Chapter

# Glomalin Arbuscular Mycorrhizal Fungal Reproduction, Lifestyle and Dynamic Role in Global Sustainable Agriculture for Future Generation

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## Abstract

Glomalin, a type of glycoprotein produced by arbuscular mycorrhizal fungi in the phylum *Glomeromycota*, contributes to the mitigation of soil degradation. Moreover, AM fungi and glomalin are highly correlated with other soil physico-chemical parameters and are sensitive to changes in the environment; also, they have been recommended for monitoring the recovery of degraded soil or stages of soil degradation. AM fungi are commonly known as bio-fertilisers. Moreover, it is widely believed that the inoculation of AM fungi provides tolerance to host plants against various stressful situations like heat, salinity, drought, metals and extreme temperatures. AM fungi, being natural root symbionts, provide essential plant inorganic nutrients to host plants, thereby improving growth and yield under unstressed and stressed regimes. The role of AM fungi as a bio-fertiliser can potentially strengthen plants' adaptability to changing environment. They also improve plant resilience to plant diseases and root system development, allowing for better nutrient absorption from the soil. As a result, they can be utilised as both a biofertilizer and a biocontrol agent. Present manuscript represents the potential of AM fungi as biostimulants can probably strengthen plants' ability to change the agriculture system for green technology.

**Keywords:** Glomalin, AM fungi, reproduction, Symbiosis, biocontrol agent

## 1. Introduction

Glomalin levels are high in soils and are linked to aggregate water stability. Glomalin contains carbon and hence contributes a significant amount of carbon to the terrestrial carbon pool. Stabilisation of aggregates, on the other hand, likely increases the effect of glomalin in soils by protecting carbonaceous molecules from degradation within aggregates. Because of the symbiotic relationship that occurs between plants and glomalin producers, AM fungus, higher atmospheric $CO_2$ can lead to increased glomalin production. The agroecosystem's management strategies have an impact on glomalin concentrations in soils. Carbon storage is an important function of glycoprotein in soil. Glomalin is a rare molecule (protein) that has been difficult to study biochemically due to its resistance and complexity. Fungi could be a microscopic microorganism of the cluster eukaryotes that consists of yeasts, moulds, and mushrooms. These organisms are terribly little requiring a magnifier for thorough observation. They are globally plentiful and located in a very vast sort of habitat.

There are some beneficial fungus species in the hemisphere that have shaped civilization and fungi have had a significant impact on human and plant longevity. Plants began putting down roots in terrestrial habitats over 460 million years ago, and they were determined by a symbiotic fungus called mycorrhizae. AM fungi (Endomycorrhiza) are grouped into a monophyletic phylum, Glomeromycota, which includes all notable AM fungi and has coevolved with the majority of plants since then. Given mycorrhizae's long evolutionary history, it's not surprising that the mycorrhizal connection is found in more than 95% of all vascular plants, as AM fungi appear to lack host specificity. Plants and glycoprotein-producing fungi form a root endosymbiosis known as AM fungi (GPPF). It is the most widely distributed terrestrial plant symbiont, helping the plant absorb more water and mineral nutrients. Mycorrhizae share some primitive fungal traits, including the ability to form spores, a lack of diversity, the lack of sexual reproduction and the inability to thrive without a living host. The hemisphere is home to a wide variety of mycorrhizae. In forest plants, ectomycorrhizas rely on fungi surrounding the roots in a sheath (mantle) and a Hartig net of hyphae that extends into the roots between cells. The fungal companion could be from the Ascomycota, Basidiomycota, or Zygomycota families. Glomeromycota fungus creates vesicular-arbuscular contacts with AM fungi in a second type. AM fungi produce arbuscular cells, which penetrate root cells and serve as a conduit for metabolic exchanges between the fungus and the host plant. The arbuscules (small trees with a bushy appearance) have a bushy appearance. Orchids are dependent on a third type of mycorrhiza. Orchids are epiphytes with little seeds that require a lot of storage to survive germination and growth. Without a mycorrhizal companion, their seeds do not germinate (Basidiomycete). Once the seed's nutrients are spent, fungal symbionts help the orchid grow by delivering vital carbohydrates and minerals. Throughout their lives, a few orchids remain mycorrhizal connections. AM fungus is obligate biotrophs, meaning they only eat the products of their live hosts' photosynthesis. Fungi aren't usually specialised for their possible hosts, yet some plant species are more conducive to the growth of those fungi than others [1–4]. Fungi are among the most commonly found soil microorganisms on the globe, and they are related to plants such as angiosperms, gymnosperms and pteridophytes with roots, as well as the gametophytes of a few mosses, lycopods and Psilotalus, which do not have true roots [2]. According to numerous studies, AM fungi increase root absorptive area and, as a result, plant nutrition [5, 6], influence plant community succession [7], their fight [8, 9] and phenology [8] equalise the extent of nutrition of co-existing plants by forming hyphal bridges that transfer nutrients among them [10], and increase soil structure by binding sand grains into aggregates by ERH [11, 12]. Plants' tolerance to heavy metals [13–15], water stressors [16], pathogenic fungus, and nematodes was increased by AM fungi [17, 18]. The need for up to 20% of host photosynthate by AM fungus for establishment and maintenance is well understood [19, 20]. This manuscript focuses on the lifecycle and potential role of AM fungi as biofertilizers inside the regulation of plant growth, development, with improved nutrient uptake to a lower place disagreeable environment, overall crop improvement and changing universal sustainable agriculture for future generations and greening agriculture.

