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Mycorrhizal Fungi: Potential Biocontrol Agent for Plant Disease Management

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Abstract

Mycorrhizal fungi are the symbiotic fungi that predominant in the roots and soils of agricultural crop plants and play an important role in decreasing the plant disease caused by *Phytophthora, Rhizoctonia, Pythium, Aphanomyces, Verticillium, Fusarium, Macrophomina,* etc. and other soil borne diseases also. The use of mycorrhizal fungi as a biocontrol method to antagonize soil-borne pathogens has received increasing interest from phytopathologists and ecologists. Disease severity is reduced by root colonization of mycorrhizal fungi via several mechanisms including competing plant pathogens for nutrients, production of antibiotics, induction of hydrolytic enzymes, enhancing the PR-protein, induction of phytoalexins and by stimulating defense related enzymes. Plant species are benefited from mycorrhizal association because of superior effectiveness in nutrient, and water uptake. Mycorrhizal fungi greatly enhance nutrient uptake especially phosphorus and improve plant growth and crop productivity. It helps to maximize ecological benefits and minimize environmental hazards. Mycorrhizal fungi improve the rhizosphere environment by influencing the physical and chemical proprieties of soil, enhancing the growth of other beneficial microorganisms, and by competing with pathogenic microorganisms.

Keywords: Mycorrhizal fungi, biocontrol, nutrition uptake, disease management

Introduction

Biological control of plant pathogens is the key practice in the sustainable agriculture which strives to minimize the use of synthetic pesticides and to use as alternative management strategy to control plant pathogens. Biological control of plant diseases can boost yields by suppressing or eliminating pathogens, improving plant resistance, and providing protection against pathogens. Biological control has several advantages, including being environmentally friendly, resistant to chemical pesticide resistance, safe and risk-free, and compatible with sustainable agriculture. Mycorrhizal fungi have become an important biocontrol agent in integrated disease management systems. Mycorrhizal fungi are a major natural component of the soil ecosystem, located in the roots of more than 80% of all terrestrial plant species (including many agronomically important species) and they are members of the fungus kingdom. A symbiotic association of fungus and roots was discovered by Franciszek Kamienski (1881) in *Monotropa hypopitys*. The term *'mycorrhiza'* coined by Professor Albert Bernhard Frank in 1885. Until recently, Mycorrhizal fungi were classified as Zygomycota, however research of 18S ribosomal RNA suggests that they share ancestry with Ascomycota and Basidiomycota. As a result, they have been classified to a new monophyletic phylum known as the Glomeromycota. Even though there are many types of endomycorrhizae, the most commonly known endomycorrhizae is Vesicular-arbuscular (VA), ericoid, arbutoid, orchid and monotropoid mycorrhiza. Arbuscular mycorrhizal fungi (AMF) are the most common, largest biomass and the most significant beneficial fungal group in the mycorrhiza, with a specific antagonistic or inhibitory effect on soil-borne pathogens. In sustainable agriculture, biological control of plant diseases is a significant approach to reduce the usage of synthetic fungicides and provide an alternative management method for soil-borne infections. Various biocontrol agents, including *Pseudomonas fluorescens, Bacillus subtilis, Trichoderma harzianum, T. viridae, Mycorrhizal fungi (Glomus spp.), Agrobacterium radiobacter* strain 84, and K1026, are being used commercially to combat soil-borne infections. *Arbuscular mycorrhizal* fungi (AMF) are the most prevalent, largest in biomass, and most significant beneficial fungal group in mycorrhiza, with a specialized antagonistic or inhibitory effect on soil-borne diseases. AMF can reduce the damage caused by fungi, nematodes, bacteria, and other pathogens of *Cucumis sativus, Fragaria ananassa, Lycopersicon esculentum, Citrus reticulata, Olea europaea, Medicago truncatula, Cucumis melo, Zea mays, Solanum tuberosum, Musa nana,* and other plants, and can also reduce the use of pesticides.

