International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(1): 2179-2188

Received: 21-11-2017
Accepted: 23-12-2017

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Vesicular arbuscular mycorrhiza as potential Biocontrol agent for nutrition and management of Soil-borne diseases: A review

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Abstract
Mycorrhizae is symbiotic organism that have potential as biological control agent of soil borne disease. Vesicular arbuscular mycorrhizae (VAM) represent a group of fungi that are associate with most agricultural pants influence the nutrition *i.e.*, macro and micro and provide protection against soil borne disease. Difficulty of the application of VAM as biological control agents can be related to variations within each pathogen host-plant VAM system. Soil borne diseases are one of the important limiting factors for the commercial cultivation of various crops. The management of these diseases with chemical pesticides has exhibited numerous ill effects to 88 biotic system and environment and it provide effective and durable protection to root system. The role of mycorrhiza against pathogenic population is well established and benefits of these associations have been found to reduce the vulnerability of root system by decreasing abiotic stresses besides improving the ecological fitness of plant species in the soil environment. Balanced plant nutrition with macro and micro nutrients attributes to host endurance against different biotic and abiotic stresses. Plant species are benefited from mycorrhizal association because of superior effectiveness in nutrient and water uptake. Abiotic stresses influence the host to pathogenic infections. Some of the diseases are more in nutrient-poor or moisture-deficient soils. Several studies have proved that seedlings with symbiotic associations exhibit more resistance to the host system against pathogenic fungi/bacteria/nematodes with various mechanisms. Symbiotic fungi utilize surplus carbohydrates from the root exudates and transform the monosaccharide to less soluble sugars which discourages the germination of propagules and attractiveness of the roots to the pathogens which are helps in establishment of seedling. Symbiotic associations have been found to enhance the concentration of these inhibitors many times greater than non-symbiotic roots and protecting the plant species against infection. This review provides an overview of the potential of AM fungi as bio-protection agents against soil borne disease and emphasizes the complex nature of plant–fungus interactions. Several mechanisms, including modulated plant tolerance, manipulation of induced systemic resistance (ISR), and altered vector pressure are involved in such interactions, considering multiple benefits, Enhanced plant nutrition uptake, Damage compensation, Competition for colonization or infection sites, better establishment of plant, Anatomical and morphological changes in the root system etc. Mycorrhiza incorporation can be considered as one of the important components of integrated disease management strategies and influence the nutrition which are provide better establishment of crops.

Keywords: Arbuscular mycorrhizal fungi, nutrition, soil borne disease management

1. Introduction

There is a worldwide growing awareness regarding the negative repercussions of the indiscriminate use of chemical pesticides, which are not only toxic to human life but also lead to environmental well as ecosystem pollution. The long-term use of broad-spectrum chemical pesticides has been recognized as one of the major causes of environmental pollution and contributes to the deterioration of agricultural land and ecosystem as a whole. The present needs concern the use of safer bio control measures that are easily degradable, environmentally friendly with greater selectivity, requiring low dosage rates with less harmful effects on non-target organisms. The greatness of the problem can be minimised or avoided by fully exploiting chemicals in combination with biological, physical and cultural control measures in integrated pest and disease management programmes. Integrated pest management (IPM) is an effective mean for disease control and holds tremendous potentials in the future [58]. The use of appears of great advantage, since it is both environmentally friendly and ecologically sound.

any microbial-based biotechnology in IPM. The most important issue in the use of biological control resides in developing biodegradable, consistent, persistent control measures coupled with high performance.

Mycorrhizal fungi are a major component of the agricultural natural resource and they are members of the fungus kingdom. A symbiotic association of fungus and roots has been discovered in Monotropy Hypopity. The studies of the Polish botanist Frank 1885 had initiated worldwide interest on a fungus-root (Myco-rhiza). Also, he gave the name MYCORRHIZA to the peculiar association between root trees and ectomycorrhizal fungi. Mycorrhizal fungi association widely varied in structures and functions, but the Arbuscular Mycorrhizae (AM) are the most common interaction [40].Six genera of arbuscular mycorrhizal fungi have been recognized based on morphological characteristics of a sexual spores and also based on various biomolecules studies as well as molecular methods [62]. 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 character. 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) [62]. AMF are *i.e., Glomus*, *Gigaspora*, *Sclerocystis*, *Acaulospora*, *Entropho spora* and *Scutellospora* (Garbaye, 1994) [30]. The classification of AMF is based on the structure of their soil-borne resting spore, biochemical and molecular studies. The latest classification of AMF contains 4 orders with 9 families. Plant species belonging to the Cruciferae and Chenopodiaceae are not known to form AMF symbiosis (Smith and Read, 1997) [73]. The AMF reproduce asexually by spore production. There is no evidence that AMF replicate sexually. Microbes inhabiting the soil have intimate relation with the soil organic matter and other living organisms including plants. The most dynamic and complex area within the soil environment is root rhizosphere. Rhizosphere is the region of soil surrounding the plant root characterized with highest microbial activity. This region differs from the surrounding soil in physiochemical characteristics since root surface and rhizosphere is colonized by wide range of microorganisms. Three different populations existing among soil inhabitants are:

1.1 Saprophytic microbes.

These contribution in soil formation; augment of soil fertility and nutrient transformation by natural cycles and the dynamic component of agricultural sustainability.

1.2 Parasitic population

These infect the root system of plant species and exhibit various types of disease syndrome *viz,* root rots, collar rots, galls, knots, wilts etc. This group of diseases is more disastrous than airborne diseases because these kill the plant irrespective of the age, and in general their diagnosis is possible only when much damage to the host system has already been caused. The disease management has its peculiar limitations. Besides, many pathogen affecting aerial parts also perpetuate a part their life cycle in the soil.

2. Types of mycorrhizal fungi

The diagnostic feature of EM is the presence of hyphae between root cortical cells producing a simply netlike structure called the "Hartig net". Many EM also have a sheath or mantle of fungal tissue that may completely cover the absorbing root. The mantle can vary widely in thickness, color, and texture depending on the particular plant-fungus combination. Mycorrhizal associations are of different types (*Ectomycorrhizae, Arbuscular Mycorrhizae, Actendomycorrhiza, Ericaceous Mycorrhizae, Orchidaceous Mycorrhizae*) but broadly categorized in to two *viz.* Ectomycorrhiza (EM) and Endomycorrhiza (VAM).

2.1 Ectomycorrhizae

These are found on woody plants ranging from shrubs to forest trees. Many of the host plants belong to the families Pinaceae, Fabaceae, Betulaceae, Salicaceae, Juglandaceae, Tiliaceae, Myrtaceae etc. About 4,000 fungal species, belonging primarily to the Basidiomycotina, and Ascomycotina, are known to form ectomycorrhizae. Some of these fungi produce fruiting (reproductive) structures in the form of mushrooms and puffballs on the forest floor. Some of the prominent species forming ectomycorrhiza and producing metabolites protecting the plants root systems against diseases [81].The general term for all mycorrhizal types where the fungus grows within cortical cells is endomycorrhiza.