## 2. AM fungi upbringing

Intraradical hyphae (IRH) within the roots and extraradical hyphae (ERH) structures outside the roots are found in AM fungi. Arbuscules, vesicles and intraradical hyphae are among the IRH structures. The extraradical hyphal structures are spores, and the auxiliary cells are Gigaspora, Pacispora and Scutellospora members. The principal locations of nutrition exchange between a host plant and a fungal flora are haustoriums and arbuscules [4, 12, 13, 15, 20]. They are made up of cells in the internal root cortex (IRC) [1, 4, 21, 22] and are signs of active, lively and alive mycorrhizae. Arbuscules come in a variety of shapes and sizes, and their form is based on the common association of arbuscular fungi [23]. Arbuscules with cylindrical or slightly flared, slender trunks are produced by fungi of the genera Acaulospora, Archaeospora, Ambispora, Diversispora, Entrophospora, Glomus, Intrapora, Kuklospora, Pacispora and Paraglomus. Members of the genera Gigaspora and Scutellospora have large trunks and branches that taper abruptly at the tips. Globose, spherical, or ovoid, thin-walled vesicles are lipid and glycolipid storage organs [24]. Intercalary swelling in the root ends of intraradical hyphae produces AM fungal vesicles.

Glomus vesicles are mostly elliptical, but Acaulospora, Entrophospora and Kuklospora vesicles have a wide range of shapes and rarely feature knobs or concavities on their surface [23]. Members of the genera Gigaspora and Scutellospora never produce vesicles. Vesicles are rarely produced by members of the genera Archaeospora, Intraspora and Paraglomus. To boot, intercellular hyphae (ICH) in roots store materials and help transfer elements absorbed by extraradical hyphae from the soil to arbuscules or directly to the host plant’s root cells [1, 4, 5]. Intraradical hyphae can be straight or have branches that form an H or Y shape. They may additionally form coils, whose frequency of incidence depends upon their position in a root and therefore the generic affiliation of the arbuscular fungous species [23].

In general, coils proliferate at access locations. Glomus species’ intraradical hyphae are sometimes coiled within the other areas of an AM fungal root. Coils produced by other AM fungus genera, on the other hand, are occasionally abundant and evenly scattered, along with mycorrhizal roots. The degree of evenness of dispersion of roots among AM fungus, and hence the intensity of staining, varies as well. Members of the genera Ambispora, Archaeospora, Acaulospora, Diversispora, Entrophospora, Intraspora, Kuklospora and Paraglomus have patchy distributions of AM fungous structures, whereas mycorrhizae of the genera Gigaspora, Glomus, Pacispora and Scutellospora have a consistent distribution. The staining power of Ambispora, Archaeospora, Diversispora, Intraspora and Paraglomus mushrooms may be very faint to faint, Acaulospora, Entrophospora and Kuklospora fungi faint to moderate, Glomus fungi dark, Gigaspora, Pacispora and Scutellospora fungi extremely dark [25, 26]. The sub-phylum Glomeromycota of the phylum Mucoromycotina contains the bulk of AM fungus species [27]. Glomerales, Archaeosporales, Paraglomerales and Diversisporales are the four orders of AM fungi that make up this subphylum, which also includes twenty-five genera [28]. They are obligate biotrophs and ingest plant photosynthetic products [29] and lipids to perform their lifecycle [30]. AM fungi-mediated growth promotion is not solely by enhancing water and mineral nutrients uptake from the conterminous soil but to boot by means of safeguarding the plants from fungal pathogens [31, 32]. Therefore, AM fungi are essential endosymbionts taking part in an efficient role in plant productivity and therefore the functioning of the ecosystem for sustainable crop enhancement.

