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## Mycorrhizal Fungi as a Biocontrol Agent

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**Abstract:** Arbuscular mycorrhizae fungi (AMF) are the symbiotic fungi that predominate in the roots and soils of agricultural crop plants. The AMF form beneficial symbioses in most terrestrial ecosystems and crop production systems. Ninety percent of land plant species are colonized by one or more of the mycorrhizal fungi species ranging from flowering to non flowering plants, while only a few plant families do not form this association. The relationship between mycorrhiza and plant is very widely spread among terrestrial vascular plants. The AMF must have a host to complete its life cycle and this association has been found to be mutually beneficial; thus, the fungus assists the plant in mineral nutrients uptake, while the plant supplies the fungus with carbon as a result of this relation. The negative-antagonistic interaction of AMF with various soilborne plant pathogens is the reason for their use as a bio-control agents. Many workers have observed an antagonistic effect of AMF against some fungal pathogens.

**Key words:** Biological control, endo-mycorrhizal fungi, diseases, control

### INTRODUCTION

Mycorrhizal fungi are a major component of the agricultural natural resource and they are members of the fungus kingdom. Asymbiotic association of fungus and roots has been discovered in *Monotropa Hypopity* by Franciszek Kamienski (1881). The studies of the Polish botanist Frank 1885 had initiated worldwide interest on a fungus-root (*Mycorrhiza*). Also, he gave the name MYCORRHIZA to the peculiar association between root trees and ectomycorrhizal fungi. The AMF play an important function in the reduction of plant pathogens (Whipps, 2004; St-Arnaud *et al.*, 1994; Azcon-Aguilar and Barea, 1997), such as *Rhizoctonia solani* (Yao *et al.*, 2002) and *Pythium ultimum* and *Phytophthora* species (Trotta *et al.*, 1996; Cordier *et al.*, 1996). In different crops the AMF have also been shown to reduce bacterial diseases (Dehne, 1982), for example, *Glomus mosseae* suppressed *Ralstonia solanacearum*, bacterial wilt causal organism on tomato (Tahat *et al.*, 2009).

There have been a few studies of the potential role of Arbuscular Mycorrhizal Fungi (AMF) for the protection of plant from pathogens.

### IDENTIFICATION, DISTRIBUTION AND CLASSIFICATION

Mycorrhizal fungi association widely varied in structures and functions, but the Arbuscular Mycorrhizae (AM) are the most common interactions (Harrier, 2001). Six genera of arbuscular mycorrhizal fungi have been

recognized based on morphological characteristics of a sexual spores and also based on various biochemical studies as well as molecular methods (Peterson *et al.*, 2004). Further, various criteria have been used for the identification of AMF like hyphal character, auxiliary cells subtending hyphae, spore or sporocarp ontogeny, morphology, germination, shield spore wall, biochemical, molecular and immunological characteristics (Mukerji *et al.*, 2002). Few species of host roots synthesize a yellow pigment when colonized by mycorrhizal fungi which is considered as a sign of infection (Peterson *et al.*, 2004). AMF are zygomycetous belonging to the genera *Glomus*, *Gigaspora*, *Sclerocystis*, *Acaulospora*, *Entrophospora* and *Scutellospora* (Garbaye, 1994).

The classification of AMF is based on the structure of their soil-borne resting spore, biochemical properties and molecular studies (Morton and Benny, 1990). The latest classification of AMF contains 4 orders with 9 families (Table 1) (Sieverding and Oehl, 2006). Plant species belonging to the cruciferae and chenopodiaceae are not known to form AMF symbiosis (Smith and Read, 1997).

The AMF reproduce asexually by spore production. There is no evidence that AMF reproduce sexually (Kuhn *et al.*, 2001).

### TYPES OF MYCORRHIZAL FUNGI

Seven different types of mycorrhizal fungi association have been recognized and the most important types are:

Table 1: Recent classification of arbuscular mycorrhizal fungi (Sieverding and Oehl, 2006)

Phylum		
Class	Glomeromycetes	
Orders	families	Genera
1-Glomerales	Glomeraceae	<i>Glomus</i>
2-Diversisporales	Gigasporaceae	<i>Gigaspora, Scutellospora</i>
	Acaulosporaceae	<i>Acaulospora, Kuklospora</i>
	Entrophosporaceae	<i>Entrophospora</i>
	Pacisporaceae	<i>Pacispora</i>
3-Paraglomerales	Diversisporaceae	<i>Diversispora</i>
	Paraglomeraceae	<i>Paraglomus</i>
4-Archaeosporales	Geosiphonaceae	<i>Geosiphon</i>
	Arthaeosporaceae	<i>Arthaeospora, Inraospora</i>

**Endo-mycorrhizae:** Endo-mycorrhizae represent a group of fungi that are associated with most agricultural crops and provide biological protection against soil-borne diseases (Smith and Read, 2008). They occur in most ecosystems of the world and are found in many important crop species (wheat, maize, rice, grape, soybean and cotton) and horticultural species roses, petunias and lilies) (Peterson *et al.*, 2004). AMF are obligatory biotrophs feeding on the products of their live plant host and those fungi are not specialized to their potential hosts. The host plant receives mineral nutrients from outside the roots depletion zone via the extraradical fungal mycelium, while the AMF obtains photo-synthetically produced carbon compound from the host (Smith and Read, 1997).

Many endomycorrhizal fungi form terminal or intercalary vesicles in the root cortex. When the vesicles are expanded the thin walled structures, which are not septum and it's contain a large quantity of lipids. They may be oval, spherical, or lobed in shapes and may become thick walled and resting spores (Pirozynski and Dalphe, 1989). The term arbuscular mycorrhiza replaced the earlier term vesicular arbuscular mycorrhizae (VAM) because some endomycorrhiza produce vesicles, but all form arbuscules (Strack *et al.*, 2003).

**Ecto-mycorrhizae:** Ecto-mycorrhizal (ECM) fungus forms a thick mantle structure within the intercellular spaces of root cortex and a sheath around the feeder root acting as an interface for channeling of nutrients from the plant to the fungus and vice versa (Kumar and Satyanarayana, 2002). Ectomycorrhizal fungi do not penetrate living cells in host roots, but can only surround them. The extensive mycelium produced by ectomycorrhizal may function in transferring nutrients directly from the decaying leaves (Suverch *et al.*, 1991).

