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ROLE OF MYCORRHIZAE AS BIOFERTILIZER AND BIOPROTECTANT

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ABSTRACT

Mycorrhizae are obligate fungi that predominate in the roots and soil of higher plants. They form association with plant roots in a host-non specific manner. Seven types of mycorrhizae have been known i.e. arbuscular, ecto, arbutoid, ectendo, ericoid, monotropoid and orchidaceous mycorrhizae. Out of these, arbuscular and ectomycorrhizae are the most abundant and wide spread. They promote plant growth by enhancing nutrient acquisition and promoting growth hormones. They also increase the resistance in plants against plant pathogens and surface area of root system for better absorption of nutrient from soil. Therefore, they can be used as biofertilizer and as biocontrol agent. This article presents an overview of current knowledge on mycorrhiza and their potential benefits to agriculture as biofertilizer and biocontrol agent.

KEYWORDS: Biocontrol agent; Biofertilizer; Plant growth promoter; Soil-borne pathogens; Vesicular-arbuscular mycorrhizae

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1. INTRODUCTION

India is an agricultural based country and in order to feed the increasing population, it has to increase its productivity. After green revolution the crop productivity in India has increased many folds. In last few years the crop yield has increased due to the use of inorganic fertilizers and pesticides (51). Now, agricultural practices totally depend on the chemical fertilizer and pesticides for the productivity of various crops. Use of nitrogen, phosphorus and potassium based fertilizers increase the crop productivity to some extent but, on the other hand, increased doses of chemical fertilizers posed devastating effect on soil fertility, cause environmental pollution and kill the beneficial microorganisms which are present in soil. The indiscriminate use of pesticides has induced resistance in pests against these pesticides. Moreover, the toxic chemicals which are applied in the field are absorbed by plants and enter the food chain through vegetables and cereals causing many health problems. So, in order to cope up with all these problems and make agriculture sustainable development, we should focus on such certain agricultural practices which are ecofriendly. The concept of sustainable development is the management of natural resources for human use and is one of the best ways for the sustainable agriculture and to decrease the negative impact of pesticides and fertilizers on environment (2). Sustainable agriculture means full utilization of environmental resources with no harm to it (61). One such approach towards sustainable agricultural practice is to move towards the microbial technology such as use of *Mycorrhizae* as biofertilizer and biocontrol agent (27). In agricultural ecosystem, they play a vital role in nutrients fixing, solubilizing and mobilizing. Mycorrhizae have profound effect on the rhizosphere. They alter the microbial community structure of the soil (57). They interact with other soil biota such as phosphate solubilizing bacteria, Plant growth promoting rhizobacteria, plant pathogens and other bioagents, and microfauna which results in a significant positive or negative effects on plant growth (47). Mostly positive effects on plant growth have been reported, although numerous negative effects on plant growth have also been reported (68). Arbuscular mycorrhizal (AM) fungi play a significant role in sustainable farming system because AM fungi are efficient when nutrient availability is low and nutrients are bound to organic matter and soil particles. They directly or indirectly affect plant growth (Fig. 1). Indirectly they promote plant growth by improving the soil quality and by suppressing the pathogens responsible for reduced crop production (78). Mycorrhizae are important for plants and ecosystem. They affect the plant production and soil health (24; 62; 82; 63; 29). AM fungi colonize the roots of many economically important crops and could serve as biofertilizer and bioprotectors in environmentally sustainable agriculture (20).