The diagnostic feature of vesicular arbuscular mycorrhizae (VAM) which are designated as arbuscular mycorrhizal fungi (AMF) are the development of a highly branched arbuscule within root cortical cells. The fungus initially grows between cortical cells, but soon penetrates the host cell wall and grows within the cell. In this association neither the fungal cell wall nor the host cell membrane is breached. As the fungus grows, the host cell membrane in vaginates and envelops the fungus, creating a new compartment where material of high molecular complexity is deposited. This apoplectic space prevents direct contact between the plant and fungus cytoplasm and allows for efficient transfer of nutrients between the symbionts. The arbuscules are relatively short lived. Vesicles are thin walled, lipid-filled structures that usually form in intercellular spaces. Primary function of vesicle is storage and production of reproductive propagules for the fungus. Reproductive spores are formed asexually (chlamydospores) by the differentiation of vegetative hyphae in the root or in the soil. AMF are formed by non-septate phycomycetes fungi belonging to genera *viz.*, and in the Ectomycorrhiza (EM). Many EM also have a sheath or mantle of fungal tissue that may completely cover the absorbing root. The mantle can vary widely in thickness, color, and texture depending on the particular plant-fungus combination.

2.2 Endomycorrhizae

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2.3 Ericaceous mycorrhizae

In mycorrhizal associations found on plants in the order Ericales, the hyphae in the root can penetrate cortical cells of plant (endomycorrhizal habit); however, no arbuscules are formed.

2.4 Actendomycorrhiza

Act endomycorrhizal formation induces the growth of short roots, similar to the EM association in apple seedlings. Emergent roots become covered in a matrix of highly branched hyphae, a coarse sheath develops behind the apex, between root hairs, and will eventually cover the entire root, except when the lateral roots grow very rapidly.

2.5 Orchidaceous mycorrhizae

Orchid seeds are colonized shortly after germination, and the mycorrhizal fungus supplies carbon and vitamins to the developing embryo. For achlorophyllous species, the plant depends on the fungal partner to supply carbon throughout its life. The fungi participating in the symbiosis are basidiomycetes, saprophytes and pathogenic. In mature orchids, mycorrhizae also have roles in nutrient uptake and translocation.

3 Modes of mycorrhizae-mediated disease control

3.1 Host nutritional effects (improved plant nutrition)

Mycorrhizal plants are generally able to tolerate pathogens and compensate for root damage and photosynthate drain by pathogens [3 and 22], because AMF enhance host nutrition and overall plant growth. For example, [22] found that *G. proliferum* and a *Glomus* sp. isolate not only stimulated growth and increased shoot P content of banana in the presence and absence of the root rot fungus *Cylindrocladium spathiphylli,* but also reduced root damage by the pathogen, indicating direct interactions between the AMF and the pathogen. In contrast, some reports indicate that AMF are capable of biological control activity [9, 66]. It is believed that AMF interact equally with host plants, but in fact AMF prefer one host or host cultivar over another, as shown by Grey *et al.,* [36] who reported that mycorrhizal barley cultivar WI2291 not only exhibited greater control of the barley common root rot pathogen *Bipolarissorokiniana* than a mycorrhizal cultivar Harmal, but also produced significantly higher yields. On the other hand, biological control activity is dependent on the AMF species as demonstrated for common root rot of barley by Boyetchko and Tewari [22]. There are suggestions that root colonization by natural AMF communities occurring in field soils has an inverse relationship with *B. sorokiniana* infection, indicating not only a direct interaction between the AMF and the pathogen, but also an AMF-mediated improvement in host nutrition [79]. In contrast, there are also reports suggesting a lack of interaction between AMF and *B. sorokiniana* under field conditions [84]. Interaction between naturally occurring AMF and pathogens or the lack thereof in the field likely depends on the distribution of the organisms particularly under the different crop alternations. Significantly reduced the disease severity as a result of AMF colonization and enhanced P uptake followed by modifications in root exudation patterns has also been reported for take-all disease of wheat [33, 34]. Enhancement in host P nutrition is one of the initial proposed mechanisms of AMF-mediated pathogen or disease tolerance that is still very pertinent.

3.2 Tolerance to pathogen

Arbuscular mycorrhizal fungi are known to enhance plant tolerance to pathogens without excessive yield losses, and in some cases, enhance pathogen inoculum density. This compensation is apparently related to enhanced photosynthetic capacity [1, 42] and a delay in senescence caused by the pathogen, which cancels the positive relationship between disease severity and yield loss [42]. For example, soybean plants grown in the soil infested with *M. phaseolina, Rhizoctonia solani*, or *F. solani* exhibited lower shoot and root weight and plant height compared to control plants in soil not infested with the pathogens or with *G. mosseae* [87]. The incidence of infection by the pathogens was not affected by *G. mosseae* colonization but the mycorrhizal plants were able to tolerate infection of pathogens better than nonmycorrhizal plants.

The efficacy and efficiency of AMF in promoting plant growth enables mycorrhizal plants to tolerate pathogens, as demonstrated by Hwang [43] using alfalfa challenged with *P. paroecandrum* and using olive seedlings. It is unclear whether mycorrhizal alfalfa tolerated *P. paroecandrum* or if other additional mechanisms were involved. Despite the presence of a pathogen benefits of AMF to susceptible hosts can occur until a pathogen inoculum threshold level, beyond which no AMF-mediated benefits can be realized [76]. On the other hand, high tissue P levels in mycorrhizal plants may not only improve vigor and fitness of the plant but also modify pathogen dynamics in the mycorrhizosphere by modifying root exudation [48]. Tolerance of the plant to a pathogen can vary depending on the AMF species and their ability for enhancing host nutrition and growth, although some ineffective AMF species reduce pathogen entry by triggering a defense reaction in plants [21]. For example, Matsubara *et al.,* [54] noted that there were significant differences in the ability of *G. margarita, G. fasciculatum, G. mosseae,* and *Glomus* sp. *R10* to not only enhance asparagus growth but also in their ability to tolerate the severity of violet root rot caused by *Helicobasidiummompa. Asparagus* seedlings inoculated with *Glomus* sp. *R10* had the lowest incidence of violet root rot. This important fact highlights the care that needs to be exercised in the selection of AMF species for biological control of diseases.

