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Role of Mycorrhizae in Plant Health Management

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Abstract

The feeder roots of most flowering plants growing in nature are generally infected by symbiotic fungi that do not cause root disease but, instead, are beneficial to their plant hosts. The infected feeder roots are transformed into unique morphological structures called mycorrhizae, *i.e.*, "*fungus roots*." On the basis of morphological and anatomical features, mycorrhizal fungi are majorly three types, *viz*., endomycorrhizae, ectomycorrhizae, and ectendomycorrhizae. Mycorrhizal fungi reduce the pathogen by root colonization, 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. They greatly enhance nutrient uptake especially phosphorus and improve the growth as well as productivity of plants. Mycorrhizal fungi are used for treatment of soil, root, planting materials, nursery beds *etc*. for management of plant diseases and enhancement in productivity of crops.

Keywords: Ectendomycorrhizae, Ectomycorrhizae, Endomycorrhizae, Mycorrhizae

Introduction

German Botanist, Plant Pathologist and Mycologist Albert Bernard Frank studied on soil microbial-plant relationships and coined the Greek term '*mycorrhiza*', which literally means "*fungus roots*". The word mycorrhiza is made up of two words, '*myco*' means '*fungus*' and '*rhiza*' means '*roots*'. Mycorrhiza can be defined as the mycelial hyphae living in association with roots of higher plants. The nature of this association is believed to be symbiotic or mutualistic. The term mutualism can be simply defined as a relationship in which both species are mutually benefited. This relationship can either be within the species or between the two different species. The species with this relationship is termed as symbionts. Mycorrhizal fungi form symbiotic relationships with plant roots in a fashion similar to that of root nodule bacteria within legumes. Mycorrhizal association is symbiotic association between plants and fungi, where both the partners are benefitted from each other. The most preferred plant species for the symbiotic fungi are acacia, citrus, legume, sorghum, maize, onion and other grasses. Mycorrhizal fungi can absorb, accumulate and transport large quantities of phosphate within their hyphae and release to plant cells in root tissue.

Based on anatomical and morphological features, mycorrhizae are categorized into 7 groups:

1. Endomycorrhizae known as Vesicular Arbuscular Mycorrhiza (VAM) or Arbuscular Mycorrhiza (AM) consisting of genera Acaulospora, Endogone, Gigaspora, Glomus and Glazialla.

2. Ectomycorrhizae (ECM) *e.g.*, *Amanita muscaria* and *Scleroderma citrinum*.

3. Ectendomycorrhizae *e.g.*, Wilcoxina.

4. Arbutoid mycorrhizae *e.g.*, Boletus.

5. Monotropoid mycorrhizae *e.g.*, *Monotropa hypopitys*.

6. Ericoid mycorrhizae *e.g.*, Rhizoscyphus and Sebacina.

7. Orchidaceous mycorrhizae *e.g.*, Sesbania and Russula.

Among them, ectomycorrhizae are most prevalent in forestry. However, endomycorrhizae are abundant and widespread in agricultural ecosystems (Akhtar and Siddiqui, 2008).

Article History

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Types of Mycorrhizal Fungi

On the basis of morphological and anatomical features, mycorrhizal fungi are majorly divided into three groups as mentioned under.

a) Endomycorrhizae

It is a mycorrhizal association in which the fungal hyphae are present on root surface as individual threads that may penetrate directly into root, other epidermal cells and into cortical hairs. It is further classified into five categories.

1. VAM fungi (Vesicular Arbuscular Mycorrhizae): Vesicular arbuscular mycorrhizae are characterized by the formation of unique structuressuch as arbuscules and vesicles by fungi of the phylum *Glomeromycota*; earlier known as *Endogonales* of *Zygomycetes*. VAM 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 acrucial role in the initial colonization of land by plants and in the evolution of the vascular plants. All VAM 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, 2021).

2. Monotropoid mycorrhizae: The fungi belong to subdivision Basidiomycotina, colonizing achlorophyllous members of angiosperms belonging to family Monotropaceae and a specific subset of fungi in the Russulaceae or the Boletaceae family. These plants are heterotrophic or mixotrophic and derive their carbon from the fungus partner. This is thus a non-mutualistic parasitic type of mycorrhizal symbiosis.

3. Ericoid mycorrhizae: Ericoid mycorrhizae are known to form between autotrophs in the *Ericaceae* and fungi in the *Ascomycota*. Intracellular penetration of root cells occurs and there is no mantle or hartig net development. The hyphae coil in outer cells of the narrow "hair roots" of plants in the plant order *Ericales*. These associations also occur in thicker roots of Australian members of the Epacridaceae.

4. Arbutoid mycorrhizae: Arbutoid mycorrhiza possesses characteristics of both ECM and AM fungi, *i.e.,* there is a well-developed mantle, a hartig net, and prolific extrametrical mycelium. Additionally, intra-cellular penetration occurs and hyphal coils are produced in autotrophic cells. A major difference between the arbutoid and ectomycorrhizal association is that the hyphae penetrate the outer cortical cells of plant roots and fill them with coils. These mycorrhizae are associated with members of the Ericales; namely, Arbutus and Arctostaphylos species. The fungal symbionts are exclusively Basidiomycete species, which may form ECM with other autotrophic hosts.