Arbuscular Mycorrhizal Fungi (AMF):

AM fungi comprise the most common mycorrhizal association and form mutualistic relationships with over 80% of all vascular plants. Vesicular arbuscular mycorrhizae are characterized by the formation of unique structures such as arbuscules and vesicles by fungi of the phylum *Glomeromycota*; earlier known as *Endogonales* of *Zygomycetes.* AMF fungi help plants to capture nutrients such as phosphorus and micronutrients from the soil. It is believed that the development of the arbuscular mycorrhizal symbiosis played a crucial role in the initial colonization of land by plants and in the evolution of the vascular plants (Siddiqui *et al.*, 2008, Kakraliya *et al.*, 2020). All AMF fungi are obligate biotrophic, as they are completely dependent on plants for their survival. Some important genera are *Glomus, Acaulospora, Gigaspora, Scutellospora, Enterophospora and Sclerocystis* (Ejersa, MT, 2021). In this article, the mechanisms of action to diseases management caused by fungal, bacterial, nematode, and viruses (table 1) and also method of application of mycorrhizal formulations have been summarized.

Mechanism of action of mycorrhizae:

Mycorrhizal fungi have attracted a lot of interest in recent years because they are useful as bio-control agents and have other agricultural applications. Mycorrhizal mode/mechanism of action working either separately or together. The limitations of using AM fungus for bio-control include their obligatory nature, a lack of knowledge of the processes involved, and the influence of environmental conditions in these interactions. The several mechanism in control of plant diseases are involved by mycorrhizal symbiosis and these are:-

1. **Mycorrhizae creating physical/mechanical barrier for the pathogen to penetrate:** VAM fungi act as a barrier/ creating a mechanical/physical barrier for the pathogen penetration and subsequent spread. Mechanical barrier creates a physical rather than a chemical hindrance to prevent the entrance or spread of a pathogen. Some of the fungi such as which forms ectomycorrhizae with more than 46 tree species belonging to at least eight genera, provide physical barrier in the form of fungal mantle of various thickness on the surface of the root thus protect from the infection of root pathogenic fungi and nematodes. *Phytophthora cinnamomi* (Pine root rot) control by ericoid mycorrhizal fungi, because it creates a physical barrier in the in the form of mental covering the cortical cells, fungus do not penetrate the roots (Mohammad, IK, 2019).
2. **Secreting antibiotics/metabolites (Inhibition of pathogen by antibiosis):** Several Mycorrhizal fungi and other saprophytic fungi associated with mycorrhizosphere have been found to produce different types of antibiotics/metabolites exhibiting inhibition to pathogenic organisms and protecting the root systems. Several mycorrhizal fungi viz *Amanita spp*., *Boletinus spp*., *Cenococcum spp*., *Lactarius spp*., *Laccaria laccata*, *Leucopaxillus cerealis* var. *Piceina*, *Pisolithus tinctorius*, *Suillus luteus* and *Thelephora terrestris* have been found to produce antifungal, antibacterial and

antiviral metabolites. The antifungal and antibacterial antibiotics produced by *Leucopaxillus cerealis* var. *piceina* has been identified as Diatretyne nitrile, Diatretyne amine and Diatretyne-3. These have been found inhibiting number of pathogens viz nine species of *Phytophthora*, twenty-four species of *Pythium*, five species of *Rhizoctonia*, *Sclerotium bataticola* and *Cylindrocladium scoparium* (Sharma *et al.*, 2014).

3. **Competing with the pathogens for the uptake of essential nutrients in the rhizosphere and the root surface (Host nutritional effects/Improved plant nutrition):** Mycorrhizal fungi are most efficient competitor with the other pathogens, because adequate supply of carbohydrates, amino acids, vitamins, minerals etc. from root exudates and protection afforded by the host roots. Mycorrhizal association utilize surplus carbohydrates from the root exudates and transform the sucrose or monosaccharide (hexose) to less soluble sugars like trehelose, mannitol, sorbitol etc. The propagules of infectious fungi like *Pythium*, *Phytophthora*, *Rhizoctonia*, *Sclerotium*, *Fusarium* etc. require nutrients for germination and these are less available in mycorrhizosphere thus discouraging the propagules germination and attractiveness of the roots to the pathogen infection. Stimulating the host roots to produce and accumulate sufficient concentrations of metabolities (terpenes, phenols etc.) which impart resistance to the host tissue against pathogen invasion. Mycorrhizal plants are generally able to tolerate pathogens and compensate for root damage and photosynthate drain by pathogens because AMF enhance host nutrition and overall plant growth (Roy, *et al.*, 2018).
4. **Anatomical and morphological changes in the root system:** The root morphology system can be changed as a result of AMF colonisation. Roots colonised by AMF are more branching than non-colonized plants, and adventitious root diameters are bigger, providing more infection sites for a pathogen. Fusarium wilt infection of tomato and cucumber may be slowed due to morphological changes in the root cells of the endodermis of AM plants, which include lignification and incensement. Raising lignifications may protect the roots from other pathogens while increasing phenolic metabolism in the host plant. Thickening of the cell wall by lignification and synthesis of additional polysaccharides, which inhibits root pathogen entry (Tahat *et al.*, 2010).
5. **Competition for colonization and infection sites:** The primary mechanism to