3.3 Qualitative and quantitative alterations in pathogen biomass

Modifications in root exudate composition following changes in host root membrane permeability as a result of AMF colonization [34] can enforce changes in the rhizosphere microbial equilibrium [10, 48]. Changes in the rhizosphere microfloral community cancollectively benefit host plants by creating favourable conditions for the proliferation of microflora antagonistic to pathogens such as Phytophthora and Pythium spp. as shown for eucalyptus seedlings by [53]. Unfavourable conditions induced by AMF colonization resulted in qualitative changes in the mycorrhizosphere that prevented *P. cinnamon* sporangial induction in tomato plants [56]. Proliferation of *G. mosseae* inside grapevine roots was associated with a significant reduction in replant disease-causing fluorescent pseudomonad inoculum in soil [85]. Promoting AMF diversity that will ensure that at least a component of the AMF community may be active against pathogens can further enhance the benefits of this mechanism.

3.4 Competition
The AMF spores in soil are not known to compete for nutrients as spore reserves are utilized for survival until root contact is achieved. Following root entry, competition can occur for infection sites, host photo synthates, and root space [73]. Competition between AMF and pathogens can be used for physical exclusion of pathogen, if the host is pre-inoculated with AMF. Simultaneous colonization of AMF and the pathogen may not provide a competitive edge for AMF for inoculum build-up [20] because of its relatively slow growth rate compared with the pathogen. In contrast, some others have noted that competition may not occur between AMF and other organisms [69]. Competition, as a mechanism of suppressing pathogens by AMF did not receive much consideration, because in some cases pathogens were suppressed even in noncolonized root portions that was later described as induced resistance by AMF [64].

3.5 Physiological and biochemical alterations of the host
AMF colonization, host root tissue P levels are typically enhanced which modify the phospholipid composition and therefore the root membrane permeability resulting in a reduction in the leakage of net amount of sugars, carboxylic acids, and aminoacids into the rhizosphere [32, 33, 67]. These alterations apprehension the chemotactic effect of pathogens to plant roots and discourage pathogen entry. Prior inoculation of maize plants with *G. mosseae* decreased the number of *Alternaria alternata* colony forming units, but when both organisms were inoculated at the same time, there was no effect on pathogen inoculum density in soil [55]. It is possible that the *G. mosseae* symbiont altered membrane permeability of the host roots, thereby reducing the quality and quantity of substances exuded by the roots [32, 33], restricting pathogen propagule germination, indicating that the timing of inoculation can enhance bio control activity.
Plant cells are capable of elaborating inhibitory substances during their metabolic response to pathogenic attack, which are considered to be important in imparting resistance in the plant tissues. Symbiotic associations have been found to enhance the concentration of these inhibitors many times greater than non-symbiotic roots. Pine (*Pinus sylvestris*) seedlings with variegatus 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*, *Pisolithustinctorious* 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 to many pathogenic fungi some of which are *Phytophthora Cinnamomum, Rhizoctonia undulates. Phymatotrichumomnivorum, Fomesannosus Pastalotiarhododendry etc.*

3.6 Systemic induced resistance
Systemic-induced resistance (SIR) is typically the sustained induction of resistance or tolerance to disease in plants by previously inoculating with a pathogen, exposing to an environmental influence or treating with a chemical, which may or may not have antimicrobial activity [39]. Researchers have suggested that AMF-inoculated plants may employ SIR as a mechanism of biocontrol [11]. The SIR phenomenon in mycorrhizal plants is demonstrated as localized and systemic resistance to the pathogens [19].
An increase in the lignin deposition in plant cell walls following AMF colonization can restrict the spread of pathogens [23]. Using a split root system, Cordier *et al.*, [19] demonstrated that *G. mosseae* protected tomato plants against *P. parasitica* by reducing pathogen development and spread by growing cell wall appositions containing callose close to the intercellular hyphae and accumulation of phenolic compounds and plant cell defense responses. Root damage was observed in portions of mycorrhizal root systems not containing mycorrhizal structures. The SIR reaction to the pathogen in mycorrhizal plants was further illustrated by host wall thickenings containing none sterified pectins and pathogenesis related (PR)-1 protein in the non mycorrhizal areas of the roots. They also noted that the PR-1 protein was found only in the pathogen-invaded tissues of pea. These responses were observed in the non mycorrhizal pathogen-infected root tissues that ultimately led to cell death. Bodker *et al.*, [8] reported that the observed increased resistance to *A. euteiches* in *Gossaeintraradices*-inoculated pea was probably due to an "induced systemic factor," induced by *G. intraradices.*
The AMF-mediated SIR phenomenon is speculated to play a role in the protection of potatoes against post-harvest suppression of potato dry rot, wherein dry rot in *G. intraradix*-inoculated potato was reduced by up to 90% compared to uninoculated control [23]. If inoculation of AMF for the disease control or surpasses the growth and reproduction phase of the host and extends to the storage phase of the product. The area of SIR response in mycorrhizal plants is silent developing and several aspects including whether all AMF species can equally elicit SIR response in the host are not known. Some researchers have examined the role of PR proteins in the disease control process mediated by AMF [52]. Enhanced levels of 10 different PR proteins were detected in cotton plants inoculated with *G. mosseae, G. versiforme* challenged with *V. dahlia* compared with plants not challenged by the pathogen. The PR proteins retarded the hyphal growth of *V. dahlia* and killed their conidia. This appears to be a promising field that can be used for the effective control of plant diseases.

3.7 Phytoalexins and phytoanticipins
Phytoalexins are produced in response to microbial infection [61], whereas phytoanticipins are stored in plant cells in anticipation of or prior to pathogen attack [82]. The level of phytoalexins elicited by pathogens has been shown to be much higher than those elicited by symbiotic organisms [86]. The function of an is o flavonoid molecule as a phytoalexin or phytoanticipin can be predicted based on the cellular location of the molecule [75]. An increase in the level of total soluble plant phenolics content such as iso flavonoids or flavonoids, lignin, syringic, ferulic or coumaric acids, etc. have been reported as synthesis of phytoalexins following AMF colonization of roots [41]. Some flavonoids that are not true phytoalexins may also respond to AMF colonization of roots [41, 83].
The production of phytoalexins as a result of pathogen invasion in mycorrhizal plants has been explored. Tomato plants inoculated with *G. mosseae* posed greater resistance to

the pathogen *F. oxysporum* and were found to have increased phenylalanine and b-glucosidase activity and total phenol content in their roots compared to plants inoculated with either organism alone [23]. Sundaresan *et al.*, [77] reported that a purified ethanol fraction of mycorrhizal cowpea root extract inhibited *F. oxysporum in vitro*. However, the isoflavonoid was not identified. Production of phytoalexins in mycorrhizal plants appears to be independent of the effect of fertilizer addition [14]. In general, in the presence or absence of pathogens in plant roots, phytoalexins are induced in mycorrhizal plants that neutralize the negative effects of pathogens.

