessive land use can significantly impair biodiversity and ecosystem function, according to numerous studies. Symbiotic connections play a crucial role in transferring resources including organic carbon (C) via lipids and sugars [44]. Research indicates that AMF infestation enhances plant nutrient uptake. Inoculating with AMF can significantly enhance macro- and micronutrient concentrations, leading to increased photosynthesis and biomass buildup. AMF enhances plant absorption of inorganic nutrients, especially phosphate. AMF effectively helps the plant to absorb nutrients. AMF interaction improves the phyto-availability of micronutrients like copper and zinc, in addition to macronutrients. AMF improves the host roots' ability to absorb surface energy. Experiments on tomato plants infected with AMF revealed increased leaf area and higher levels of nitrogen, potassium, calcium, and phosphorus, indicating improved plant development [45]. AMF forms a symbiotic connection with roots, absorbing nutrients from the host plant and returning minerals like P, N, K, Ca, S, Zn, etc. It provides nutritional support to plants in unfavorable root cell settings [46]. AMF produces arbuscules that help host plants absorb minerals, carbon, and phosphorus, resulting in increased vigor. As a result, they can greatly increase phosphorus levels in both the shoot and root system systems. Mycorrhizal interaction enhances phosphorus supply to infected roots of host plants in phosphorus-limited soils. AMF-colonized maize plants demonstrated considerable improvement in inorganic phosphate absorption rate. Increased frequency of AMF inoculation correlates with improved photosynthetic activity and leaf functions. AMF inoculation leads to increased growth by increasing P, N, and carbon intake, which stimulates the development of the roots. Under different irrigation regimes, AMF maintains P and N absorption, promoting plant growth at both high and low P levels. In drought-stressed *Pelargonium graveolens* L., mycorrhizal symbiosis increased N, P, and Fe concentrations [47]. AMF is hypothesized to enhance nutrient absorption while lowering Na and Cl absorption, promoting growth. Extra-radical mycelium (ERM) enhances plant growth and development by improving nutrient absorption efficiency. Nitrogen (N), a well-known mineral fertilizer, is a significant source of soil nourishment, even in areas with ample livestock and farm-yard manure (FYM). Research has shown that AMF improves soil nutrient absorption, especially P and N which promotes plant growth. N is a critical ingredient that hinders growth in certain crops and higher plants. AMF can absorb and transfer nitrogen to surrounding plants and host plants. Research has shown that transferring of N and P to enhances shoot biomass allocation to grains and panicles, especially in low fertilizer environments. AMF inoculation improves carbon and nitrogen buildup and assimilation at both low and high CO_2 concentrations [48]. AMF has been found to improve micro- and macronutrient accumulation and distribution in olive plantlets grown in Mn-rich conditions [49]. AMF colonization benefits plant performance by boosting nutrition and maintaining the Ca^{2+} & Na^{+} ratio. Chickpea grown with mycorrhizal fungi exhibits enhanced growth, protein, iron, and zinc levels. Recent meta-analyses have shown that mycorrhizal symbiosis contributes to many micronutrients in crops. According to [50], during a drought, *Antirrhinum majus* fungal connection enhanced the number of macronutrients such as P. N, K, Mg, and Ca. AMF effectively reduces high levels of Mn, Na, Mg, and Fe in roots. Recent research suggests that AMFs, such as *Glomus mosseae* and *Rhizophagus irregularis*, promote heavy metal transfer in shoots. Mycorrhizal hyphae help plants absorb micronutrients like zinc and copper, which have limited dispersion in soil.

5. Challenges and Future Direction

5.1. Limitations of AMF Application

Nowadays pesticides and fertilizers are frequently used in agriculture. High-yielding crops are becoming increasingly popular because of their susceptibility to disease compared to wild counterparts. Excessive use of fertilizers, pesticides, tillage, and crop rotation with non-mycorrhizal crops can all reduce AM activity, variety, and association. Agricultural lands have a different and less diverse AM flora compared to surrounding natural soil. High P concentrations in the soil can impede mycorrhizal symbiosis in plants. Using high P fertilizer can help plants absorb phosphorus without compromising carbohydrates. In exchange for phosphate, AM fungus seeks carbon from plants. AM requires cooperation from both sides. The plant picks the most efficient and compatible strains by exchanging resources. Nitrogen fertilizers have been demonstrated in both pot and field trials to decrease colonization. At low to medium levels, AM colonization and sporulation encourage plant growth and root formation. Applying nitrogen fertilizer at a higher rate can prevent AM colonization in plants. Excessive potassium levels impede AM transmission, decrease root exudation, and increase soluble carbohydrates in the cortex. The application of agrochemicals can harm the environment, soil, and human health but agricultural productivity remains unaffected. Leaf, seed, and soil diseases are managed by the application of fungicides and pesticides. On the other hand, a large number of them negatively impact phosphatase activity efficiency, extraradical hyphal growth, sporulation, colonization, and AM spore germination. Fungicides that limit nutrient transfer, particularly in dry soil, can hamper crop growth that relies on AMF. Soil disturbances and tillage can disrupt the hyphal network and crush AM spores, leading to reduced root colonization. Disrupting colonized root fragments and hyphal networks reduces AMFs' ability to remove dirt. The migration of soil layers affects the current favorable conditions for AMF species. Conventional tillage systems disrupt the extra-radical mycelium network during early colonization, influencing the absorption of water and nutrients by AM activity, glomalin-related soil aggregate formation, and protection against pathogens. Extended periods of fallow land and crop rotation, especially non-mycorrhizal crops, negatively affect propagule density, activity, and the AMF population. The fallow period and non-host species affect AMF propagule density and quantity, thereby impacting subsequent crop production. Waterlogged soil in paddy agriculture inhibits AM activity as it cannot form in damp soil. Conventional agrochemical-based agriculture destroys the symbiosis and effectiveness of AM, leaving its advantages unexplored in this context.

6. Conclusion

AMF has been widely discussed for its ability to aid soil organisms in nutrient absorption. Recent research shows that plants injected with AMF can withstand various environmental cues, and drought, including salinity, nutrient stress, cold stress, alkali stress, and extreme temperatures, leading to increased crop and vegetable yield. Promoting the application of AMFs is vital for ensuring sustainable global agricultural systems. Using AMF for agricultural development can significantly reduce pesticide and synthetic fertilizer use, promoting biohealthy farming practices. Crop plants with AMF-mediated growth and productivity can help fulfill the world's expanding consumption needs. Application of AMF Environment are friendly technology widely used and requires significant backing.

7. Future Research Directions

Future research should focus on finding genes and gene products that regulate AMF-mediated growth and development in response to stressors. Future research should determine the main physiological and metabolic pathways, as well as the host and AMF-specific protein components, that govern symbiotic cooperation in different environments. Understanding the crosstalk between plant performance and AMF-induced tolerance mechanisms can lead to higher crop production. Further research is necessary to fully understand the role of AMF in sustainable agricultural output. To improve soil/plant management, it's important to understand each channel involved in AMF-mediated nitrogen cycling and transfer. Innovative research approaches will be required for this.

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