Ectomycorrhizas are most common in ornamental and forest trees species in the family Pinaceae, Myrtaceae, Salicaceae, Dipterocarpeae, Fagaceae and *Gentum* plants (Shalini *et al.*, 2000). Ectomycorrhizas are distinguished by the presence of mantle and the Hartig net. Hartig net

(develops in cortical cells or epidermal cells. Hartig net consists of branch systems which can provide a large surface contact between cells of the two symbionts (Peterson *et al.*, 2004).

Other types of mycorrhizal fungi include (Ecto-endo Mycorrhiza, Ericoid Mycorrhiza, Monotropoid, Arbutoid mycorrhizas and Orchid mycorrhiza) (Smith and Read, 2008).

## THE FUNCTIONS OF ARBUSCULAR MYCORRHIZAL FUNGI

### **Mycorrhizal fungi offer protection against pathogens**

**(bio-control agents):** Soil borne pathogens were controlled by using several agricultural practices methods, such as resistant cultivars, seed certification, chemical fungicide,s crop rotation and soil fumigation etc. There are many problems associated with controlling pathogens with long-term persistent survival structures due to difficulties in reducing pathogen inoculum and lack of good sources of plant resistance (Azcon-Aguilar and Barea, 1997). Therefore, many researchers were trying to use alternate approaches based on either manipulating or adding microorganisms to enhance plant protection against pathogens (Grosch *et al.*, 2005). The beneficial microorganisms (antagonistic bacteria) (e.g., *Pseudomonas fluorescens*, *Bacillus subtilis*, etc.) and fungi (e.g., AMF, *Trichoderma*, etc.) compete with plant pathogens for nutrients and space, by producing antibiotics, by parasitizing pathogens, or by inducing resistance in the host plants. These microbes have been used for biocontrol of pathogens (Berg *et al.*, 2007).

The extensive use of chemicals to control diseases poses a serious threat to the present day plant production systems (Dehne, 1982). Currently the use of beneficial microorganisms is one of the alternative management practices reviewed to have protective effect against plant soilborne pathogens (Brimmer and Boland, 2003; Mukerji *et al.*, 2002).

The protective effect of mycorrhizal symbioses against root pathogenic fungi has been tested by many researchers (Caron, 1989; Dehne, 1982). Disease reduction within host plants colonized by AMF is the result and output of the complex interactions between pathogens, AMF and plant (Harrier and Watson, 2004). AMF symbiosis has been shown to reduce the damage caused by soilborne pathogens (Azcon-Aguilar *et al.*, 2002). *Phytophthora parasitica* proliferation greatly reduced when tomato root colonized by *Glomus mosseae* and *P. parasitica* compared with non-mycorrhizal tomato roots (Cordier *et al.*, 1996). Trotta *et al.* (1996) found that phosphate by AMF may contribute to lessen the damage by *P. parasitica* in tomato. The presence of AMF

successfully delays the time required by *Ganoderma boninense* to infect and kill oil palm plant and the seedlings were more resistant to *G. boninense* (Rini, 2001). AMF has shown no indirect interaction with soilborne pathogen through antagonism, mycoparasitism and or antibiosis (Harrier and Watson, 2004). Different mechanisms have been reported to explain bio-control by AMF including biochemical changes in plant tissues, microbial changes in rhizosphere, nutrient status, anatomical changes to cells, changes to root system morphology and stress alleviation (Hooker *et al.*, 1994). Therefore, those mechanisms by which AMF could control the soil borne pathogen are listed below:

**Enhancing plant nutrition uptake:** Improvements in plant growth followed by root colonization by AMF occurs as a result of enhancement of the mineral nutrient status of plants. Some reports indicate that phosphorus induced changes in root exudation could reduce the germinations of pathogen spores (Graham, 1982; Sharma *et al.*, 2007). Some studies suggest that competition for space between AMF and pathogen, AMF may increase host tolerance to pathogen by increasing the uptake of essential nutrients rather than phosphorus which are otherwise deficient in the non-mycorrhizal plants (Gosling *et al.*, 2006). The AMF spores germinate and thick-walled hyphae penetrate the host root causing internal infection. After penetrating into the root, the hyphae spread inter- and/or intra-cellularly in the root cortex without damaging the integrity of the cells (Strack *et al.*, 2003). The increasing nutrient uptake resulted in more vigorous plants; thus, the plant itself may be more resistant or tolerant to pathogen attack (Linderman, 1994).

**Damage compensation:** It is suggested that AMF increase host tolerance of pathogen attack by compensating for the loss of root functional and biomass caused by soilborne pathogens (Linderman, 1994) including fungi and nematodes (Cordier *et al.*, 1996). This illustrates an indirect contribution to the biological control through the conservation of root system function both by AMF hyphae growing out into the soil and increasing the root absorbing surface area as well as by the maintenance of root cell activity through arbuscules formation (Gianinazzi-Person *et al.*, 1995).

**Soil microbial population interactions:** The first report attempted to specifically study the interaction of plant pathogenic fungus and a species of AM fungus was that of Safir (1968). The role of AMF in improving plant nutrition and their interactions with other soil biota have been investigated with reference to the host plant growth.

Few information's known about how these interactions affect soil structure (Schreiner and Bethlenfalvay, 1995). Plants colonized by AMF differ from non-mycorrhizal plant in rhizosphere microbial community, resulted in alterations in root respiration rate quality and quantity of the exudates (Marschner *et al.*, 2001).

Hyphae emerging from spores in the presence of bacteria smoothly developed small vesicles, longer and more branched than those without bacteria (Khan, 2005). The growth and health of plants influenced by the microbial shifts occur in the mycorrhizosphere (Azcon-Aguilar *et al.*, 2002). This effect has not been specifically evaluated as mechanisms for AM-associated biocontrol, but there are indications that such a mechanism does operate (Linderman, 1994). Some reports suggest that AMF alter the composition of functional groups of microbes in the mycorrhizosphere, including the numbers and/or activity of pathogens antagonists (Secilia and Bagyaraj, 1987).