explain the interaction between AMF and soil microorganism is physical completion between AMF and rhizosphere microorganism to occupy more space in the root architecture. Stimulating microbial activity and competition in the root zone (rhizosphere, rhizoplane), restricting pathogen access to the roots. Roots colonised by VAM/AM fungus may also harbour actinomycetes that become antagonistic to root pathogens (Tahat *et al.*, 2010).

6. **Check in leakage of nutrients from host cell (Physiological and biochemical alterations of the host):** During AMF colonisation, host root tissue phosphorous levels are often increased, which modifies the phospholipid composition and hence the root membrane permeability, resulting in a decrease in net sugar, carboxylic acid, and amino acid leakage into the rhizosphere. These changes reduce pathogen chemotactic effects on plant roots and hinder pathogen entry. Symbiotic associations have been found toenhance the concentration of these inhibitors many timesgreater than non-symbiotic roots. Pine (*Pinus sylvestris*)seedlings with variegatus symbiotic association have beenfound to produce eight times higher concentration offungistatic compounds like terpenes and sesquiterpene.Similar compounds have been also reported in certain ectomycorrhizal fungi like *Amanita* and *Rhizopogon*. Several mycorrhizal fungi *i.e., Amanita rubescans, Boletus variegatus, Pisolithus tinctorious* and *Hebelomasarcophllum* and have been found to produce various volatile organic compounds like ethanol, isobutanol, Isoamylalcohol, acetoin and Isobutyric acid and volatile substances are inhibitory tomany pathogenic fungi some of which are *Phytophthora cinnamomi, Rhizoctonia undulates, Phymatotrichum omnivorum, Fomes annosus, Pastalotia rhododendry etc* (Roy *et al.*, 2018).

Table 1: Important mycorrhizal fungi used to manage pathogenic organism in plants

Biocontrol of mycorrhizal fungi	Targeted organism	Disease management
Mycorrhizal fungi used to manage pathogenic fungi in plants		
Glomus versiforme	*Erysiphe flexuosa*	Powdery mildew in cowpea
Glomus fasciculatum and *Acaulospora laevis*	*Fusarium oxysporum f. sp. lycopersici*	Wilt in tomato

Glomus clarum and *Glomus deserticola*	*Pythium aphanidermatum*	Foot rot, stem rot, and root rot in pawpaw tree
Funneliformis mosseae	*Gaeumannomyces graminis*	Take-all disease in wheat
Glomus intraradices	*Fusarium verticillioides*	Root rot, stalk rot, seedling blight, and ear rot in maize
Glomus mosseae, Glomus etunicatum, Glomus fasciculatum, Gigaspora margarita	*Phytophthora capsici*	Phytophthora blight in pepper
Glomus mosseae	*Gaeumannomyces graminis var. tritici*	Take-all disease in barley
Glomus mosseae	*Fusarium oxysporum f. sp., Lycopersici* (Fol.)	Wilt disease in tomato
Glomus fasciculatum	*Fusarium oxysporum f. sp. ciceris*	Wilt in chickpea
Glomus clarum and *Glomus deserticola*	*Rhizoctonia solani*	Collar rot and web blight in cowpea
Glomus etunicatum	*Rhizoctonia solani*	Black scurf and stem canker in potato
Glomus boninense	*Ganoderma boninense*	Basal stem rot in oil palm
Glomus etunicatum and *Glomus monosporum*	*Phytophthora fragariae*	Red stele disease in strawberry
Mycorrhizal fungi used to manage pathogenic bacteria in plants		
Arbuscular mycorrhizal fungi	*Pseudomonas solanacearum*	Bacterial wilt in eucalyptus seedlings
Glomus mosseae	*Pseudomonas syringae*	Bacterial blight infection in soybean
Glomus macrocarpum	*Pseudomonas lacrymans*	Angular leaf spot in cucumber