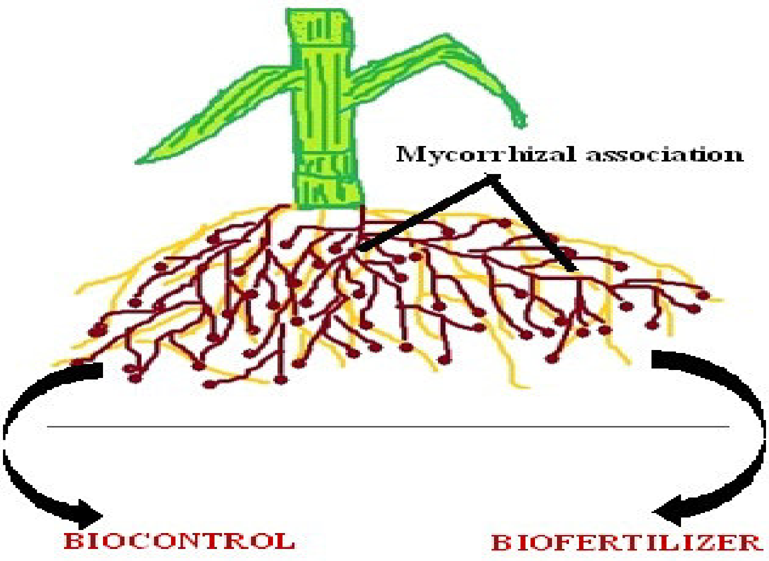

Figure 1
Diagrammatic representation showing role of Mycorrhizae as biocontrol and biofertilizers

2. Mycorrhizae

The term mycorrhizae was first time introduced by A.B. Frank in 1885. It literally means “fungal root” used to denote the association between certain soil fungi and plant roots. Mycorrhiza is a type of endophitic, biotrophic, symbiotic, mutualistic relationship special soil fungi and fine plant root (http://edis.ifas.ufl.edu.). The most ancient and abundant mutualistic on earth is found between majority of land plants and arbuscular mycorrhizal (AM) fungi by forming extensive hyphal network in soil and plants (64). Fossil records indicate that it is evolved 400-450 million years ago (65). It is neither the fungus nor the root, but it is the structure formed by these two partners. Fungus increase the plant nutrition absorption capacity from the soil by increasing the surface area of root system and in exchange fungus receives carbohydrates and growth factors from the plant (http://edis.ifas.ufl.edu.). In mycorrhizal interaction bidirectional exchange of resources across the mycorrhizal interface takes place. The mycorrhizae provides nutrients (phosphate and nitrogen) to host plants and increases the abiotic (drought, salinity and heavy metals) and biotic stress (root pathogens) resistance in host plants and in return the host plant provides 4-20% of its photosynthetically fixed carbon to the mycorrhizae (81). There are certain plants which have lost their photosynthetic property and parasitize mycorrhizae that are associated with neighbour autotrophic plants. Such type of plants are mycoheterotrophic plants (20). Vesicular-arbuscular mycorrhizal (VAM) fungi are ubiquitous in nature and act as a natural link between the roots of most plants and soil (52). They form an intimate relationship with plant root system and benefit plant health (17) by contributing to phosphorus uptake (66; 33) and nitrogen uptake (30). Besides these they also play an important role in uptake of K, S, Mg, Fe, Zn, Cu (59). They contribute up to 90% of plant P demand (79). Arbuscular mycorrhizal spores can germinate in the absence of host plant but its hyphal branching and metabolic activity increase only in the presence of strigolactones (root exudates) that induces the pre-symbiotic growth of AM fungal spores (3).