5. Orchidaceous mycorrhizae: Orchid mycorrhizae have only been found in association with Basidiomycetes species. This association is probably pseudomycorrhizal. It consists of coils of hyphae within roots of plants in the family Orchidaceae. Young orchid seedlings and some adult plants which lack chlorophyll are entirely dependent on mycorrhizal fungi for their survival.

b) Ectomycorrhizae

Ectomycorrhizal (ECM) fungi are also widespread in their distribution but associate with only the roots of around 10% of plant families, mostly woody plants including the birch, dipterocarp, eucalyptus, oak, pine, and rose families and fungi belonging to the Basidiomycota, Ascomycota and Zygomycota. Ectomycorrhizae are association, where fungi form a mantle around the roots. There is no hyphal penetration of cells. Fungal hypha is generally separate. A distinct Hartig's net is present between the cells.

c) Ectendomycorrhizae

It possesses characteristics of both ECM and AM fungi. As with ECM, both a hartig net and mantle structures are produced in ectendomycorrhizae, although the mantle may be reduced compared with ECM. The fungi belong to Basidiomycotina, which covers both gymnosperms and angiosperms plants. The formation of Ectendomycorrhizae begins with formation of a Hartig's net, which grows behind the apical meristem of the growing root. The hartig net penetrates between the epidermal and outer cortical cells and later extends to the inner cortex. Intracellular penetration of healthy plant cells by these fungi also occurs, a characteristic unlike that of ECM but consistent with AM.

Mode of Action of Mycorrhizae

Mycorrhizal fungi involve in management of plant diseases and improving the plant health through different mechanisms as described under.

1. Physical 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 form ectomycorrhizae with more than 46 tree species belonging to 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 ECM 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, 2019).

2. Inhibition of Pathogen through Antibiosis

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 a number of pathogens *viz*., *Phytophthora*, *Pythium*, *Rhizoctonia*, *Sclerotium bataticola* and *Cylindrocladium scoparium*.

3. Competing with the Pathogens for the Uptake of Essential Nutrients

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 metabolites (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 arbuscular mycorrhizal fungi (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 lignification may protect the roots from other pathogens while increasing phenolic metabolism in the host plant. Thickening of the cell wall due to lignification and synthesis of additional polysaccharides inhibits the entry of pathogen in the roots (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 competition between AMF and rhizosphere microorganism to occupy more space in the root architecture. AMF colonize feeder roots and thereby interact with root pathogens that parasitize these same tissues. Thus, AMF have been shown to reduce the incidence and severity of root diseases. 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

The phosphorous levels are often increased in AMF colonised tissues of plant roots. It modifies the phospholipid composition in host root tissues and decreases the levels of net sugar, carboxylic acid and leakage of amino acid into the rhizosphere. Symbiotic associations have been found to enhance the concentration of inhibitors many times greater than non-symbiotic roots. Pine (*Pinus sylvestris*) with various symbiotic association have been found to produce eight times higher concentration of fungistatic 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 *Hebelomas arcophllum* have been found to produce various volatile organic compounds like ethanol, isobutanol, Isoamylalcohol, Isobutyric acid and volatile substances inhibiting growth of many pathogenic fungi (Roy *et al.,* 2018).

Application Methods of Mycorrhiza Culture

1. 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.

2. Root Treatment

Root treatment can be done in vegetables and other plantation crops. For this, prepare the suspension @ 20 g of Mycorrhiza culture by mixing 15-20 g of jaggery with 1 litre 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 g of culture in it.

3. 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 $acre^{-1}$ is more than 40,000, then 8-10 kg of culture should be mixed with 400-500 kg of rotten cow dung/FYM.

4. Soil Drenching

2-3 kg Mycorrhiza culture formulation mix in 200 litres of water and drench the soil in one acre area or 15-20 g $litre^{-1}$ of water in soil in the nurseries from time to time. Maintain optimum soil moisture while applying.

5. Use at the Time of Plantation

At the time of plantation, apply Mycorrhiza culture @ 5 g $plant^{-1}$ per 3×3 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 g $plant^{-1}$ along with well decomposed farm yard manure in the pits.

Conclusion

Mycorrhizal fungi are beneficial in agriculture because they act as bio-fertilizers and favors to plant root system for absorption of phosphorus and other nutrients. It converts insoluble phosphorus into a soluble form in the soil and making it more accessible to plants. It improves the performance of nitrogen-fixing bacteria such as Rhizobium and Azotobacter and increase the crop yield. It releases hydrogen cyanide around plant roots which kills pathogenic fungi, bacteria, nematodes *etc*. in the soil. Mycorrhiza colonization of plant roots reduces translocation of heavy metals (Bioremediation) to arial parts by binding it to the cell walls of the fungal hyphae in roots and helps the higher plants to survive in contaminated habitats. It enhances water availability in non-irrigated locations where crops are rain-fed and increases drought resistance in plants.

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