No alteration was observed in the total numbers of actinomycetes or bacteria isolated from *Trifolium subterraneum* L. and *Zea mays* colonized by *Glomus fasciculatum*. However, there was a change in the functional groups of these microbes, including more facultative anaerobic bacteria in mycorrhizosphere of AMF colonized *T. subterraneum*. The total number of bacteria isolated from rhizoplane of *T. subterraneum* and *Zea mays* increased as a result of AMF colonization (Meyer and Linderman, 1986). The population of *Fusarium oxysporum* in the mycorrhizosphere soil of tomato reduced in AM plants relative to non-mycorrhizal one (Johansson *et al.*, 2004).

Plant root systems colonized by AMF differ in their effects on the bacterial community composition within the rhizosphere and rhizoplane (Burke *et al.*, 2002). Several biotic and a biotic factors are very important for determination of efficiency of AMF as a disease control agent. The most important factors are, soil moisture, soil contents, host genotype, mycorrhizal level inoculums, inoculation time of mycorrhiza, mycorrhizal fungi species virulence, inoculums potential of pathogen and soil microflora (Singh *et al.*, 2000).

Systemic bio-protection of plant against take all disease of barely plant depends on a high degree of AMF root colonization (Khaosaad *et al.*, 2007). The use of AMF resulted in resistance increment against the wilt pathogen *Fusarium oxysporum* f. sp. Lini (Dugassa *et al.*, 1996). Two zones of interactions can be defined (1) The rhizoplane and the surrounding rhizosphere soil and (2) The mycosphere (Bansal and Mukerj, 1994). Mycorrhization Helper Bacteria (MHB) certainly improve the ability of mycorrhiza fungi to colonize plant roots (Fitter and Garbaye, 1994).

**Competition for colonization and infection sites:** Physical competition between endomycorrhizal fungi and rhizosphere microorganisms to occupy more space in the root architecture is the first mechanism to explain the interaction between AMF and soil microorganisms (Bansal and Mukerji, 1996). Mycorrhizal fungi depend on the plant host photosynthates, so the competition for carbon compounds maybe, a cause of the pathogen suppression in mycorrhizal plant. The interaction between AMF and *Phytophthora* in tomato plant has shown that the pathogen dose not penetrate arbuscular containing cells (Cordier *et al.*, 1998). Dehne (1982) documented how AM fungi and root pathogens colonize in the same host tissues and how they develop in different root cortical cells, indicating some sort of or competition for space. The interaction of *Glomus mosseae* and *phytophthora nicotiana* var. *parastica* in tomato was shown to increase the AMF at the root apex site.

**Morphological and anatomical changes:** Root morphology system can be altered due to the colonization of root by AMF (Tahat *et al.*, 2008). Roots colonized by AMF are more highly branched compared to non colonized plants and also the adventitious root diameters are larger (Berta *et al.*, 1993), which can provide more infection sites for a pathogen (Hooker *et al.*, 1994). Dugassa *et al.* (1996) found that the infection of tomato and cucumber by *Fusarium* wilt might slow down due to the morphological changes in the root cells of the endodermis of AM plants which include lignifications incensement. The raising lignifications may protect the roots from penetration by other pathogens, while elevating of phenolic metabolism within the host plant (Morandi, 1996).

The colonization of tomato root by *Glomus mosseae* lead to a bigger root size and more branching which increase the number of root tips, length, surface area and root volume (Tahat *et al.*, 2008). Root damage by *Gaeumannomyces graminis* var. *tritici* was systemically reduced when barley plants showed high degree of mycorrhizal root colonization. Allowing mycorrhizal root infection exhibited no affect on *Gaeumannomyces graminis* var. *tritici* infection (Khaosaad *et al.*, 2007).

**Competition for host photosynthates:** The growth of AMF and root pathogen depends on the host photosynthates and they compete for the carbon compounds received by the root (Smith and Read, 1997). When AMF have primary access to the photosynthates, the higher carbon demand may inhibit the pathogen growth (Linderman, 1994). AMF is dependent on the host plant for carbon source. 4-20% net photosynthates of host are transferred to the fungus;

nevertheless, there is only a limited data to support this mechanism (Smith and Read, 2008).

**Changes in chemical constituents of plant tissues (root exudates):** Phytoalexins toxic components are not detected during the first stages of AM formation but can be detected in the later stages of symbiosis (Morandi, 1996). Wall-bound peroxidase activity has been detected during the initial stage of AM colonization (Azcon-Aguilar *et al.*, 2002). *Phytophthora parasitica* development decreased in *Glomus mosseae* and non *G. mosseae* parts of tomato mycorrhizal root systems in association with plant cell defense responses and accumulation of phenolics. Cortical cells containing *G. mosseae* are immune to the pathogen and exhibit a localized resistance response (Cordier *et al.*, 1998). Corresponding proteins involved in plant defense responses have been studied in AMF symbioses; these include hydroxyproline-rich glycoproteins, phenolics peroxidases, chitinase, B-1-3 glucanases-callose deposition and PR-phathogenesis related proteins (Morandi, 1996).

Root exudates play an important role in AMF establishment symbiosis (Vierheilig *et al.*, 2003). The germination of *Fusarium oxysporum* f.sp., *Lycopersici* was inhibited in the presence of root exudates from tomato (Scheffknecht *et al.*, 2006). Root exudates from mycorrhizal strawberry plants suppressed the sporulation of *Phytophthora fragariae* (in) *in vitro* study (Norman and Hooker, 2000). Differential growth of *Fusarium oxysporum* f.sp *chrysanthemi*, *Trichoderma harzianum*, *Clavibacter michiganensis* and *Pseudomonas chlororaphis* was explained by substances released from *Glomus intraradices* under *in vitro* culture conditions (Filion *et al.*, 1999). Grandmaison *et al.* (1993) suggested that phenolic compounds bound to cell wall could be indirectly responsible for the resistance of AMF roots to pathogenic fungi since they increased the resistance of cell wall to the action of digestive enzymes.

**Nutrient uptake:** The primary goal of AMF inoculation is to increase and enhance the yield and production of plants (Brundrett and Juniper, 1995). The main benefits of AMF are enhancing plant the acquisition of mineral nutrients and increasing the ability of host plants to withstand or reduce acquisition of toxic elements to growth (Clark, 1997). AMF provide a greater effective root surface area to explore greater volumes of soil and to overcome water and nutrient depletion zones around active root surfaces (Smith and Read, 2008).