## 3. AM fungi paleobiology

AM fungi are thought to be an ancient symbiosis that began over a million years ago, based on paleobiological and molecular evidence. The symbiosis of AM fungus with terrestrial plants is widespread, implying that mycorrhizas were present in the ancestors of all contemporary universal living plants. This favourable relationship with plants may have aided the development of terrestrial plants. Wherever AM fungi are found, fossils of the first land plants have been found in the Rhynie chert from the lower Devonian period [32]. Colonised fossil roots had been ascertained in Aglaophyton foremost and Rhynia, which might be ancient plants possessing characteristics of vascular plants and bryophytes with primitive protostelic rhizomes [33]. The fossil arbuscules seem much similar to those of existing AM fungi [33]. Mycorrhizas from the Miocene show a vesicular morphology closely resembling that of present Glomerales. This preserved morphology can even to boot replicate the prepared accessibility of nutrients provided by the plant hosts in each fashionable and Miocene symbiosis [32]. However, it might be argued that the effectiveness of sign approaches is probable to have evolved since the Miocene, and this cannot be detected within the fossil record.

### 3.1 AM fungi molecular signal

The upward interest in AM fungal symbiosis and the improvement of sophisticated molecular techniques have resulted in a rapid improvement in the genetic signals. Wang et al. [34] studied plant genes including DMI1, DMI3, IPD3, which are involved in communication with associated fungi of the order Glomales. The phylogeny of these three genes has been proven to be congruent with the present phylogeny of land plants, and they can be sequenced from all major clades of modern land plants, including liverwort, the maximum basal group. This suggests that mycorrhizal genes must have existed in the common ancestor of land plants and must have been passed down vertically to colonised land plants [34].

## 4. AM fungi reproduction and lifecycle

AM fungi reproduce by forming spores at the ends of the hyphae. These thick-walled spores stayed underground for a long period of time. Spores of AM fungi can germinate and form hyphae with living hosts.

### 4.1 AM fungi pre-symbiosis

The amplification of AM fungi before root colonisation (RC), called pre-symbiosis, involves three stages, including spore germination, hyphae growth, host recognition, and appressorium formation.

#### *4.1.1 AM fungal spore germination*

The reproduction of AM fungal spores is usually carried out with the help of asexual spores. AM fungal spores are thick-walled, multinucleated, resting structures, especially at the end of continuous sporulating hyphae with mycorrhizal extraradical hyphae. Spore germination has nothing to do with plants because spores germinate *in vitro* (modified living roots) and *in vivo* experimental conditions with and without plants; however, with the help of host root exudates, the germination rate may be hyperbolic. AM fungal spores germinate under suitable soil substrate conditions, temperature, $CO_2$ concentration, pH value and phosphate condition (PC).

#### *4.1.2 AM fungi hyphal development*

Host root exudates were known as strigolactones, and hence the soil PC, control the development of AM fungal hyphae through the soil. Low PC levels in the soil promote hyphal growth (HG) and branching, as well as plant exudation of chemicals that regulate hyphal branching intensity [35, 36]. AM fungal hyphae produced in 1 mM P media had significantly less branching; however, the length of the germ tube and overall hyphal development are unaffected. Every hyphal development and branching of AM fungus has a stage of 10 mM P pent-up. This PC occurs in natural soil environments and may hence contribute to lower AM fungus invasion [35].

#### *4.1.3 AM fungi host recognition*

It has been shown that root exudates (RE) of AM fungal host plants grown in phosphorus-containing and non-phosphorus-containing liquid media can affect mycelial growth. *Gigaspora margarita* and *Glomus intraradices* spores grow on host exudate. Hyphae of AM fungi, compared with plant exudates injected with P, root exudates lacking P grow in large numbers and form tertiary branches. Among the highest concentrations of arbuscular branches, the AM fungal structure is formed by phosphorus exchange [35]. This allows the hyphal growth (HG) to grow closer to the roots of potential host plants; the spores of *Glomus mosseae* are separated from the roots of the host plant through an osmotic membrane, rather than separated from plants and dead plants, effectively becoming hyphae. When treated with host plants, the fungi penetrated the membrane and appeared continuously within 800 μm of the roots, but now they are no longer included in the preparation of non-host plants and dead plants [37].

#### *4.1.4 AM fungi appressorium/infection structure*

The hyphae of AM fungi encounter the root foundation of the host plant, forming appressorium or infectious structures in the root epidermis. From this structure, the hyphae can enter the parenchymal cortex of the host. AM fungi would really like no chemical signals from the plant to make the appressoria. AM fungi can form adherent cells on the cell wall of ghost cells, where the protoplasts are removed to prevent signal transmission between the fungus and the host plant. Hyphae do not invade cells in a similar manner and develop near the root cortex, which suggests that once attachments are formed, signal transmission between symbionts is necessary for similar increased growth as soon as appressoria [36].