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Glomus fasciculatum or Glomus mosseae	*Pseudomonas syringae pv. mori*	Bacterial leaf spot in mulberry
Arbuscular mycorrhizal fungi	*Actinomycetes*	Apple replant disease in apple seedlings
Arbuscular mycorrhizal fungi	*Pseudomonas*	Bacterial inflorescence rot, stem canker in grapevine
Glomus mosseae	*Pseudomonas syringae*	Bacterial speck in tomato
Mycorrhizal fungi used to manage pathogenic viruses in plants		
Arbuscular mycorrhizal fungi	Grape vine fanleaf virus	Grape vine
Rhizophagus intraradices (Syn. *Glomus intraradices* isolate BEG141)	Grape vine fanleaf virus	Grapevine rootstock
Funneliformis mosseae (Syn. *Glomus mosseae* BEG12)	Tomato yellow leaf curl virus	Tomato
Rhizophagus irregularis	Potato virus Y	Potato
Funneliformis mosseae (Syn. *Glomus mosseae*)	Cucumber mosaic virus (CMV-Y, yellow strain)	Cucumber cv. Tokiwa Jibai
Funneliformis geosporum (Syn. *Endogone macrocarpa var. Geospora*)	Citrus leaf rugose virus	Alemow, Grape fruit, Sour orange
Rhizophagus intraradices (Syn. *Glomus intraradices*)	Potato virus Y	Potato
Rhizophagus irregularis	Cucumber green mottle mosaic virus (CGMMV)	Cucumber
Rhizophagus irregularis	Tobacco mosaic virus (TMV)	Tobacco
Claroideoglomus etunicatum (Syn. Glomus tincture)	Citrus tristeza virus	Alemow, Grape fruit, Sour orange
Rhizophagus intraradices (Syn. *Glomus intraradices*)	Tobacco mosaic virus (strain U1)	Tobacco
Mycorrhizal fungi used to manage pathogenic nematode in plants		

Glomus mosseae	*Meloidogyne incognita*	Root-knot disease in several crop plants

Method of application of Mycorrhiza culture: Mycorrhizal inoculants come in liquid, powder and granular forms. It can be used as soil application, seed coating, root/seedling treatment, soil drenching, sprinkled onto root during transplanting or watered in via existing irrigation systems. Treating seeds either before or during sowing produces excellent results.

1. **Soil application/treatment:** While preparing the field, 4-5 kg Mycorrhiza culture (powder formulation) is added in 200-300 kg well decomposed farm yard manure (FYM). Mixed thoroughly, cover with jute bag/sugarcane leaves/paddy straw and kept for 1-2 week in shade for proper multiplication. Maintain moisture and mix the mixture in every 3-4 days intervals before broadcasting in the field. Apply well mixed/decomposed Mycorrhiza culture based FYM to the field before 15 days of sowing. This mixture can be applied in furrow/pit/pot and at the time of transplanting/sowing. This mixture is sufficient for one acre of land. Keep in mind that if the number of plants per acre is more than 40,000, then 8 to 10 kg of culture should be mixed with 400 to 500 kg of rotten cow dung/FYM.
2. **Root treatment:** Root treatment can be done in vegetables and other plantation crops. For this, prepare the suspension @ 20 grams of Mycorrhiza culture by mixing 15 to 20 grams of jaggery with 1 liter of water. Dip the roots of seedlings in to this prepared suspension for 15-20 minutes and transplant immediately. Root dipping is effective against soil borne diseases. At the time of sowing and planting of vegetable crops, the distance from plant to plant is being kept more, then sowing and transplanting should be done by making a small pit in the prepared field by spud and mixing @ 2 grams of culture in it.
3. **Use at the time of plantation:** At the time of plantation, apply Mycorrhiza culture @ 5 gram/plant/3x3 feet pit at 3-4 inches depth. In old orchards, while giving fertilizers in the month of February/July, it can be given at the rate of 5-10 grams per plant along with well decomposed farm yard manure in the pits.

4. **Nursery bed treatment:** 1-2 kg Mycorrhiza culture (powder formulation) mix in 40-50 kg well decomposed FYM/compost/vermicompost and broadcast in a one-acre area at evening time and at proper moisture conditions.
5. **Soil drenching:** Two-to-three-kilogram Mycorrhiza culture formulation mix in 200 litre of water and drench the soil in one acre area or 15-20 gm/litre of water in soil in the nurseries from time to time. Maintain optimum soil moisture while applying.

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