Mycorrhizal plant roots have increased weight, length, number and layer diameters than the

non-mycorrhizal one (Hetrick *et al.*, 1988). Since, the average diameter of fungal hyphae is 3-4  $\mu\text{M}$ , which is smaller than the root hair diameter ( $>10 \mu\text{M}$ ). Therefore, fungal hyphae penetrate soil pores and contact with soil so that roots hair would not be able to contact. AM roots greatly enhance the acquisition of mineral nutrient in plant (Jakobsen, 1995). Mycorrhizal research has shown the increased nutrient uptake; mainly Phosphorus (P), in mycorrhizal plants compared to non-mycorrhizal plants (Akthar and Siddiqui, 2008). Soil phosphorus absorption by mycorrhizal plants is complete and faster than the non-mycorrhizal plants, because the distance of diffusion for  $\text{HPO}_4^{-2}$  and  $\text{H}_2\text{PO}_4$  ion in the soil will be shorter to the hyphae than to the root (Li *et al.*, 1991). Some studies indicate that increased phosphorus nutrition has the same effect as inoculation with AMF (Davies *et al.*, 1992). Numbers of physiological changes are induced in AMF root as a result of an increase in nutrient uptake (Graham, 2001). Enhancement of phosphorus status is the major benefit of mycorrhizal fungi. This is due to the uptake of phosphorus from the soil by the AMF and then transfers it to the host plant (Smith *et al.*, 2003).

The improvement of P nutrition of plants has been the most recognized and well established beneficial effect of mycorrhizas (Karandashov and Bucher, 2005; Cardoso *et al.*, 2006). Phosphate is converted into polyphosphate by polyphosphate kinase in vacuoles (incorporated) and is transported between the hyphal tips and a sink at the symbiotic interface (Pearson and Tinker, 1975). Translocation rate is affected by rates of net efflux of P at hyphal tips and net uptake (Johanson *et al.*, 1993). The abnormally high P loss from the arbuscules has been explained and two mechanisms have been proposed in this connection: Firstly, a high arbuscular P concentration will reduce hyphal re-absorption of lost P and this is in accordance with low expression of high P affinity transporter in the fungal tissue inside roots, compared to its expression level in the external hyphae (Harrison and Van Buuren, 1995). Secondly, P efflux may be promoted by altered operation of trans-membrane that is carrying and opening of ion channels. Mycorrhizal fungi are able to mobilize P and N from their organic substrates (Smith and Read, 1997).

AMF is the most efficient ecological factor in improving growth and N content in legumes (Barea *et al.*, 2002b). Enhanced nitrogen (N) acquisition by AM plants has been reported. This enhancement has been explained by high nitrogen demand because of enhanced phosphorus (George *et al.*, 1995). The hyphal of AMF have the capacity to take-up and transport N from soil to root (Bago and Becard, 2002). The uptake and translocation of nitrogen by hyphal fungus is regulated

by host plant's demand for N (Hawkins and George, 2001). AM hyphae absorb and translocated amounts of nitrogen when provides as  $\text{NH}_4^+$  and  $\text{NO}_3^-$  (George *et al.*, 1992). Hyphae took up about 40 % of the nitrogen applied as  $(\text{NH}_4)_2\text{SO}_4$  to a hyphal soil compartment, while some nitrogen was transported by hyphae over a distance of 5 cm within six days (Fery *et al.*, 1994). In addition to phosphorus and Nitrogen, AM fungi are known to have enhanced uptake of Zn, S and Ca (Clark and Zeto, 2000) and also Iron (Fe) acquisition has been enhanced. It is found that AM plants that are grown at low pH had higher Fe acquisition than AM plants grown at high pH (Treeby, 1992). Manganese acquisition generally was lower in AM plants compared to non AM plants (Azaizeh *et al.*, 1995).

**Enhance tolerance to heavy metals (bioremediation):** The effect of AMF plants on trace elements uptake was reported (Clark and Zeto, 2000). The AMF have higher shoot concentrations of copper (Cu) and zinc (Zn) when grown in soil with low concentration of these elements. Copper and zinc concentrations increased in leaves of AM soybean plants compared to nonmycorrhizal plants. Sulfur acquisition was enhanced in sorghum colonized by *Glomus fasciculatum* compared to non colonized plants (Raju *et al.*, 1990). Boron content was increased in AM maize shoot in acidic and alkaline soils while the acquisition of calcium (K), sodium (Ca) and magnesium (Mg) was also increased compared to the non AM *Gigaspora gigantea* soybean plants in low Phosphorus. At the same time *Gigaspora gigantea* colonized maize plant was decreased (K) and Ca but increased Mg acquisition (Lambert *et al.*, 1979). Aluminum (Al) acquisition toxicity was lower in AM switch grass grown in acidic soil compared to non AM plants (Clark, 1997).

The AMF were shown to enhance the acquisition of (Br) and (Cl) (Ellis *et al.*, 1995) and (Cd) (Copper and Tinker, 1978). (Co), (Cs) and (Ni) (Rogers and Williams, 1986). AM hyphae can uptake trace elements in very low concentration including Zn, Fe and Cu from the soil solution (Bago *et al.*, 1996).

**Mycorrhizosphere:** Mycorrhizosphere refers to the zone of soil influence by mycorrhizal association (Oswald and Ferchau, 1968). The first reported about the role of the mycorrhizosphere in biocontrol of pathogens was by Meyer and Linderman (1986). They found that extracts of rhizosphere soil from mycorrhizal plants reduced sporangia formation of *Phytophthora cinnamomi* in comparison with extracts of rhizosphere soil from non-mycorrhizal plants. These authors postulated that

either the sporulation-inducing microorganisms were missing or that the number of sporulation-inhibiting microorganisms increased. The changes in root exudates affect the microbial communities around the roots leading to the formation of mycorrhizosphere (Varma *et al.*, 1999). In mycorrhizosphere the appearance of mycorrhizae exert a strong influence on the microflora in the rhizosphere. The mycorrhizosphere microbiota differs qualitatively as well as quantitatively from the non rhizosphere mycorrhizal plants. Mycorrhizosphere has two components:

- The layer of soil surrounds the mycorrhizal roots
- The layer of soil surrounding AMF hyphae in the soil referred to as the hyphosphere

Data have been acquired that rhizosphere bacteria have efficient impacts on AMF growth (Azcon-Aguilar *et al.*, 2002). The interaction between AMF and other soil microbes in mycorrhizosphere can be classified as positive (synergistic) as well as negative (antagonistic) interaction (Mukerji *et al.*, 2002). The positive interaction of AMF with Plant growth promoting bacteria (PGPR), phosphorus-solubilising bacteria and N<sub>2</sub>-fixing bacteria can enhance the AMF spores germination and the plant growth (Mayo *et al.*, 1986). Negative interaction is related to the ability of AMF to suppress and inhibit the occurrence of various pathogens (Dehne, 1982).