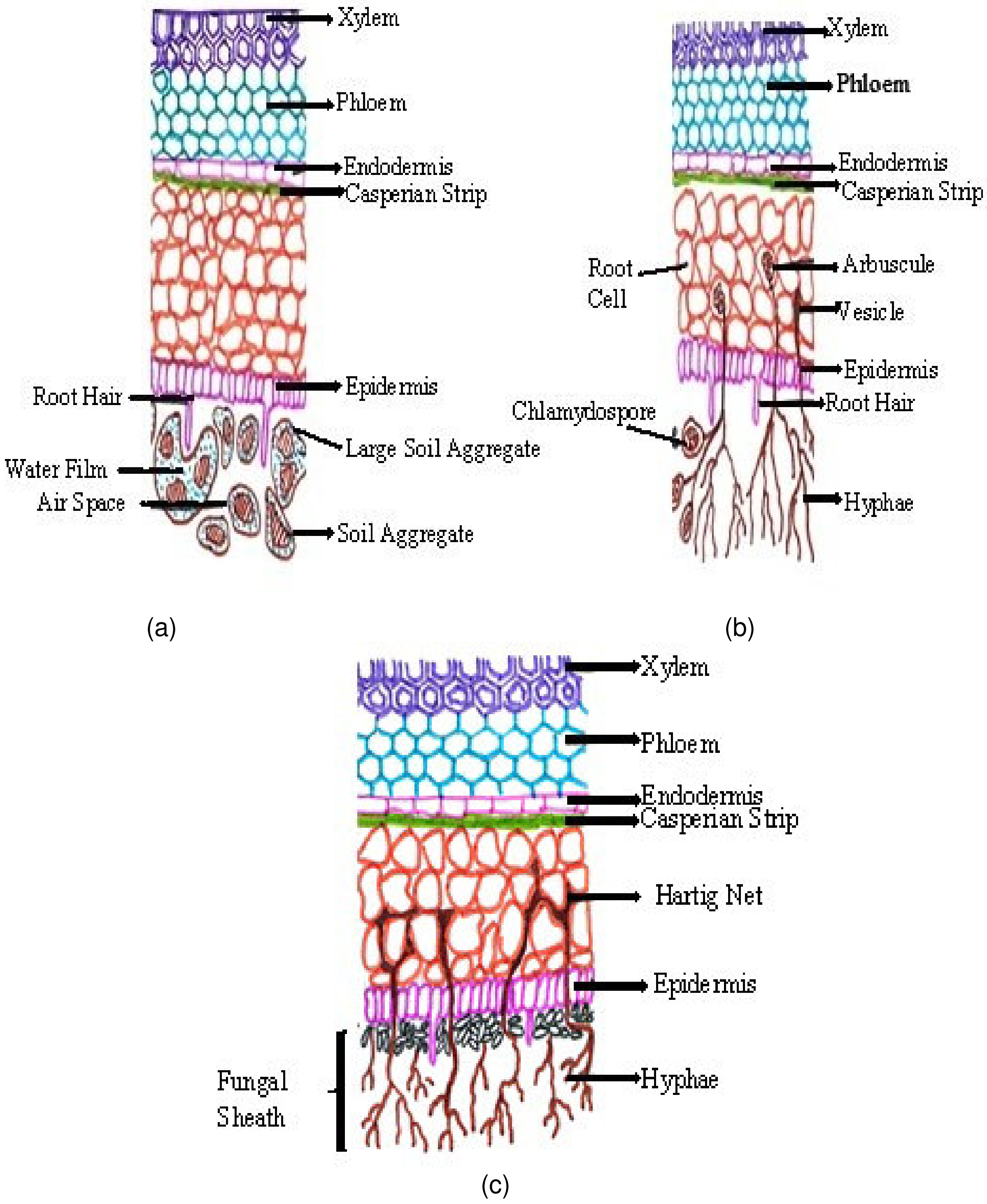

Figure 2
(a) root without Mycorrhizae, (b) root with Endomycorrhizae, (c) root with Ectomycorrhizae

There are three major groups of Mycorrhizae: *Ectomycorrhiza* (Fig 2c), *Ectendomycorrhiza* and *Endomycorrhiza* (Fig 2b), out of these *Ectomycorrhiza* and *Endomycorrhiza* play a vital role in agriculture. *Ectotrophic* types or *Ectomycorrhizal* fungus penetrates between the cell walls of the cortex and forms a covering sheath of fungal hyphae around the entire root system. Whereas *Endotrophic* types or *Endomycorrhizae* or *Arbuscular Mycorrhizae* do not form mantle or covering sheath of fungal hyphae over the root, they just enter the cortex cells (http://edis.ifas.ufl.edu.). The fungi of Glomeromycota (AM fungi) form a unique structure such as arbuscules and vesicles known as arbuscular mycorrhizae (AMs). Out of seven mycorrhizae i.e. arbuscular, eco, ectendo, arbutrid, monotropoid, ericoid and orchidaceous mycorrhizae, the arbuscular and ectomycorrhizae are the most abundant and widespread (58). The VAM fungi are the most common mycorrhizal type which are involved in agricultural system (16). *Ectomycorrhizae* are found in the roots of pines, birches, willows and oaks and *Endomycorrhizae* are present in most agronomic vegetable crops and fruits (http://edis.ifas.ufl.edu.).