3.8 Hydrolases

Differential expression of defense-related genes in mycorrhizal plants has been the recent focus of AMF mediated bio control [63]. Researchers have shown that AMF enter into host (*e.g.,* tomato) roots and induce a local, weak, and transient activation of the host defence mechanism against pathogens such as *P. parasitica,* which involves the induction of hydrolytic enzymes such as chitinase, chitosanase, b-glucanase, and superoxide dismutase. In addition, portions of the mycorrhizal root system not containing mycorrhizal structures appear to have alterations in the constitutive isoforms of the enzymes indicating systemic changes following AMF colonization [63]. A high positive correlation between the level of glucanase activity in host tissues and pathogen resistance hasbeen established [35]. Further studies examining the role of these glucanases will help in the development of strategies for control of pathogens using AMF.

3.9 Antibiosis

Some researchers reported that the production of antimicrobial substances by AMF are not common. However, recently, it was shown that antimicrobial substances (unidentified) produced by the extraradical mycelium of the AMF species *G. intraradices* reduced conidial germination of *F. oxysporum f. sp. chrysanthemi*, which was independent of changes in pH [26, 27]. Budi *et al.* [12] isolated a *Paenibacillus* sp. strain from the mycorrhizosphere of *Sorghum bicolour* plants inoculated with *G. mosseae* that exhibited significant antagonism against *P. parasitica.* Regardless of the source of these bio control activities, it is important to realize and utilize the significance of AMF in plant disease control. Additional research in this area may prove to be fruitful in the control of pathogenic bacteria and fungi.

3.10 Enhance tolerance to heavy metals (Bioremediation)

The effect of AMF plants on trace elements uptake was reported. 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. 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 decreased (K) and Ca but increased Mg acquisition [50]. Aluminium (Al) acquisition toxicity was lower in AM switch grass grown in acidic soil compared to non-AM plants [18]. The interaction between mycorrhizal fungi and other soil organisms are complex and often poorly understood; they may be inhibitory or stimulatory [28].

The PGPR interact with mycorrhiza in the mycorrhizosphere. Inoculation of *Glomus faciculatum* has shown a positive influence on actinomycetes population in tomato rhizosphere. The survival of *Azotobacter paspali increasedin* mycorrhizosphere [4]. 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 [68]. The relationship between Phosphate-Solubilizing Bacteria (PSB) and AMF is well reported [5]. The PSB can survive longer in root's mycorrhizosphere. A plant with higher concentration of P benefits the bacterial symbiont and nitrogenase functioning. Dual inoculation of AMF and PSB significantly increased microbial biomass and N and P accumulation in plant tissues [4, 5]. 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) [6].

4 Examples of AMF-mediated plant disease control

Soil borne pathogens were controlled by using several agricultural methods like resistant cultivar seed certification use of fungicides and crop rotation etc. there are many problems associated with controlling pathogens with long term persistant surviving structures due to difficulties in reducing the pathogen inoculum [1]. So now many workers were trying to use alternate approach based on either manipulating or adding microorganisms to enhance plant protection ad against pathogens [37]. The protective effect of mychorrhizal symbiosis against soil borne pathogen has been tested by many workers [24] etc. They concluded that AM association can reduce the ill-effects of soil borne pathogens through following mechanisms *viz.,* enhanced plant nutrition uptake, damage compensation of plant, competition for infection or colonization sites, Anatomical and morphological changes in the root system and microbial changes in rhizosphere.

4.1 Phytopathogenic fungi

Plant pathogenic fungi contribute significantly to crop damage and hug amount of yield losses, followed by plant pathogenic bacteria and viruses. The potential of AMF to control various plant pathogenic fungi has been clearly demonstrated [7, 47]. In contrast, there are reports wherein AMF inoculation did not have any effect on disease severity [38]. In order for practical and routine use of AMF as protectors of plants against plant pathogenic fungi, AMF performance must be consistent, specific, and effective. Specificity of AMF for the control of crop diseases is crucial in order to mitigate any nontarget effects to beneficial micro-organisms.

However, there are conflicting reports on the specificity of AMF. For example, inoculation of micro propagated banana with *Glomus intraradices* and a *Glomus* spp. isolate reduced rhizome necrosis and external disease symptoms caused by *Fusarium oxysporum f. sp. cubense,* but differences between the two AMF isolates were not noted, indicating that either both AMF species were equally effective against the pathogen or that they lacked specificity[45]. In contrast, eggplant and cucumber seedlings transplanted into soils inoculated with *G. versiforme* and subsequently challenged with *Verticillium dahliae* and *Pseudomonas lacrymans* alleviated wilt symptoms caused by *V. dahliae*, but not *G. mosseae*, *Glomus* spp.-1, or *Glomus* spp.-2, indicating species-specific antagonistic symbiont– pathogen interactions [51]. Pozo *et al*., [64] demonstrated the expression of two new basic glucanase isoforms, a phytoalexin elicitor-releasing factor between *G. mosseae* and *G. intraradices* used for the control of *Phytophthora parasitica var. nicotianae*. Because of the potential of AMF as bioprotectors against phytopathogens, this is an area that needs further study. In order to enhance AMF efficacy, some researchers have used an AMF species mixture or a combination of microorganisms including AMF that act in concert to eliminate pathogens. For example, co-inoculation of groundnut with *G. fasciculatum*, *Gigaspora margarita*, *Acaulosporalaevis*, and *Sclerocystisdussii* eliminated the damaging effects of *Sclerotium rolfsii* [49]. Also, tobacco inoculated with a mixture containing *G. fasciculatum* and *Trichoderma harzianum* effectively controlled damping-off caused by *Pythium aphanidermatum* and black shank disease caused by *P. parasitica var. nicotianae* [74].

In some cases, microbial mixtures act synergistically with pesticides to result in effective control of plant diseases. A combination of wheat straw, carbendazim, *G. fasciculatum*, and *T. viride* protected safflower seedlings from the root rot pathogen *Macrophomina phaseolina*, resulting in 100% seedling survival [65]. Sharma *et al.*, [71] effectively managed ginger yellows disease caused by *F. oxysporum f. sp. zingiberi* using a combination of *G. margarita*, pine needles, and T. harzianum. The requirement of a fully established AM symbiosis for elicitation of bio protective activity by AMF has been disputed.

The invasion of phytopathogenic fungi is said to be prevented by an aggressively root colonizing AMF species, indicating that AMF root colonization was satisfactory for control of disease. For example, Feldmann and Boyle (1998) [25] found an inverse correlation between *G. etunicatum* root colonization of begonia cultivars and susceptibility to the foliar pathogen caused by the powdery mildew fungus Erysiphe *cichoracearum*. However, it was not clear whether *G. etunicatum* colonization preceded infection by *E. cichoracearum* or whether pathogen suppression was accompanied by other mechanisms of biocontrol. Using an *in vitro* system, Filion *et al*. (1999) [6] demonstrated that extracts from the extraradical mycelium of *G. intraradices* reduced the conidial germination of *F. oxysporum f. sp. chrysanthemi*. Alternatively, alterations in the chemical equilibrium of the mycorrhizosphere may have resulted in pathogen control. In another study, pea mutants defective for mycorrhization and nodulation challenged with Aphanomyces euteiches required a fully established AMF symbiosis for protection against the pathogen [72].