**Arbuscular mycorrhizal fungi and beneficial soil microorganism's interactions:** The interaction between mycorrhizal fungi and other soil organisms are complex and often poorly understood; they may be inhibitory or stimulatory (Fitter and Garbaye, 1994). The PGPR interact with mycorrhiza in the mycorrhizosphere. Inoculation of *Glomus fasciculatum* has shown a positive influence on actinomycetes population in tomato rhizosphere. The survival of *Azotobacter paspali* increased in mycorrhizosphere (Barea *et al.*, 2002b). Higher bacterial population and number of nitrogen fixer such as streptomycin were reported and it has been detected that plants in the presence of AMF and bacteria produced more phytohormones (Secilia and Bagyaraj, 1987).

The relationship between Phosphate-Solubilizing Bacteria (PSB) and AMF is well reported (Barea *et al.*, 2002a). The PSB can survive longer in mycorrhizosphere root. A plant with higher concentration of P benefits the bacterial symbiont and nitrogenase functioning (Barea *et al.*, 1993). Dual inoculation of AMF and PSB significantly increased microbial biomass and N and P

accumulation in plant tissues (Barea *et al.*, 2002a, b). Mycorrhizae increased nitrogen nutrition in plant by facilitating the use of nitrogen forms that are difficult for mycorrhizal plants to exploit. Many rhizobium strains improve processes involved in AM formation (mycelia growth, spore germination) (Barea, 1997).

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## REFERENCES

- Akhtar, M.S. and Z.A. Siddiqui, 2008. Arbuscular Mycorrhizal Fungi as Potential Bioprotectants against Plant Pathogens. In: Mycorrhizae: Sustainable Agriculture and Forestry, Siddiqui, Z.A., M.S. Akhtar and K. Futai (Eds.). Springer Netherlands, Dordrecht, The Netherlands, pp: 61-97.
- Azaizeh, H.A., H. Marschner V. Romheld and L. Wittenmayer, 1995. Effects of a vesicular-arbuscular mycorrhizal fungus and other soil microorganisms on growth, mineral nutrient acquisition and root exudation of soil grown maize plants. *Mycorrhiza*, 5: 321-327.
- Azcon-Aguilar, C. and J.M. Barea, 1997. Applying mycorrhiza biotechnology to horticulture significance and potentials. *Sci. Hortic.*, 68: 1-24.
- Azcon-Aguilar, C., M.C. Jaizme-Vega and C. Calvet, 2002. The Contribution of Arbuscular Mycorrhizal Fungi for Bioremediation. In: Mycorrhizal Technology in Agriculture. From Genes to Bioproducts, Gianinazzi, S., H. Schuepp, J.M. Barea and K. Haselwandter (Eds.). Birkhauser Verlag, Berlin, ISBN-10: 0-89054-245-71, pp: 187-197.
- Bago, B. and G. Becard, 2002. Bases of the Obligate Biotrophy of Arbuscular Mycorrhizal Fungi. In: Mycorrhizal Technology in Agriculture, Gianinazzi, S.H., J. Schuepp M. Barea and K. Haselwandter (Eds.). Birkhauser Verlag, Basel, Switzerland, pp: 33-48.
- Bago, B., H. Vierheilig, Y. Piche and C. Azcon-Aguilar, 1996. Nitrate depletion and pH changes induced by the extraradical mycelium of the arbuscular mycorrhizal fungus *Glomus intraradices* grown in monoxenic culture. *New Phytologist*, 133: 273-280.
- Bansal, M. and K.G. Mukerji, 1994. Positive correlation between AM-induced changes in root exudation and mycorrhizosphere mycoflora. *Mycorrhiza*, 5: 39-44.