Table1

Direct and indirect effects of mycorrhizal fungi on crop productivity

Direct effects on crops	Indirect effects on crops
Stimulation of plant productivity Nutrient acquisition (P, N, Cu, Fe, Zn) Enhanced seedling establishment Drought resistance Heavy metal resistance	Weed suppression Stimulation of nitrogen fixation by legumes Stimulation of soil aggregation and soil structure Suppression of some soil-borne pathogens Stimulation of soil biological activity Increased soil carbon storage Reduction of nutrient leaching

(Source: van der Heijden et al., 2008)

AM fungi can enhance plant growth (15), affect the cellular and biochemical compositions (44; 37) and suppress plant disease (85). These can also increase the bacterial density in soil, produce siderophore and reduce nematode population in mycorrhizosphere of plants. During the last few decades the government and entrepreneurs have paid special attention towards the setting up of biofertilizers production facilities due to which production and promotion of biofertililizer in agriculture has increased. Now the farmers have realized the benefits of biofertilizers. The role of biofertilizer like AM fungi in the growth and multiplication of crop plant can prove to be the most effective alternative to chemical fertilizers for enhancing growth and biomass production of crop. In addition, it can also improve vigour and nutrient uptake, disease resistance and drought tolerance (76). It has been reported that phosphate solubilizing bacteria (PSB) interact with VAM and release phosphate ions in the soil which have a synergistic effect on P solubilization (48) because the phosphate solubilized by the bacteria can be more efficiently absorbed by plants through the bridge formed by mycorrhizae among the roots and surrounding soil (38). Moreover, it has also been found that PSB and VAM in combination improved mineral (N and P) accumulation in plants tissues (77). In addition, it has been reported that AM fungi could mobilize phosphorus from rock phosphate (12).

2.1. Mycorrhizal fungi as biofertilizer

AM fungi directly influence the growth of its host plant such, for instance, by providing nutrition through plant roots (65). Moreover, some extracellular secretions from fungal hyphae (50) directly affect microflora of the mycorrhizosphere and also play a very significant role in soil aggregation (53). VAM fungi have some special structures known as vesicles and arbuscules. They increase the length of the root 100 fold of the normal because of which the root reach up to wetter soil and help plants to absorb many less available nutrients such as phosphorus, zinc, molybdenum and copper. Some VAM fungi form a covering sheath around the root; they increase the tolerance of seedling to drought, high temperature, pathogens and soil acidity. The greatest growth response to mycorrhizal fungi is found in plants of highly weathered tropical acid soil where P is less and has high toxic value due to presence of Aluminium. The microbiologically solubilized phosphate is taken up by mycorrhizal mycelium which develops a synergistic microbial interaction (14; 25; 21). Besides this, it also stimulates foliar content

(25; 21). Mycorrhizal symbiosis plays a very important role in nutrient cycling in agricultural and natural ecosystem (49; 11). It also increases the plant resistance to different environmental stress (11). The microorganisms present in mycorrhizosphere affect the AM formation and its function (11). The mycorrhizosphere has two zones i.e. mycorrhizosphere and mycosphere. Mycorrhizosphere is the zone which is under the influence of root and fungal partners of the mycorrhiza whereas mycosphere is the zone which supports bacterial activities (7). Microorganisms in the mycosphere of the AM fungi affect mycorrhizae functions such as nutrients and water uptake carried out by the external hyphae of AM fungi (25) and they are called as 'mycorrhiza helper bacteria' (MHB). These stimulate the growth of mycorrhiza (31) in the soil. The term was coined by Duponnois and Gerbaye (26).