Several researchers have been also demonstrated AMF mediated reduction of root rot disease in cereal crops [79] and take-all disease of wheat [31, 32]. *Phytophthora* spp., which cause diseases in a variety of plants have been model systems for AMF-mediated plant disease control. Using the AMF species *G. intraradices* and pathogen *F. oxysporum f. sp. Lycopersici* on tomato, Caron and co-workers have shown that the growth medium used (Caron *et al.*, 1985) [16], the application of P (Caron *et al*., 1986a) [13], and pre-treatment of the growth medium with AMF (Caron *et al.*, 1986c) [15]may influence disease severity. Despite proof of AMF potential in controlling plant diseases, few published reports have successfully demonstrated biological control of plant pathogens by AMF in the field (Bodker *et al*., [8] showed that pre-inoculating the annual grass *Vulpiaciliata var. ambigua* with an indigenous *Glomus* sp. and re-introducing the grass into a natural grass population extended a favourable effect against an indigenous *F. oxysporum*. Onion pretreated with *Glomus sp. Zac-19* delayed the development of onion white rot caused by *S. cepivorum* by two weeks in the field and protected onion plants for 11 weeks after transplanting in the field and resulted in a yield increase of 22% [80].

One of the first reports on the effect of indigenous AMF on the development of introduced *A. euteiches* infection and disease development on field-grown pea [8] showed that there was no correlation between AMF root colonization and disease incidence or severity, and emphasized the importance of field evaluations for authenticating the use of AMF as biocontrol agents. Although the indigenous AMF community composition was not described, this study underscores the importance of a richly diverse indigenous AMF community to defend plants from plant pathogens. Thus, there appears to be tremendous potential for AMF control of plant pathogens and the need for more detailed and well-planned and executed studies that will address problems of inconsistent and unreliable results.

4.2 Plant pathogenic bacteria

The AMF interact with functionally diverse bacteria such as diazotrophs, biological control agents, and other commonrhizosphere inhabitants (Nemec 1994) [59] that often result in significant changesin plant growth, yield, and nutrition. Interactions between mycorrhizal fungi and bacteria may have negative (Filion *et al.*, 1999) [6] beneficial effects (Edwards *et al.*, 1998), or have no effect at all on the plant pathogenic bacterium (Otto and Winkler 1995) [60]. *Glomus mosseae* prohibited the infection of soybean plants by *P. syringae* (Shalaby and Hanna 1998) [70], by suppressing the population density of the pathogen in soybean rhizosphere. Li *et al*. (1997) also reported that the *G. macrocarpum* reduced the infection percent caused by *P. lacrymans* in eggplant and cucumber, although no positive growth or yield effect was noted, indicating tolerance to the pathogen as a possible mode of action. Inoculation of mulberry with *G. fasciculatum*or *G. mosseae* in combination with 60–90kg of P per hectare per year reduced the incidence of bacterial blight caused by *P. syringae*pv. *Mori* (Sharma 1995) [71]. Inoculation of grapevines with AMF reduced the number of *Pseudomonads fluorescent* on the rhizoplane thereby reducing the incidence of grapevine replant disease (Waschkies *et al.*, 1994) [85]. Otto and Winkler (1995) [60] Similarly result was also found that reduction in the colonization of apple seedling rootlets by *actinomycetes* causing replant disease was reported, while a proportionate increase in root colonization by AMF.

4.3 Phytopathogenic viruses

Viruses remain the least studied amongst all the plant disease causing target organisms listed for mycorrhizae-mediated biocontrol. The general response of mycorrhizal plants to the occurrence of viral pathogens is as follows: (a) mycorrhizal plants apparently enhanced the rate of multiplication of viruses in some plants (Nemec and Myhre 1984) [59], (b) more leaf lesions were found on mycorrhizal plants than on nonmycorrhizal plants [23], and (c) the number of AMF spores in the rhizosphere was reduced considerably [46, 59]. Enhanced viral multiplication and activity in mycorrhizal plants is speculated to be attributed to higher P levels compared to nonmycorrhizal plants. A similar effect was noted in nonmycorrhizal plants fertilized with plants. Some workers found that host plants were more susceptible to AMF colonization following infection by a virus. For example, Schonbeck and Spengler (1979) [23] reported that following the inoculation of mycorrhizal and nonmycorrhizal tobacco (*Nicotiana glutinosa* L.) with *Tobacco mosaic virus* (*TMV*), mycorrhizal plants exhibited higher levels of AMF colonization. In contrast, mung bean *yellow mosaic bigeminy virus* reduced the AMF colonization and yield of mycorrhizal plants (Jayaraman *et al.*, 1995) [46], while lack of response to viral infection by a mycorrhizal host was also demonstrated [78]. Early studies using electron microscopy revealed that mycorrhizae were not viral vectors because virus particles were absent in the AMF hyphae and around arbuscules, suggesting that AMF did not interact with viruses [44]. Thus, potential for the biocontrol of plant pathogenic viruses using mycorrhizae does not appear to be promising. However, it may be worthwhile to investigate the role of viruses in the reduction of mycorrhizal colonization and related host plant effects.

5 Conclusions

Literature presents a prosperity of evidence to indicate potential for AMF-mediated control of plant diseases. While it is generally recognized that mycorrhizae aid tree growth and that they probably are necessary for survival on many sites, the reasons for this benefit are not clear. It is usually ascribed to improved nutrition by the mycorrhizal, as compared to the nonmycorrhizal rootlet. Some workers, including the writer, believe that part of this benefit results from protection of delicate root tissues by the fungus symbiont from attack by parasitic fungi. This association of AM fungi with plants improves moisture and nutrient uptake efficiency of plant species resulting in increased vigor and endurance against biotic and abiotic stresses. It helps in establishment of plant species in nutrient and moisture deficient degraded soils. It reduces the vulnerability of plant species to pathogens by various protective mechanisms like (a) enhancing biochemical Défense mechanisms (b) production of plant growth hormones and antibiotics (c) altering root exudates as well as microbial population of mycorrhizosphere (d) utilizing surplus carbohydrates and thus reducing attractiveness of the root to pathogens, (e) serving as a physical barrier to infection, (f) secreting antibiotics, and (g) favouring. Visible aboveground symptoms often develop quickly following injury to roots. Forest soil, however, is a complex and variable ecosystem not easily studied. Disorders of fine roots, especially those involving delicate, un rubberized tissues, are difficult to discover and to inspect. Above-ground symptoms in older trees appear slowly and may escape detection until contributory factors hasten dying and obscure primary injury. Nevertheless, the pathologist must seek a better understanding of this important but long neglected segment of the root system. It is here that he may find the answers to many puzzling decline diseases confronting the forester today. In the future, mycorrhizosphere management must become one of the viable and well ecosystem friendly solutions to managing plant diseases and reducing pathogen inoculum. Thus, mycorrhizal incorporation can be considered as an important component of integrated disease management.