- Bansal, M. and K.G. Mukerji, 1996. Root Exudates and its Rhizosphere Biology. In: Concepts in Applied Microbiology and Biotechnology, Mukerji, K.G., V.P. Singh and S. Dwivedi (Eds.). Adita Books Private Ltd., New Delhi, pp: 79-119.
- Barea, J.M., R. Azcon and C. Azcon-Aguilar, 1993. Mycorrhiza and crops. *Adv. Plant Pathol.*, 9: 167-189.
- Barea, J.M., 1997. Mycorrhiza-Bacteria Interactions on Plant Growth Promotion. In: Plant Growth Promoting Rhizobacteria, Ogoshi, A., K. Kobayashi, Y. Homma, F. Kodama, N. Kondo and S. Akino (Eds.). OECD Press, Paris, France, pp: 150-158.
- Barea, J.M., R. Azcon and C. Azcon-Aguilar, 2002a. Mycorrhizosphere interactions to improve plant fitness and soil quality. *Antonie Van Leeuwenhoek*, 81: 343-351.
- Barea, J.M., M. Toro, M.O. Orozco, E. Campos and R. Azcon, 2002b. The application of isotopic ( $^{32}\text{P}$  and  $\text{N}^{15}$ ). Dilution techniques to evaluate the interaction effect of phosphate solution rhizobacteria, mycorrhizal fungi and rhizobium to improve agronomic efficiency of rock phosphate for legume crops. *Nutr. Cycle. Agroecosyst.*, 63: 35-42.
- Berg, G., R. Grosch and K. Scherwinski, 2007. Risk assessment for microbial antagonists: Are there effects on non-target organisms. *Gesunde Pflanzen*, 59: 107-117.
- Berta, G., A. Fusconi and A. Trotta, 1993. VA mycorrhizal infection and the morphology of root systems. *Environ. Exp. Bot.*, 33: 159-173.
- Brimmer, T. and G.J. Boland, 2003. A review of the non-target effects of fungi used to biologically control plant diseases. *Agric. Ecosyst. Environ.*, 100: 3-16.
- Brundrett, M.C. and S. Juniper, 1995. Non-destructive assessment of germination and single spore isolation of VAM fungi. *Soil Biol. Biochem.*, 27: 85-91.
- Burke, D.J., E.P. Hamerlynck and D. Hahn, 2002. Interactions among plant species and microorganisms in salt march sediments. *Applied Environ. Microbiol.*, 68: 1157-1164.
- Cardoso, I.M., B.H. Boddington, O. Janssen and T.W. Oenema Kuyper, 2006. Differential access to phosphorus pools of an oxisol by mycorrhizal and non-mycorrhizal maize. *Commun. Soil Sci. Plant Anal.*, 37: 1537-1551.
- Caron, M., 1989. Potential use of mycorrhizae in control of soil-borne diseases. *Can. J. Plant Pathol.*, 11: 177-179.
- Clark, R.B. and S.K. Zeto, 2000. Mineral acquisition by arbuscular mycorrhizal plants. *J. Plant Nutr.*, 23: 867-902.
- Clark, R.B., 1997. Arbuscular mycorrhizal adaptation, spore germination, root colonization and host plant growth and mineral acquisition at low pH. *Plant Soil*, 192: 15-22.
- Copper, K.M. and P.B. Tinker, 1978. Translocation and transfer of nutrients in vesicular-arbuscular mycorrhizas. *New Phytol.*, 81: 43-52.
- Cordier, C., M.J. Pozo, J.M. Barea, S. Gianinazzi and V. Gianinazzi-Pearson, 1998. Cell defense responses associated with localized and systemic resistance to *Phytophthora parasitica* induced in tomato by an arbuscular mycorrhizal fungus. *MPMI*, 11: 1017-1028.
- Cordier, C., S. Gianinazzi and V. Gianinazzi-Pearson, 1996. Colonization patterns of root tissues by *Phytophthora nicotiana* var. *parasitica* related to reduced disease in mycorrhizal tomato. *Plant Soil*, 185: 223-232.
- Davies, F.T., J.R. Potter and R.G. Linderman, 1992. Mycorrhiza and repeated drought exposure affect drought resistance and extraradical hyphae development of pepper plants independent of plant size and nutrient content. *J. Plant Physiol.*, 139: 289-294.
- Dehne, H.W., 1982. Interaction between vesicular-arbuscular mycorrhizal fungi and plant pathogens. *Phytopathology*, 72: 1115-1119.
- Dugassa, G.D., H. von Allen and F. Schonbeck, 1996. Effect of Arbuscular Mycorrhiza (AM) on health of *Linum usitatissimum* L. infected by fungal pathogen. *Plant Soil*, 185: 173-182.
- Ellis, J.R., D.M. Watson, G.E. Varvel and M.D. Jason, 1995. Methyl bromide soil fumigation alters plant elements concentration. *Soil Sci. Soc. Am. J.*, 59: 848-852.
- Fery, B., A. Vilarino, H. Schuepp and J. Arines, 1994. Chitin and ergosterol content of extraradical and intraradical mycelium of the vesicular-arbuscular mycorrhizal fungus *Glomus intraradices*. *Soil Biol. Biochem.*, 26: 711-717.
- Filion, M., M. St-Arnaud and J.A. Fortin, 1999. Direct interaction between the arbuscular mycorrhizal fungus *Glomus intraradices* and different rhizosphere microorganisms. *New Phytol.*, 141: 525-533.
- Fitter, A.H. and J. Grabaye, 1994. Interaction between mycorrhizal fungi and other soil organisms. *Plant Soil*, 159: 123-132.
- Grabaye, J., 1994. Helper bacteria: A new dimension to the mycorrhizal symbiosis. *New Phytol.*, 128: 197-210.
- George, E., H. Marchner and I. Jakobsen, 1995. Role of arbuscular mycorrhizal fungi in uptake of phosphorus and nitrogen from soil. *Crit. Rev. Biotechnol.*, 15: 257-270.