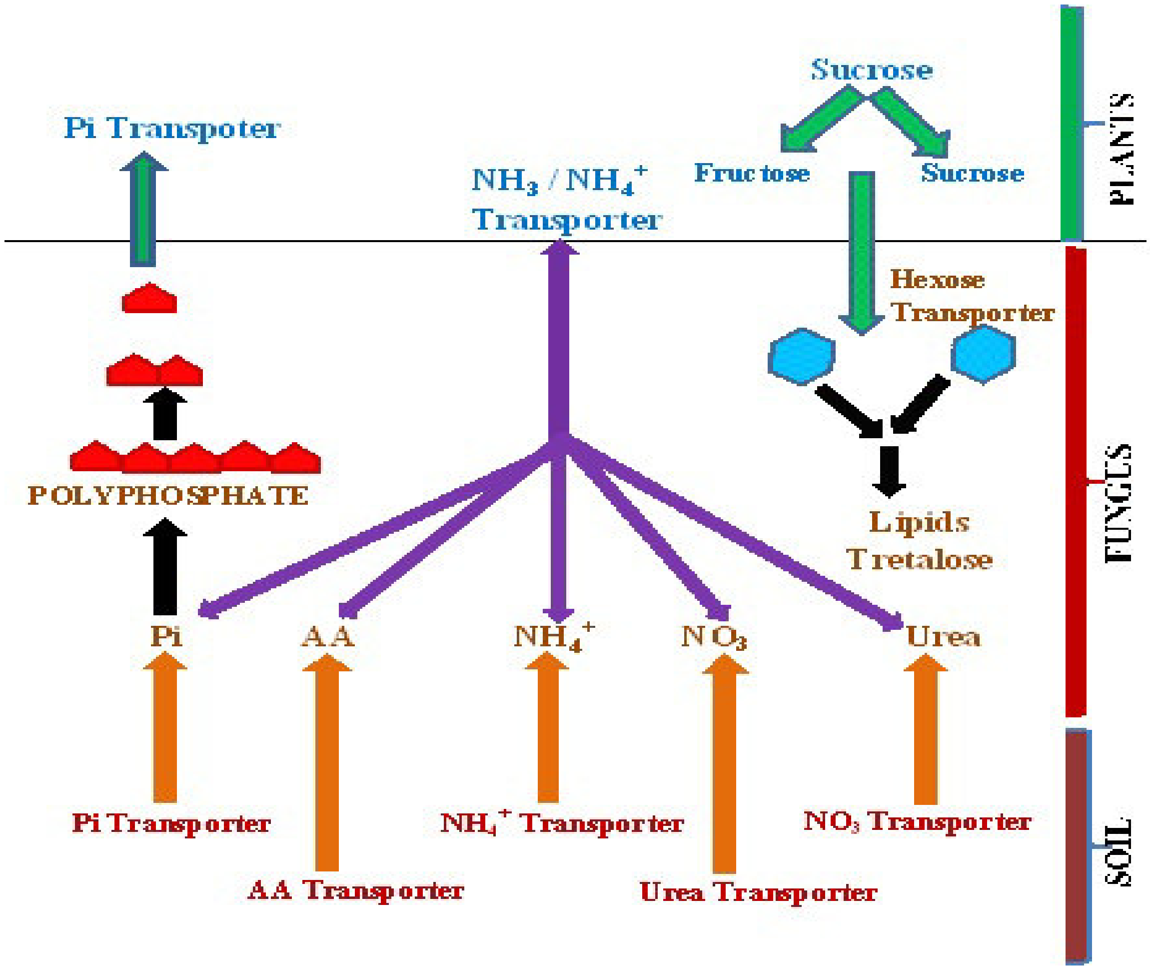

Figure 3
Nutrient uptake by Mycorrhizae

Mycorrhizal plants can absorb nutrients by two pathways. Firstly by absorbing nutrients directly from the soil through 'plant pathway', but due to this, a nutrient depletion zone is formed around the root. In nutrient deficient situation 'mycorrhizal pathway' is useful where extraradical mycelium (ERM) grows into the soil, uptake the nutrient and transport it to hartig net in ectomycorrhizal (ECM) interaction or to intraradical mycelium (IRM) (55). The extraradical mycelium absorbs nutrients from the soil and transfers it to the host root whereas in second pathway the intraradical mycelium releases nutrients into interfacial apoplast and exchange them against carbon from the host (20). The use of rock phosphate as a cheap alternative source has been used for sustainability purposes (86). Phosphorus is a very important element which is required by the plants for its metabolism and soil microbiological processes. They are present in soil in insoluble form and so, they are unavailable to plants. But AM fungi have the capability to convert insoluble P into soluble (ortho-phosphate) form. They play a very significant role in phosphate solubility through different mechanisms such as production and secretion of organic acids (34). Moreover, under P limiting conditions the external hyphae of AMF extend beyond the P depletion zone and provide nutrients from undepleted zones. It also helps in the formation of lateral roots and root branching which increases the surface area about 100 fold for the absorption of soil nutrients (56). AMF not only dissolves insoluble P but also produce some extracellular phosphatases that help in the mobilization of P from organic sources to plants (74). Besides P, AMF are also responsible for the uptake of nitrogen and sulphur. Sulphur is taken up by AMF in the form of amino acids i.e. cysteine and methionine (6) whereas N is taken in the form of nitrate (NO_3^-) and ammonium (NH_4^+) (19; 71; 73). It also helps in organic nitrogen uptake from soil (65). Increased concentration of both phosphorus and nitrogen in the plant biomass was reported when soybean was inoculated with AMF (36). Sabannavar and Lakshman (54) reported that the use of AMF alongwith *Pseudomonas striata* helps in solubilization of the mineral phosphate and contribute to biogeochemical P cycling, thus promoting sustainable nutrient supply to crop plants for higher yield. Similarly, Yousefi et al. (84) reported that the combined application of phosphate solubilizing bacteria and AMF increased the shoot dry matter yield, seed grain spike number and grain yield. In the same way synergistic relationship between phosphate solubilizing bacteria and AMF have been reported by Baquall and Das (13).