6. References

1. Abdalla ME, Abdel-Fattah GM. Influence of the endomycorrhizal fungus *Glomus mosseae* on the development of peanut pod rot disease in Egypt. Mycorrhizae. 2000; 10:29-35.
2. Area JM, Azcon R, Azcon-Aguilar C. Mycorrhizosphere interactions to improve plant fitness and soil quality. Antonie Van Leeuwenhoek. 2002b; 81:343-351.
3. Azcon-Aguilar C, Barea JM. Interactions between mycorrhizal fungi and other rhizosphere microorganisms. In: Allen MF ed. Mycorrhizal Functioning: An Integrative Plant-Fungal Process. New York: Chapman and Hall, 1992, 163-198.
4. Barea JM, Azcon R, Azcon-Aguilar C. Mycorrhiza and crops. Adv. Plant Pathol. 1993; 9:167-189.
5. Barea JM, Toro M, Orozco MO, Campos E, Azcon R. The application of isotopic (32P and N15). 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. 2002a; 63:3542.
6. Barea JM. 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, 1997, 150-158.
7. Becker DM, Bagley ST, Podila GK. Effects of mycorrhizal-associated streptomycetes on growth of *Laccariabicolor*, *Cenococcumgeophilum*, and *Armillaria* species and on gene expression in Laccariabicolor. Mycologia.1999; 91:33-40.
8. Bodker L, Kjoller R, and Rosendahl S. Effect of phosphate and the arbuscular mycorrhizal fungus *Glomus intraradices* on disease severity of root rot of peas (*Pisum sativum*) caused by *Aphanomyces euteiches*. Mycorrhiza. 1998; 8:169-174
9. Boyetchko SM and Tewari JP. The effect of VA mycorrhizal fungi on infection by *Bipolarissorokiniana* in barley. Can J Plant Pathol.1998; 10:361. [Abstr]
10. Brejda JJ, Moser LE, Vogel KP. Evaluation of switchgrass rhizosphere microflora for enhancing seedling yield and nutrient uptake. Agron Journal.1998; 90:753-758.
11. Brendan NA, Hammerschmidt R, Safir GR. Postharvest suppression of potato dry rot (Fusarium sambucinum) in prenuclear minitubers by arbuscular mycorrhizal fungal inoculum. Am Potato Journal.1996; 73:509-515.
12. Budi SW, van Tuinen D, Martinotti G, Gianinazzi S. Isolation from the *Sorghum bicolor* mycorrhizosphere of a bacterium compatible with arbuscular mycorrhiza development and antagonistic towards soilborne fungal pathogens. Appl Environ Microbiol. 1999; 65:5148-5150.
13. Caron M, Fortin JA, Richard C. Effect of *Glomus intraradices* on the infection by *Fusarium oxysporum f. sp. radicis-lycopersici* in tomatoes over a 12-week period. Can J. Bot. 1986a; 64:552-556.
14. Caron M, Fortin JA, and Richard C. Effect of phosphorus concentration and *Glomus intraradices* on Fusarium crown and root rot of tomatoes. Phytopathology. 1986a; 76:942-946.
15. Caron M, Fortin JA, Richard C. Effect of pre-infestation of the soil by a vesicular-arbuscular mycorrhizal fungus, *Glomus intraradices*, on Fusarium crown and root rot of tomatoes. Phytoprotection. 1986c; 67:15-19.
16. Caron M, Fortin JA, Richard C. Influence of substrate on the interaction of Glomus intraradicesand Fusarium oxysporum f. sp. radicis-lycopersici on tomatoes. Plant Soil. 1985; 87:233-239.