- George, E., K. Haussler, S.K. Kothari, X.L. Li and H. Marschner, 1992. Contributions of Mycorrhizal Hyphae to Nutrient and Water Uptake of Plants. In: *Mycorrhizas in Ecosystems*, Read, D.R., D.H. Lewis, A.H. Fitter and I.J. Alexander (Eds.). CAB International, Wallingford, UK, pp: 42-47.
- Gianinazzi, S., A. Trouvelot, P. Lovato, D. van Tuinen, P. Franken and V. Gianinazzi-Pearson, 1995. Arbuscular mycorrhizal fungi in plant production of temperate agroecosystems. *Critical Rev. Biotechnol.*, 15: 305-311.
- Gosling, P., A. Hodge, G. Goodlass and G.D. Bending, 2006. Arbuscular mycorrhizal fungi and organic farming. *Agric. Ecosyst. Environ.*, 113: 17-35.
- Graham, J.H., 1982. Effect of citrus root exudates on germination of chlamydospores of vesicular-arbuscular mycorrhizal fungus *Glomus epigaeum*. *Mycologia*, 74: 831-835.
- Graham, J.H., 2001. What do root pathogens see in mycorrhizas? *New Phytologist*, 149: 357-359.
- Grandmaison, J., G.M. Olah, M.R. Van Calsteren and V. Furlan, 1993. Characterization and localization of plant phenolics likely involved in the pathogen resistance expressed by endomycorrhizal roots. *Mycorrhiza*, 3: 155-164.
- Grosch, R., J. Lottmann, F. Faltin and G. Berg, 2005. Use of bacterial antagonists to control diseases caused by *Rhizoctonia solani*. *Gesunde Pflanzen*, 57: 199-205.
- Harrier, L.A. and C.A. Watson, 2004. The potential role of Arbuscular Mycorrhizal (AM) fungi in the bioprotection of plants against soil-borne pathogens in organic and/or other sustainable farming systems. *Pest Manage. Sci.*, 60: 149-157.
- Harrier, L.A., 2001. The arbuscular mycorrhizal symbiosis: A molecular review of the fungal dimension. *J. Exp. Bot.*, 52: 469-478.
- Harrison, M.J. and M.L. Van Buuren, 1995. A phosphate transporter from the mycorrhizal fungus *Glomus versiforme*. *Nature*, 378: 626-629.
- Hawkins, H.J. and E. George, 2001. Reduced <sup>15</sup>N-nitrogen transport through arbuscular mycorrhizal hyphae to *Triticum aestivum* L. supplied with ammonium vs. nitrate nutrition. *Ann. Bot.*, 87: 303-311.
- Hetrick, B.A.D., D.G. Kitt and G.W.T. Wilson, 1988. Mycorrhizal dependency and growth habit of warm season and cool season tall grass prairie plants. *Can. J. Bot.*, 66: 1376-1380.
- Hooker, J.E., M. Jaizme-Vega and D. Alkinson, 1994. Biocontrol of Plant Pathogen Using Arbuscular Mycorrhizal Fungi. In: *Impact of Arbuscular Mycorrhizas on Sustainable Agriculture and Natural Ecosystems*, Gianinazzi, S. and H. Schhepp (Eds.). Birkhauser Verlag, Basle, Switzerland, pp: 191-209.
- Jakobsen, I., 1995. Transport of Phosphorus and Carbon in VA Mycorrhizas. In: *Mycorrhiza: Structure, Function, Molecular Biology and Biotechnology*, Varam, A. and B. Hock (Eds.). 1st Edn., Springer, USA., pp: 297-324.
- Johanson, A., I. Jakobsen and E.S. Jensen, 1993. External hyphae of vesicular arbuscular fungi associated with *Trifolium subterraneum*. 3 Hyphal transport of <sup>32</sup>P and <sup>15</sup>N. *New Phytol.*, 124: 61-68.
- Johansson, J.F., L.R. Paul and R.D. Finlay, 2004. Microbial interactions in the mycorrhizosphere and their significance for sustainable agriculture. *FEMS Microbiol. Ecol.*, 48: 1-13.
- Karandashov, V. and M. Bucher, 2005. Symbiotic phosphate transport in arbuscular mycorrhizas. *Trends Plant Sci.*, 10: 22-29.
- Khaosaad, T., J.M. Garcia-Garrido, S. Steinkellner and H. Vierheilig, 2007. Take-all disease is systemically reduced in roots of mycorrhizal barley plants. *Soil Biol. Biochem.*, 39: 727-734.
- Kuhn, G., M. Hijri and I.R. Sanders, 2001. Evidence for the evolution of multiple genomes in arbuscular mycorrhizal fungi. *Nature*, 414: 745-748.
- Kumar, S. and T. Satyanarayana, 2002. Isolation of Ectomycorrhizal Fungi: Methods and Techniques. In: *Techniques in Mycorrhizal Studies*, K.G. Mukerji, C. Manoharachary and B.P. Chamola (Eds.). Kluwer Academic Publishers, London, pp: 143-166.
- Lambert, D.H., D.E. Baker and H.Jr. Cole, 1979. The role of mycorrhizae in the interactions of phosphorus with zinc, copper and other elements. *Soil Sci. Soc. Am. J.*, 43: 976-980.
- Li, X., E. George and H. Marschner, 1991. Extension of the phosphorus depletion zone in VA mycorrhizal white clover in a calcareous soil. *Plant Soil*, 136: 41-48.
- Linderman, R.G., 1994. Role of VAM Fungi in Biocontrol. In: *Mycorrhizae and Plant Health*, Pflieger, F.L. and R.G. Linderman (Eds.). The American Phytopathological Society, St. Paul, MN., USA., ISBN: 0-89054-158-2, pp: 1-27.
- Marschner, P., D. Crowley and R. Lieberei, 2001. Arbuscular mycorrhizal infection changes bacterial 16S DNA community composition in the rhizosphere of maize. *Mycorrhiza*, 11: 297-302.
- Mayo, K., R.E. Davis and J. Motta, 1986. Stimulation of germination of spores of *Glomus versiforme* by spore-associated bacteria. *Mycologia*, 78: 426-431.
- Meyer, J.R. and R.G. Linderman, 1986. Selective influence on population of rhizosphere or rhizoplane bacteria and actinomycetes by mycorrhizas formed by *Glomus fasciculatum*. *Soil Biol. Biochem.*, 18: 191-196.