2.2 Mycorrhizal fungi as biocontrol agent

There are many disease management methods such as crop rotation, use of resistant varieties and chemical pesticides. However, frequent and indiscriminate use of these pesticides affects the physical and chemical property of the soil. It also affects the non-target organisms and has developed resistance among the pathogen against these chemicals (8). Biocontrol potential of AM fungi against various phytopathogens is well documented (60; 39; 10; 18; 83; 70; 69). Arbuscular Mycorrhizal Fungi (AMF) are the major component of the rhizosphere of most of the plants and play a very important role as biocontrol agent and help in decreasing plant disease incidence (4). Application of combined VAM and Biological Control Agents (BCAs) reduced the growth of *Fusarium solani* and *Machrophomina phaseolina,* the causal agent of root-rot disease of *Geranium* plants. They had a synergistic effect on disease control (80). Thygesen et al. (75) reported that *Glomus claroideum* and *G. intraradicus* induced tolerance in pea against *Aphanomyces euteiches* causing pea root-rot. Mixture of *Glomus intraradices, G. mosseae, G. clarum, Gigaspora margarita* and *G. gigantean* affects the growth of *Sclerotium cepivorum* and significantly reduced the white rot disease in onion when applied in green house and in field experiment (28). Later on Al-Askar and Rashad (5) used the mixture of *Glomus mosseae, G. intraradices, G. clarum, Gigaspora gigantean* and *G. margarita* against *Fusarium* root-rot disease of bean and reported that they significantly reduced the percentage of disease severity and incidence in infected bean plants.Several AM fungi have been reported to have ability to control soil-borne pathogens such as species of *Aphanomyces, Cylindrocladium, Fusarium, Macrophomina, Phytophthora, Pythium, Rhizoctonia, Sclerotium* and *Verticillium* (35). *Glomus mosseae* reduced the growth of pathogen *Gaeumannomyces graminis* var. *tritici* (40). Matsubara et al. (43) reported *Glomus fasciculatum* and *Gigaspora margarita* to be antagonistic against *Fusarium oxysporum* f. sp. *asparagi*, the causal agent of root rot disease of *Asparagus*. Similarly, *Glomus clarum* decrease the growth of the pathogen of root rot necrosis in cowpea i.e. *Rhizoctonia solani* (1). Some mycorrhizae as biocontrol agent against several pathogens are presented in Table 2.