### **4.2 AM fungal cell structure, metabolism and natural life**

AM fungus is obligatory organism that must complete their life cycle and produce next-generation spores on living photosynthetic autotrophic hosts. AM fungi are spores that grow on the top of the hyphae and are fully asexual. The spores of the AM fungus grow on the outside or inside of the host root. AM fungal spores can germinate in vitro without a host plant when they come into contact with modified live roots. Spores develop and form a germination tube that extends through the soil until it finds a host root in the absence of live roots. AM fungal spores penetrate roots and develop between root cells or penetrate cell walls and grow inside root cells. Once the spore penetrates the root cell, arbuscular branches are formed. Arbuscules branches are tree-like subcellular structures used to exchange nutrients between AM fungi and related symbiotic plants. The hyphae in the soil may also exceed 100 meters per cubic centimetre [38]. This network of hyphae is designed to increase the absorption of important macro and micronutrients by plants, including N, P, K, Zn, Fe, S, Mn, Mg, Cu, and water.

### 4.3 AM fungi symbiosis

AM fungi form a highly branched structure in the parenchyma, which is used to exchange nutrients in the plant referred arbuscules [1, 4, 6, 39]. These are specific structures unique to AM fungi. Arbuscules are exchange points for replacing phosphorus, carbon, water and other nutrients [1, 4, 15, 18, 40, 41]. There are two types: Paris forms, which have hyphae propagating from one cell to the next, and Arum forms, which have hyphae developing in homes between plant cells [42]. Although some families or species have both types, the decision between Paris and Arum is largely influenced by the host family [42]. Host plants affect ERH proliferation and arbuscules formation [1]. Plant chromatin is depolymerized from body material, which indicates increased transcription of plant deoxyribonucleic acid (DNA) in arbuscules cells [42]. Major alterations are needed within the plant host cell to accommodate the arbuscules. The vacuoles contract and various cellular organelles proliferate. The cytoskeleton structure of plant cells surrounds the arbuscules organisation. There are two different types of hyphae that come from the roots of the host plants being colonised: after colonisation occurs, transient runner hyphae grow from the roots of the plants to the ground soil. These are ERHs that absorb phosphorus and other nutrients into plants. The hyphae of AM fungi have a high quantitative surface area to volume quantitative ratio, which means that their absorption capacity is greater than that of plant roots [43]. The hyphae of AM fungi are also smaller than roots and can penetrate into soil pores where roots cannot enter [1, 44]. The fourth type of hyphae of AM fungi is different in morphology, it grows from roots and colonises different roots of host plants [40].

### 4.4 Multiplicity of AM fungi and dominant genera

There are 336 species of AM fungi. Among them, the dominant genera include 6 species, including Acaulospora, Glomus, Gigaspora, Scutellospora and Entrophospora, which have greater advantages in farmland than uncultivated ones (on Google.com). Glomus is the dominant genus, which can be obtained on land all over the world and reproduced by biostimulants.

### 4.5 AM fungi characteristics and utilisation

The symbiotic relationship of AM fungi is a traditional instance of a mutualistic relationship that can regulate plant growth and development. The fungal mycelium network extends under the roots of the plant, facilitating the absorption of nutrients uptake (NU) that are otherwise unavailable. The mycelium of AM fungi colonises the roots of many different plant species, forming a common mycorrhizal network (CMN). Common mycorrhizal network is considered to be the main component of the terrestrial ecosystem (TES) and has a profound impact on various plant communities, especially on invasive plants [1, 15, 20, 45], and the fungal removal of phosphorus and nitrogen (N) are transferred to plants [6, 31, 46, 47]. In addition, the transfer of common nutrients from fungi to plants has a variety of side effects and improves plant resistance to biological and non-biological factors. They have the ability to improve soil properties, thereby stimulating plant improvement under normal conditions and under stress [47, 48]. The colonisation of AM fungi increases the plant's resistance to stressful signals, which leads to its morphological and physiological characteristics having a large number of changes [48, 49]. AM fungi are considered to be a natural growth regulator for most terrestrial plants. AM fungi are used as biological vaccines (bioinoculants), and researchers are promoting their use as excellent biological fertilisers to achieve sustainable crop yields. Constant mass and significantly higher extraradical hyphae mycelium [1, 4, 15, 20, 50]. Glomalin-related soil protein (GRSP) is believed to maintain the water content of soil exposed to various abiotic stresses [51], then adjust the water frequency between soil and plants and automatically trigger plant improvement. Glomalin contains 30–40% carbon and its related compounds, which can prevent soil from drying out by increasing its water holding capacity [52]. Growth associated functions, including stomatal conductance, leaf water potential (LWP), relative water content (RWC), PSII efficiency and $CO_2$ assimilation, depend on AM fungal inoculation [15, 53]. AM fungi also help increase resistance to water stress through physiological changes in organs and tissues on the earth [54]. AM fungi can improve the accumulation of dry matter and improve the absorption of water, thereby enhancing the plant's resistance to stress. The use of AM fungi for plant growth in various biological [55] ecosystems can make a significant contribution to the cultivation of organic culturing to stimulate growth and increase yield.