- Morandi, D., 1996. Occurrence of phytoalexins and phenolic compounds in endomycorrhizal interactions and their potential role in biological control. *Plant Soil*, 185: 241-251.
- Morton, J.B. and G.L. Benny, 1990. Revised classification of arbuscular mycorrhizal fungi (zygomycetes): A new order glomales, two new suborders, glomineae and gigasporineae and gigasporaceae, with an amendment of glomaceae. *Mycotaxon*, 37: 471-491.
- Mukerji, K.G., C. Manoharachary and B.P. Chamola, 2002. *Techniques in Mycorrhizal Studies*. 1st Edn., Kluwer Academic Publishers., London-Netherlands, ISBN-10: 1402005326, pp: 285-296.
- Norman, J.R. and J.E. Hooker, 2000. Sporulation of *Phytophthora fragaria* shows greater stimulation by exudates of non-mycorrhizal than by mycorrhizal strawberry roots. *Mycol. Res.*, 104: 1069-1073.
- Oswald, E.T. and H.A. Ferchau, 1968. Bacterial associations of coniferous mycorrhizae. *Plant Soil*, 28: 187-192.
- Pearson, V. and P.B. Tinker, 1975. Measurement of Phosphorus Fluxes in the External Hyphae of Endomycorrhizas. In: *Endomycorrhizas*, Sanders, F.E., B. Mosse and P.B. Tinker (Eds.). Academic Press Inc., London, pp: 277-287.
- Peterson, R.L., H.B. Massicotte and L.H. Melville, 2004. *Mycorrhizas: Anatomy and Cell Biology*. NCR Research Press, Ottawa, Canada.
- Pirozynski, K.A. and Y. Dalpe, 1989. Geological history of the Glomaceae with particular reference to mycorrhizal symbiosis. *Symbiosis*, 7: 1-36.
- Raju, P.S., R.B. Clark, J.R. Ellis and J.W. Maranville, 1990. Effects of species of VA-Mycorrhizal fungi on growth and mineral uptake of sorghum at different temperatures. *Plant Soil*, 121: 165-170.
- Rini, V.M., 2001. Effect of arbuscular mycorrhiza on oil palm seedling growth and development of basal stem rot disease caused by *Ganoderma boninense*. Master Thesis, Universiti Putra Malaysia.
- Safir, G., 1968. The influence of vesicular-arbuscular mycorrhiza on the resistance of onion to *Pyrenochaeta terrestris*. M.Sc. Thesis, University of Iuinois, Urban.
- Scheffknecht, S., R. Mhammerler, S. Steinkellner and H. Vierheilig, 2006. Root exudates of mycorrhizal tomato plants exhibit a different effect on microconidia germination of *Fusarium oxysporum* f. sp. *lycopersici* than root exudates from non-mycorrhizal tomato plants. *Mycorrhiza*, 16: 365-370.
- Schreiner, R.P. and G.J. Bethlenfalvy, 1995. Mycorrhizal interactions in sustainable agriculture. *Crit. Rev. Biotechnol.*, 15: 271-287.
- Secilia, J. and D.J. Bagyaraj, 1987. Bacteria and actinomycetes associated with pot cultures of vesicular-arbuscular mycorrhizas. *Can. J. Microbiol.*, 33: 1069-1073.
- Shalini, R., B.P. Chamola and K.G. Mukerji, 2000. Evolution of Mycorrhiza. In: *Mycorrhizal Biology*, Mukerji, K.G., B.P. Chamola and J. Singh (Eds.). Plenum Publishers, USA.
- Sharma, M.P., A. Gaur and K.G. Mukerji, 2007. Arbuscular Mycorrhiza Mediated Plant Pathogen Interactions and the Mechanisms Involved. In: *Biological Control of Plant Diseases*, Sharma, M.P., A. Gaur and K.G. Mukerji (Eds.). Haworth Press, Binghamton, USA., pp: 47-63.
- Sieverding, E. and F. Oehl, 2006. Revision of *Entrophospora* and description of *Kuklospora* and *Intraspora*, two new genera in the arbuscular mycorrhizal Glomeromycetes. *J. Applied Bot. Food Qual.*, 80: 69-81.
- Singh, R., A. Adholega and K.G. Mukerji, 2000. Mycorrhiza in Control of Soil Borne Pathogens. In: *Mycorrhizal Biology*, Mukerji, K.G., B.P. Chamola and J. Singh (Eds.). Kluwer Academic/Plenum Publishers, New York, USA., pp: 173-196.
- Smith, S.E. and D.J. Read, 1997. *Mycorrhizal Symbiosis*. 2nd Edn., Academic Press, London, UK., ISBN: 0-12-652840-3, pp: 605.
- Smith, S.E. and D.J. Read, 2008. Mineral Nutrition, Toxic Element Accumulation and Water Relations of Arbuscular Mycorrhizal Plants. In *Mycorrhizal Symbiosis*. 3rd Edn., Academic Press, London, ISBN-10: 0123705266, pp: 145-18.
- Smith, S.E., F.A. Smith and I. Jokobsen, 2003. Mycorrhizal fungi can dominate phosphate supply to plants irrespective of growth responses. *Plant Physiol.*, 133: 16-20.
- St-Arnaud, M., C. Hamel and J.A. Fortin, 1994. Inhibition of *Pythium ultimum* in roots and growth substrate of mycorrhizal *Tagetes patula* colonized with *Glomus intraradices*. *Can. J. Plant Pathol.*, 16: 187-194.
- Strack, D., T. Fester, B. Hause, W. Schliemann and M.H. Walter, 2003. Arbuscular mycorrhiza: Biological, chemical and molecular aspects. *J. Chem. Ecol.*, 9: 1955-1979.
- Suverch, K.G., K. Mukerji and D.K. Arora, 1991. Ectomycorrhizal: Handbook of Applied Mycology. In: *Soil and Plants*, Arora, D.K., B. Rai, K.G. Mukerji and G.R. Kndson (Eds.). Vol. 1, Marcel Dekker Inc., New York, pp: 187-215.
- Tahat, M.M., S. Kamaruzaman, O. Radziah, J. Kadir and H.N. Masdek, 2008. Response of (*Lycopersicum esculentum* Mill.) to different arbuscular mycorrhizal fungi species. *Asian J. Plant Sci.*, 7: 479-484.

- Tahat, M.M., S. Kamaruzaman, O. Radziah, J. Kadir and H.D. Masdek, 2009. Mechanisms involved in the biological control of tomato bacterial wilt caused by *Ralstonia solanacearum* using arbuscular mycorrhizal fungi. Ph.D. Thesis, Unviversity Putra Malaysia.
- Treeby, M.T., 1992. The role of mycorrhizal fungi and non-mycorrhizal micro-organisms in iron nutrition of citrus. *Soil Biol. Biochem.*, 24: 857-864.
- Trotta, A., G.C. Vanese, E. Gnani, A. Fascon, S. Sampo and G. Berta, 1996. Interaction between the soilborne root pathogen *Phytophthora nicotianae* Var *parasitica* and the arbuscular mycorrhizal fungus *Glomus mosseae* in tomato plant. *Plant Soil*, 185: 199-209.
- Varma, A., 1999. Function and Applications of Arbuscular Mycorrhizal Fungi in Arid and Semi-Arid Soils. In: *Mycorrhiza: Structure, Function, Molecular Biology and Biotechnology*, Varma, A. and B. Hock (Eds.). 2nd Edn., Springer-Verlag, Germany, pp: 521-556.
- Vierheilig, H., S. Lerat and Y. Piche, 2003. Systemic inhibition of mycorrhiza development by root exudates of cucumber plants colonized by *Glomus mosseae*. *Mycorrhiza*, 13: 167-170.
- Whipps, J.M., 2004. Prospects and limitations for mycorrhizas in biocontrol of root pathogens. *Can. J. Bot.*, 82: 1198-1227.
- Yao, M.K., R.J. Tweddell and H. Desilets, 2002. Effect of two vesicular-arbuscular mycorrhizal fungi on the growth of micropropagated potato plantlets and on the extent of disease caused by *Rhizoctonia solani*. *Mycorrhiza*, 12: 235-242.