17. Caron M. Potential use of mycorrhizae in control of soil-borne diseases. Can J Plant Pathol. 1989a; 11:177-179.
18. Clark RB. Arbuscular mycorrhizal adaptation, spore germination, root colonization and host plant growth and mineral acquisition at low pH. Plant Soil. 1997; 192:1522.
19. Cordier C, Pozo MJ, Barea JM, Gianinazzi S, Gianinazzi Pearson V. Cell defense responses associated with localized and systemic resistance to *Phytophthora* induced in tomato by an arbuscular mycorrhizal fungus. Mol. Plant-Microb. Interact. 1998; 11:1017-1028.
20. Daniels BA, Menge JA.Hyperparasitization by *Anquillosporapseudo longissima* and *Humicola fusco art* of vesicular-arbuscular mycorrhizal fungi *Glomus epigaeus* and *Glomus fasciculatus*. Phytopathology. 1980; 70:584-588.
21. Davis RM, Menge JA. Phytophthora parasitica inoculation and intensity of vesicular-arbuscular mycorrhizae in citrus. New Phytol. 1981; 87:705-715.
22. Declerck S, Risede JM, Ruflikiri G, Delvaux B. Effects of arbuscular mycorrhizal fungi on severity of root rot of bananas caused by *Cylindrocladium spathiphylli*. Plant Pathol. 2002; 51:109-115.
23. Dehne HW, Schonbeck F. The influence of endotrophic mycorrhiza on plant diseases. II. Phenol metabolism and lignification *Fusarium oxysporum*. Untersuchungenzum Einfluss der endotrophen Mycorrhiza auf Pflanzenkrankheiten. II. Phenolstoffwechsel und Lignifizierung. Phytopathol-Z. 1979; 95:210-216.
24. Erman M, Demirb S, Ocakc E, Tufenkc SE, O‘guza F, Akkoprub A. Effects of Rhizobium, Arbuscular Mycorrhiza and whey applications on some properties in 83 chickpea (*Cicer arietinum* L.) under irrigated and rainfed conditions on yield components, nodulation and AMF colonization. Field Crops Research. 2011; 122:1424.
25. Feldmann F, Boyle C. Concurrent development of arbuscular mycorrhizal colonization and powdery mildew infection on three Begonia hiemalis cultivars. Z Pflanzenkr Pflanzenschutz. 1988; 105:121-129.
26. Filion M, St. Arnaud M, and Fortin JA. Direct interaction between the arbuscular mycorrhizal fungus Glomus intraradices and different rhizosphere microorganisms. New Phyto. 1999; 141:525-533.
27. Filion M, St. Arnaud M, and Fortin JA. Direct interaction between the arbuscular mycorrhizal fungus *Glomus intraradices* and different rhizosphere microorganisms. New Phytol. 1999; 141:525-533.
28. Fitter AH, Grabaye J. Interactions between mycorrhizal fungi and other soil organisms. Plant Soil 1994; 159:123-132.
29. Frank AB, Ueber die auf Wurzelsymbioseberuhende Ernahrunggewisser Baume durchunterirdische Pilze, Ber. Deut. Botan. Ges. 1885; 3:12845.
30. Garbaye J. Helper bacteria: a new dimension to the mycorrhizal symbiosis. *New Phytologist*. 1994; 128:197-210.
31. Graham JH, Menge JA. Influence of vesicular-arbuscular mycorrhizae and soil phosphorus on take-all disease of wheat. Phytopathology. 1982; 72:95-98.
32. Graham JH, Menge JA. Influence of vesicular-arbuscular mycorrhizae and soil phosphorus on take-all disease of wheat. Phytopathology. 1982; 72:95-98
33. Graham JH, Menge JA. Influence of vesicular-arbuscular mycorrhizae and soil phosphorus on take-all disease of wheat. Phytopathology. 1982; 72:95-98.
34. Graham JH, Leonard RT, Menge JA. Membranemediated decrease in root exudation responsible for inhibition of vesicular-arbuscular mycorrhiza formation. Plant Physiol. 1981; 68:548-552.
35. Graham TL, Graham MY. Cellular coordination of molecular responses in plant defense. Mol Plant-Microb Interact. 1991; 4:415-422.
36. Grey WE, Van Leur JAG, Kashour G, El-Naimi M. The interaction of vesicular-arbuscular mycorrhizae and common root rot (Cochliobolus sativus) in barley. Rachis. 1989; 8:18-20.
37. Grosch R, Lottmann J, Faltin F, Berg G. Use of bacterial antagonists to control diseases caused by *Rhizoctoniasolani*. *Gesunde P flanzen*. 2005; 57:199-205.
38. Guillon C, St-Arnaud M, Hamel C, Jabaji-Hare SH. Differential and systemic alteration of defence-related gene transcript levels in mycorrhizal bean plants infected with Rhizoctonia solani. Can J Bot. 2002; 80:305-315.
39. Handelsman J, Stabb EV. Biocontrol of soilborne plant pathogens. Plant Cell. 1996; 8:1855-1869.
40. Harrier LA, Watson CA. The potential role of Arbuscular Mycorrhizal (AM) fungi in the bio protection of plants against soil-borne pathogens in organic and/or other sustainable farming systems. Pest Manage. Sci. 2004; 60:149-157.
41. Harrison MJ, Dixon RA. Isoflavonoid accumulation and expression of defense gene transcripts during the establishment of VA mycorrhizal associations in roots of *Medicago truncatula*. Mol. Plant-Microb. Interact. 1993; 6:643-654.
42. Heike G, Von Alten H, Poehling HM. Arbuscular mycorrhiza increased the activity of a biotrophic leaf pathogen: is a compensation possible? Mycorrhiza. 2001; 11:237-243.
43. Hwang SF. Effect of VA mycorrhizae and metalaxyl on growth of alfalfa seedlings in soils from fields with "*alfalfa sickness*" in Alberta. Plant Dis. 1988; 72:448-452.
44. Jabaji-Hare SH, Stobbs LW. Electron microscopic examination of tomato roots coinfected with *Glomus* sp. And *Tobacco mosaic virus*. Phytopathology. 1984; 74:277-279.
45. Jaizme-Vega MC, Sosa-Hernandez B, Hernandez JM, and Galan Sauco V. Interaction of arbuscular mycorrhizal fungi and the soil pathogen *Fusarium oxysporum f. sp. cubense* on the first stages of micro-propagated Grande Naine banana. Acta-Hortic. 1989; 490:285-295.
46. Jayaraman J, Kumar D, Jayaraman J, Kumar D. Influence of *Mungbean yellow mosaic virus* on mycorrhizal fungi associated with Vigna radiata var. PS 16. Ind Phytopathol. 1995; 48:108-110.
47. Kasiamdari RS, Smith SE, Smith FA, Scott ES. Influence of the mycorrhizal fungus, Glomus coronatum, and soil phosphorus on infection and disease caused by *binucleate Rhizoctonia* and *Rhizoctonia solani* on mung bean (Vigna radiata). Plant Soil. 2002; 238:235-244.
48. Kaye JW, Pfleger FL, Stewart EL. Interaction of *Glomus fasciculatum* and *Pythium ultimum* on greenhouse-grown poinsettia. Can J Bot. 1984; 62:1575-1579.
49. Kulkarni SA, Kulkarni S, Sreenivas MN, and Kulkarni S. Interaction between vesicular-arbuscular (VA)