## 5. AM fungi for environmental implication

AM fungi are extremely beneficial to the environment and make a significant contribution to improving soil and plant health and maximising the intake of macro and micronutrients. This symbiotic relationship between fungi and plants spans millions of years, and these characteristics allow plants to survive. Colonise areas that are difficult to resist; however, their presence in the soil makes them vulnerable to erosion and tilling. Tilling reduces the effectiveness of soil inoculation and fungi by destroying the mycelial network.

## 6. AM fungi utilisation as a biofertilizer and substitute the chemical fertiliser

AM fungus produces glomalin protein in the soil environment, which may promote soil particle aggregation. It also boosts soil oxygen and carbon content, which is beneficial to plant and soil health. AM fungal-mediated plant growth is accelerated by a factor of 10, allowing for faster plant establishment. It improves standard root biomass and root yield in cereals, legumes, vegetables, spices, and fruits crops by up to 50 times. AM fungus inoculums are a mixture of naturally occurring material (spores, root bit, hypha, mycelium and substrate) used to improve soil fertility, production and importance in agroecosystems. AM fungi, like plant growth and development, are extremely important to soil health (SH). Various studies and research on AM fungus have been conducted over the last three decades, highlighting its numerous benefits to soil and plant health as well as crop productivity (CP). As a result, it is widely assumed that AM fungi might be considered as a chemical fertiliser (CF) substitute due to the fact that the utility of AM fungi can effectively minimise the quantitative usage of chemical fertilisers input [1, 4, 15]. Through their poor impact on the quality of food products, soil health, air, and water systems, the continued use of lifeless chemical fertilisers, herbicides and fungicides has caused a slew of problems for soil, plants and human health (HH) [47, 56]. It is estimated that AM fungus can reduce the use of chemical fertilisers by up to 50% for pleasant agricultural output; however, this estimate is dependent on plant species morphology and traditional traumatising regimes.

## 7. AM fungi nutrients translocation and exchange effectiveness

AM fungi have a mutually beneficial symbiotic relationship with the host. These biologically active phytochemicals and AM fungi participate in the interaction between plants and soil microorganisms. They have limited saprobic ability and rely on host plants as their carbon nutrient for food. The photosynthetic product of the host plant in the form of hexose. The transfer of carbon from plants to fungi can also occur through arbuscules or intraradical hyphae [1, 33, 57]. The intraradical mycelium is where AM fungus perform secondary hexose production (IRM). Hexose is metabolised to trehalose and glycogen in the mycelium. Trehalose and glycogen are carbon storage forms that can be swiftly generated and degraded, and they can help to buffer intracellular sugar levels [4]. The intraradical hexose is converted to pentose for nucleic acids via the oxidative pentose phosphate pathway. Lipid production takes place within the intraradical mycelium as well. After that, lipids are stored or exported to extraradical hyphae, where they will be stored or metabolised. Gluconeogenesis is the degradation of lipids into hexoses that occurs in extraradical hyphae [57]. The extraradical hyphae store around a quarter of the carbon transferred from the plant to the fungi [58]. The AM fungus may absorb over 20% of the carbon from the host plant [57]. This reflects the host plant's significant carbon investment in the mycorrhizal network (MNW) and contribution to the organic carbon pool below ground (OCP). AM fungus is escalating uptake and switching of P and exclusive macro and micronutrients from the host plant, increasing the plant's carbon delivery to the AM fungi. Similarly, nutrient uptake and transfer are reduced, as is the amount of photosynthate available to the fungi. The ability of different AM fungus species to supply nutrients to the plant varies. AM fungi can be poor symbionts in some situations, delivering little P while using large amounts of carbon [59]. The primary benefit of AM fungus to plants has been related to their ability to absorb nutrients/vitamins over longer periods of time, particularly P. AM fungus may be far more efficient at absorbing P than plant roots. Diffusion transports phosphorus and other minerals to the roots, and hyphae shorten the distance necessary for diffusion, resulting in improved uptake. The rate of phosphorus deposition in AM fungus could be six times that of root hairs [44]. In some situations, the mycorrhizal network can totally take over the role of phosphorus and nutrient absorption, and all of the plant's phosphorus can come from hyphal sources [59]. Although mycorrhizas have been discovered in watery situations, wet soils have been demonstrated to impair mycorrhizal colonisation in numerous species [60].