Table 2
Some examples of Mycorrhizae as biocontrol agent

Brinjal	***Fusarium solani***	***Glomus fasciculatum* and Salicylic acid (0.5 and 1.0 mM)**	**Ojha et al. (46)**
Cotton	*Verticillium wilt*	*Glomus etunicatum*	Kobra et al. (41)
Sesame	Wilt and root-rot/ *Fusarium oxysporum* f.sp. *sesame (Zap.) cast* and *Macrophomina phaseolina (Moubl) Ashby*	*Glomus* spp. and *Lums* spp. *Trichoderma viride* or *Bacillus subtilis*	Ziedan et al. (87)
Bean	Root-rot / *Fusarium solani*	Arbuscular Mycorrhizal Fungi (AMF) *Glomus mosseae, G. intraradices, G. clarum, Gigaspora gigantea* and *Gigaspora margarita*	Al-Askar and Rashad (5)
Apple	Stem brown canker or *Botryosphaeria canker*	Arbuscular mycorrhizal fungi	Krishna et al. (42)
Tomato	*Fusarium wilt / Fusarium oxysporum* f. sp. *lycopersici*	*Fluorescent Pseudomonas, Trichoderma harzianum* and *Glomus intraradices*	Srivastava et al. (67)
Bean	*Sclerotinia sclerotiorum (Lib.) de Bary*	Arbuscular Mycorrhizal Fungi (AMF) *Glomus mosseae (Gm), Glomus fasciculatum (Gf)* and *Rhizobium leguminosarum biovar phaseoli (Rlp)*	Aysan and Demir (9)
Bean	Dry root-rot / *Macrophomina phaseolina*	AM fungi *viz., Glomus fasciculatum, G. mosseae, G. aggregatum, G. claroideum, G. macrocarpum,* and *G. multicaule*	Chandra et al. (22)
French Bean	Root-rot/ *Rhizoctonia solani*	AM fungi, *Pseudomonas fluorescens*	Neeraj and Singh (45)
Soybean	Red crown rot/ *Cylindrocladium parasiticum*	*Rhizobia* and AM fungi	Gao et al. (32)
Chilli	*Meloidogyne incognita*	*Pasteuria penetrans*	Chaudhary and Kaul (23)
Oil palm (*Elaeis guineensis*)	Basl stem rot/*Ganoderma boninense*	*Glomus intraradices* UT126, *Glomus clarum* BR152B and *Pseudomonas aeruginosa* UPMP3	Sundram et al. (72)

3. CONCLUSION

Mycorrhizal fungi play a very significant role in sustainable agriculture which is the urgent need of modern era. Mycorrhizal fungi act as an effective biofertilizer and bioprotectant. These improve the plant vigour and soil quality. They also play a very crucial role in plant nutrient (i.e. N, P, K, S, Mg, Fe, Zn, Cu) uptake, diversity and productivity of plant, biotic (root pathogen) and abiotic (drought, salinity, heavy metal) stress resistance, microbial diversity and population in mycorhizosphere, soil aggregation and soil structure, reduction of nutrient leaching, weed suppression and stimulates soil biological activity. Besides all these, mycorrhizal fungi also act as bioagent and protect the host plant root from various soil-borne plant pathogens such as bacteria, fungi and nematodes by using physical, chemical and biological mechanisms.

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