mycorrhizae and *Sclerotium rolfsii Sacc.* in groundnut. Karnataka J Agric Sci.1997; 10:919-921.
50. Lambert DH, Baker DE, Cole HJ. The role of mycorrhizae in the interactions of phosphorus with zinc, copper and other elements. Soil Sci. Soc. Am. J. 1979; 43:976-980.
51. Li SL, Zhao SJ, Zhao LZ, Li SL, Zhao SJ, Zhao LZ. Effects of VA mycorrhizae on the growth of eggplant and cucumber and control of diseases. Acta Phytophylac Sin. 1997; 24:117-120.
52. Liu RJ, Liu HF, Shen CY, Chiu WF. Detection of pathogenesis-related proteins in cotton plants. Physiol Mol Plant Pathol. 1995; 47:357-363.
53. Malajczuk N, McComb AJ. The microflora of unsuberized roots of *Eucalyptus calophylla R. Br.* and *Eucalyptus marginata Donn ex Sm.* seedlings grown in soil suppressive and conducive to *Phytophthora cinnamomi* Rands. I. Rhizosphere bacteria, actinomycetes and fungi. Aust J Bot. 1979; 27:235-254.
54. Matsubara Y, Kayukawa Y, Yano M, Fukui H. Tolerance of asparagus seedlings infected with arbuscular mycorrhizal fungus to violetroot rotcaused by *Helicobasidiummompa*. J. Jpn Soc. Hortic. Sci. 2000; 69:552-556.
55. McAllister CB, Garcia-Gairido JM, Garcia-Romera I, Godeas A, Ocampo JA. *In vitro* interactions between *Alternaria alternata, Fusarium equiseti and* Glomus mosseae. Symbiosis. 1996; 20:163-174.
56. Meyer JR, Linderman RG. Response of subterranean clover to dual inoculation with vesicular-arbuscular mycorrhizal fungi and a plant growth promoting *bacterium Pseudomonas putida*. Soil BiolBiochem. 1986; 18:185-190.
57. Mukerji KG. Rhizosphere biology. In: Mukerji KG, Manoharachary C, Chamola BP. (eds.) Techniques in Mycorrhizal studies. Kluwer Academic Publishers, Dordrecht, The Netherlands, 2002b, 87-101
58. Mukerji KG, Upadhyay RK, Kaushik A, Mycorrhiza, integrated disease management. In Upadhyay RK, Mukerji KG, Rajak RL. (eds.) IPM system in Agriculture vol.2, Biocontrol in emerging biotechnology. Aditya Books, New Delhi, 1996, 423-452.
59. Nemec S. Soil microflora associated with pot cultures of *Glomus intraradix*-infected *Citrus reticulata*. Agric Ecosyst Environ. 1994; 1:299-306.
60. Otto G and Winkler H. Colonization of rootlets of some species of Rosaceae by *actinomycetes*, endotrophic mycorrhiza, and endophytic nematodes in a soil conducive to specific cherry replant disease. Z Pflanzenkr Pflanzenschutz. 1995; 102:63-68.
61. Paxton JD. Phytoalexins-a working redefinition. Phytopathol Z. 1981; 101:106-109.
62. Peterson RL, Massicotte HB, Melville LH. Mycorrhizas: Anatomy and Cell Biology. NCR Research Press, Ottawa, Canada, 2004, 173.
63. Pozo MJ, Azcon-Aguilar C, Dumas-Gaudot E, and Barea JM. b-1,3-glucanase activities in tomato roots inoculated with arbuscular mycorrhizal fungi and/or *Phytophthora parasitica* and their possible involvement in bioprotection. Plant Sci. 1991; 141:149-157.
64. Pozo MJ, Azcon-Aguilar C, Dumas-Gaudot E, Barea JM. b-1,3-glucanase activities in tomato roots inoculated with arbuscular mycorrhizal fungi and/or Phytophthora parasitica and their possible involvement in bioprotection. Plant Sci. 1999; 141:149-157.
65. Prashanthi SK, Kulkarni S, Sreenivasa MN, Kulkarni S. Integrated management of root rot disease of safflower caused by *Rhizoctonia bataticola*. Environ Ecol. 1997; 15:800-802.
66. Rempel CB and Bernier CC. *Glomus intraradices* and *Cochliobolus sativus* interactions in wheat grown under two moisture regimes. Can J Plant Pathol. 1990; 12:338, [Abstr].
67. Schwab SM, Leonard RT, Menge JA. Quantitative and qualitative comparison of root exudates of mycorrhizal and nonmycorrhizal plant species. Can J Bot. 1983; 62:1227-1231.
68. Secilia J, Bagyaraj DJ. Bacteria and actinomycetes associated with pot cultures of vesicular-arbuscular mycorrhizas. Can. J Microbiol.1987; 33:1069-1073.
69. Sempavalan J, Wheeler CT, Hooker JE. Lack of competition between Frankia and *Glomus* for infection and colonization of roots of *Casuarina equisetifolia*. New Phytol. 1995; 130:429-436.
70. Shalaby AM, Hanna MM. Preliminary studies on interactions between VA mycorrhizal fungus *Glomus mosseae*, *Bradyrhizobium japonicum* and *Pseudomonas syringae* in soybean plants. Acta Microbiol Pol. 1998; 47:385-391.
71. Sharma S, Dohroo NP, Sharma S. Management of ginger yellows through organic amendment, fungicide seed treatment and biological methods. Ind Cocoa Arecanut Spice J. 1997; 21:29-30.
72. Slezack S, Dumas-Gaudot E, Paynot M, Gianinazzi S. Is a fully established arbuscular mycorrhizal symbiosis required for bioprotection of *Pisum sativum* roots against *Aphanomyces euteiches*. Mol Plant-Microbe Interact. 2000; 13:238-241.
73. Smith SE, Read DJ. Mycorrhizal Symbiosis. 2nd Edn., Academic Press, London, UK., ISBN-13: 978-0-12652840-4, 1997, 605.
74. Sreeramulu KR, Onkarappa T, Swamy HN. Biocontrol of damping off and black shank disease in tobacco nursery. Tob Res. 1998; 24:1-4.
75. Stafford HA. Flavonoid Metabolism. Boca Raton, FL: CRC Press, 1992, 202-207.
76. Stewart EL, Pfleger FL. Development of poinsettia as influence by endomycorrhizae, fertilizer, and root rot pathogens, *Pythium ultimum* and *Rhizoctonia solani*. Flor Rev. 1977; 159:79-80.
77. Sundaresan P, Raja NU, Gunasekaran P. Induction and accumulation of phytoalexins in cowpea roots infected with a mycorrhizal fungus *Glomus fasciculatum* and their resistance to Fusarium wilt disease. J Biosci. 1993; 18:291-301.
78. Takahashi T, Katano H, Yoshikawa N. Evidence for vesicular-arbuscular mycorrhizal infection in viroid-infected hop root tissues. Z Pflanzenkr Pflanzenschutz. 1994; 101:267-271.
79. Thompson JP, Wildermuth GB. Colonization of crop and pasture species with vesicular-arbuscular mycorrhizal fungi and negative correlation with root infection by *Bipolarissorokiniana*. Can J Bot. 1989; 69:687-693.
80. Torres-Barragan A, Zavaleta-Mejia E, Gonzalez-Chavez C, and Ferrera-Cerrato R. The use of arbuscular mycorrhizae to control onion white rot (*Sclerotium cepivorum* Berk.) under field conditions. Mycorrhiza. 1996; 6:253-258.
81. Trappe JM, Fogel RD. Ecosystematic functions of mycorrhizae. In: J. K. Marshall, (Ed.). The Belowground

Ecosystem: A Synthesis of Plant-Associated Processes. Range Science Department Science Series No. Colorado State University, Fort Collins, CO. 1977; 26:205-214.

82. Van Etten HD, Mansfield JW, Bailey JA, and Farmer EE. Two classes of plant antibiotics: phytoalexins versus "*phytoanticipins.*" Plant Cell. 1995; 6:1191-1192.
83. Volpin H, Phillips DA, Okon Y, Kapulnik Y. Suppression of an isoflavonoid phytoalexin defense response in mycorrhizal alfalfa roots. Plant Physiol. 1995; 108:1449-1454.
84. Wani SP, McGill WB, Tewari JP. Mycorrhizal and common root-rot infection, and nutrient accumulation in barley grown on Breton loam using N from biological fixation or fertilizer. BiolFertil Soils. 1991; 12:46-54.
85. Waschkies C, Schropp A, Marschner H. Relations between grapevine replant disease and root colonization of grapevine (Vitis sp.) by *fluorescent pseudomonads* and endomycorrhizal fungi. Plant Soil. 1994; 162:219-227.
86. Wyss P, Boller T, Wiemken A. Experientia. 1997; 47:395-399.
87. Zambolin L, Schenck NC. Reduction of the effects of pathogenic root-infecting fungi on soybean by the mycorrhizal fungus, *Glomus mosseae*. Phytopathology. 1983; 73:1402-1405.