## 8. Role of AM fungi in mineral nutrition and their impact on symbiotic host

As many reports have emphasised, overexploitation of land usually has serious consequences for biodiversity, which in turn will have additional impacts on ecosystem functions. AM fungi are very beneficial to increase nutrient bioavailability, which can reduce irrigation and increase fertilisation efficiency. In this symbiotic relationship, an important role is to transport nutrients from organic carbon (OC) in the form of lipids and sugars [61]. It is believed that mycorrhizal colonisation stimulates the absorption of nutrients by plants. This leads to accelerated production of photosynthesis, thereby accelerating biomass accumulation [4, 12, 46, 62]. AM fungi can improve the absorption of inorganic nutrients by almost all plants, especially phosphorus [1, 6, 12, 46]. AM fungi are also very effective in helping plants absorb nutrients from nutrient-poor soils. In addition to macronutrients, AM fungi have been reported to increase the plant utilisation of micronutrients such as zinc, iron and copper [4, 15]. AM fungi increase the absorptive capacity of the host root surface. Experimental results on tomato plants inoculated with AM fungi showed that the leaf area and N, K, calcium and P content increased, indicating that the plant is growing well [63]. AM fungi coexist with roots to obtain important nutrients from the host plant, thereby providing mineral nutrients such as N, P, K, Ca, Zn and S. Therefore, AM fungi can support plant vegetative root cells even when it is not important. AM fungi produce arbuscules fungal structures (AFS), which promote the exchange of inorganic minerals and C and P compounds, and ultimately transfer large amounts of energy to the host plant [4, 64, 65]. AM fungi have been found to help the absorption of P and N, and ultimately help improve plants in better areas and reduce P.

Under drought stress, the symbiosis of AM fungi undoubtedly increases the concentration of N, P and Fe in *Pelargonium graveolens* L. [66]. Gomez Bellot et al. [67] believed that AM fungi can increase the absorption of almost all essential nutrients, on the contrary, can reduce the absorption of Na and Cl, thereby stimulating growth [68, 69]. Many scientists have discovered that AM fungi play a significant role in absorbing nutrients from the soil, especially N and P can effectively promote the growth of host plants. Many studies have shown that AM fungi have the ability to absorb N and transfer it to nearby plants or hosts. The symbiosis of AM fungi produces huge underground extraradical mycelium from the roots and surrounding rhizosphere, which helps to improve nutrient absorption. In the case of increased environmental concentration and $CO_2$ content [69], AM fungi are said to promote the growth and accumulation of micro and macronutrients and their distribution in seedlings that grow with an accelerated increase in manganese range [6, 63, 70]. Improving plant nutrition and maintaining the ratio of $Ca^{2+}$ and $Na^{+}$ are essential dynamic properties that help enhance AM fungal colonisation of beneficial ingredients in multifunctional plant performance. Improved growth and levels of protein, Fe and Zn had been discovered in mycorrhizal chickpea [71]. In addition, various reports have shown that the mycorrhiza of *Lotus japonicus* root has excellent $K^{+}$ transporter activity [72]. In addition, the meta-analysis report confirmed the symbiosis effect of mycorrhiza and a variety of micronutrients in crops. Multiple inspections of the previous pair at the same stage. Over the years, it has been shown that AM fungi (*Glomus mosseae* and *Rhizophagus irregularis*) increase the translocation of heavy metals within the shoots [73].

## 9. Role of AM fungi in plant productivity and quality

AM fungi are no longer the most effective, they can increase the nutritional value of plants, and they can also increase the quality and quantity of plants. Improve the nutritional quality of plants through exposure and production of carotenoids and some volatile compounds [74, 75]. Prasad [63] found that AM fungi having a positive effect on the quality and yield of nightshade solanaceous crops (tomatoes, potatoes and eggplants). Zeng et al. [76] mentioned modified sugars, organic acids, vitamin C, flavonoids and minerals from *Glomus versiforme* to produce better quality citrus fruits. The symbiotic relationship of AM fungi can induce a more adequate accumulation of anthocyanins, chlorophylls, carotenoids, overall soluble phenols, tocopherols and many minerals [77–79]. AM fungi have been used in large scale field production of corn [80], yams [81], potatoes [82], soybeans [83–85] and onions [6], confirming that AM fungi have a significant increase in production. AM fungi can also promote the biosynthesis of valuable phytochemicals in edible plants and lead them into the healthy food chain [86].

## 10. Role of AM fungi in enhance production of growth hormones for host

Plants with AM fungi have higher levels of growth regulators, such as cytokinins and auxins than those without mycorrhiza. AM fungi colonised roots display adjustments in root morphology through acquiring plentiful thicker and delivering fewer root hairs. Host tissue is affected by mycorrhizal colonisation. It is suitable for cytokinin, abscisic acid and gibberellin-like substances. The influence of AM fungi on photosynthesis and host morphology can also be hormones.

## 11. Role of AM fungi in abiotic stresses

### 11.1 AM fungi drought tolerance activity

Plants inoculated with AM fungi are tolerant of drought, because these AM fungi help absorb toxic minerals and improve the overall health of plants and soil, toxic levels and mineral toxicity [4, 6, 15]. AM fungi help plants to absorb nutrients from the soil in exchange for sugar produced by the plants. In the forest ecosystems, ectomycorrhizas form filaments called hyphae net, which run between trees to act as connecting bonds. This huge underground transportation network is called the common mycorrhizal network. a common mycorrhizal network uses chemical communication to exchange nutrients between trees when needed. A common mycorrhizal network also makes it easier for trees to obtain water that cannot be reached by their roots. In the presence of excessive soil temperature, soil toxins, and extreme soil pH, plants treated with AM fungi can improve drought tolerance and survival.

### 11.2 AM fungi salinity tolerance effectiveness

Salt stress is believed to inhibit plant growth through use, affect nutrient improvement and net assimilation rate, resulting in a decline in productivity. It also contributed to the beginning of the era of excessive reactive oxygen species [87, 88]. Soil contaminated by salt and the correct use of AM fungi to reduce salt content have harmful effects on plants [89]. Several studies have shown that AM fungi improve plant growth and productivity under salt stress conditions [90]. AM fungus improved the growth rate, leaf water potential (LWP), and water usage efficiency (WUE) of Antirrhinum majus plants, according to El-Nashar [91]. Under salinity, Ait-El-Mokhtar et al. [92] found that the AM fungal symbiosis improved physiological parameters, photosynthetic rate, stomatal conductance and leaf water relations. Under saltwater circumstances, AM fungus inoculated on Allium plants showed better development, including leaf area index, fresh and dried biomass [6, 93]. Under salt stress conditions, the concentrations of total P, $Ca^{2+}$, N, $Mg^{2+}$ and $K^{+}$ in cucumber plants treated with AM fungi are higher than those of uninoculated plants [94]. Pepper exhibits better chlorophyll content and better $Mg^{2+}$ and N absorption, while at the same time reducing $Na^{+}$ transmission under salt conditions [95]. Inoculation with AM fungi can effectively regulate the level of major growth regulators. Plants colonised by AM fungi can reduce oxidative stress by inhibiting lipid membrane peroxidation under salt stress conditions [90, 96].

### 11.3 AM fungi heavy metals tolerance activity

It is generally believed that AM fungi can promote the rooting of plants in heavy metal contaminated soil because they can improve the plant defence system mediated by AM fungi and promote their growth and expansion. Heavy metals can also be obtained from food crops, fruits and vegetables and soils, inflicting numerous health hazards. The association between AM fungi and wheat actively increases nutrient uptake under aluminium stress [97]. Heavy metals can be fixed in the hyphae of endogenous and exogenous fungi [98], they have the ability to fix heavy metals in the cell wall and accumulate in vacuoles or can also chelate with some other substances in the cytoplasm [99], and then reduce the toxicity of metals in plants. The more common reason is that these fungi can improve the morphological and physiological processes of the rapid evolution of plant biomass, thereby promoting the absorption of fixed essential nutrients (copper, zinc, phosphorus, nitrogen, potassium). The toxicity in the host organism can be reduced by AM fungal mediated plants [15, 20, 100]. It is likewise believed that improved growth or chelation in the rhizospheric soil can cause metal dilution in plant tissues [101]. It has been reported that AM fungi bind to Cd and Zn in the cell wall and cortical cells of the mantle hyphae, limiting their absorption and leading to better growth, yield and nutritional status [20]. It has high cation exchange and metal absorption potential [102]. Similarly, AM fungi can also solve the problem of low Cd mobility and toxicity by increasing the pH of the soil [103], reducing Cd to extraradical mycelium [104], and combining Cd with the glomalin, a glycoprotein. AM fungi are very effective in reducing the level of Cd in each vacuole sand cell wall, which roughly contributes to the detoxification of Cd in rice [105].

### 11.4 Role of AM fungi in high and low temperature tolerance to crops

As soil temperature increases, the response of the plant community may depend on the interaction of AM fungi to ensure sustainable production. Biomass production, withering and burning of leaves and reproductive organs, leaf tearing and ageing, additional damage leading to fruit discolouration, reduced yield and cell death, and related oxidative stress increases. In general, plants treated with AM fungi perform better under heat stress. Maya and Matsubara [106] pointed out the relationship between *Glomus fasciculatum* and plant growth and the most important positive growth changes under high-temperature conditions. AM fungi can increase the resistance of plants to low temperatures. In addition, most information claims that some plants inoculated with low-temperature AM fungi grow and spread better than plants not inoculated with AM fungi [107, 108]. AM fungi help plants prevent cold stress and ultimately accelerate plant development [108]. AM fungi can also maintain water in the host plant and increase phytochemicals, thereby strengthening the plant's immune system and increasing protein levels to help the plant fight cold stress [109]. The symbiosis of AM fungi improves the relationship between water and plants, increasing the possibility of gas exchange and osmotic regulation [110]. AM fungi increase the synthesis of chlorophyll leading to a noteworthy perfection in the concentrations of numerous metabolites in plants subjected to cold stress conditions [109, 111].

## 12. Role of AM fungi in seed production, offspring fertility and tolerances to disease and pest

AM fungi can improve the vigour of offspring, and through AM fungi, the fertility and survival rate of plant seeds can be improved. AM fungi increase the resistance of pests to root and soil-borne pathogens through mycorrhizal induced resistance and the production of secondary metabolites and increase resistance to leaf pathogens [1].

## 13. Role of AM fungi in carbon cycling and phytoremediation

The production of glycoproteins, including glomalin that may be involved in the formation and stability of soil aggregates, should have an additional impact on the unusual microorganisms associated with AM fungal mycelium [41, 111]. Changes in native plant groups in areas threatened by desertification are often related to the deterioration of soil physical and biological properties, soil structure, availability of nutrients and organic matter and physical properties of soil [4]. A particularly new method of land restoration is to inoculate the soil with AM fungi and at the same time reintroduce vegetation to ecological reclamation. This allows host plants to take root in degraded soil and improves soil quality and health [1]. In the long run, compared with unmodified soil and soil inoculated with single exotic species of AM fungi, the introduction of a mixture of natural AM fungi resulted in significantly improved soil quality parameters [4]. The advantages included increased plant growth, increased P absorption [4] and soil N content, higher soil organic matter, soil aggregation, which was linked to stronger legume nodulation in the presence of AM fungus, higher water infiltration, and soil aeration. The native AM fungus aids in the removal of heavy metals from contaminated soil, making it healthier and more conducive to agricultural development [4].

## 14. Role of AM fungi on global climate change

Climate change poses a major threat to AM fungi due to irreparable damage to various ecosystems, in addition to increasing habitat loss because of human activities, so gradual steps must be taken to mitigate the next errors that occur from these concerns. Global climate change is affecting the population of AM fungi and the interaction between AM fungi and their host plants. It is generally believed that the interaction between organisms can affect their response to global climate change. In a recent meta-analysis, it was found that AM fungi increased plant biomass under drought conditions. The AM fungus itself has been shown to increase its biomass in response to accelerated emissions of carbon dioxide into the atmosphere. Climate change has brought challenges to the supply of water, food, and nutrients. There may also be deficits in some places, and surpluses in other places. The relationship between forest trees and AM fungi helps them, mainly based on the percentage of sources needed, and may help us solve these problems.

## 15. Conclusion

Several studies have recognised the positive role of AM fungi in improving plant growth in stressful environments, hence, this manuscript consistently combines existing evidence about the AM fungi general reproduction, lifestyle, and its widespread distribution to generate knowledge for agriculturists and researchers. The symbiosis and courtship of AM fungi and different plants in a stressful environment. AM fungi contribute to many aspects of plant life, especially better nutrition, better growth, stress and disease resistance. The particles accumulate to improve the soil's resistance to wind and water erosion. AM fungi reduce the leaching of nutrients in the soil, thereby promoting the retention of nutrients in the soil and reducing the risk of groundwater pollution. These multiple benefits of AM fungi translate into an important ecological benefit in natural circumstances. Formerly, AM fungi had been particulars mentioned as useful entities for nutrient uptake from soil; however, it has recently been honestly described that plants inoculated with AM fungi can effectively control various environmental factors such as salt, drought, nutrient stress, alkali stress, cold stress and high temperature, thereby controlling plant yield and productivity. A wide range of plants such as beans, oilseeds, fruits, fibre plants, vegetables, forests, and nurseries are developed. Promoting the use of additively manufactured AM fungi is critical to the sustainability of modern global agricultural systems. Agricultural development can significantly reduce the use of artificial (lifeless chemical fertilisers, pesticide, insecticide) fertilisers and various chemicals, thereby supporting biologically healthy agriculture. Inoculation with AM fungi that can increase plant growth and productivity can help meet the consumer needs of growing populations around the world. In addition, environmental protection technology can only be protected through widespread usage. The most important knowledge in fortune research should be to control AM fungal inoculum mediated growth and improve the identity of genes and gene products downregulated by stress signals. AM fungi regulate tolerance mechanisms, in addition, activating crosstalk to control the overall performance of the plant can help increase crop yields. AM fungi must be explored in any respect ranges to extra inspect their role in the landscape as a biofertilizer for sustainable agricultural production for fast increase population worldwide.

## Conflict of interest statements

There is no conflict of interest.

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