Chapter

# Role of Mycorrhizae in Crop Protection

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## Abstract

Mychorrizae are indigenous soil fungi that are found associated symbiotically with plant root system. They promote growth of the root system by protecting the plant from pathogen attack, acting directly or indirectly as biocontrol agents and offering plant resistance. These group of rhizosphere fungi also benefit from various biosynthetic substances produced by the root of the plant (root exudates). In this chapter, attempt is being made to present a balanced account of the various roles these fungi play in plant protection. This will give our cherish readers the opportunity to appreciate the mycorrhizal fungi as potential biocontrol agents or bioprotectants of soilborne plant pathogens.

**Keywords:** mycorrhizae, mycorrhizal fungi, bioprotectant, biocontrol agents, rhizosphere fungi

## 1. Introduction

With ever increasing world population and its impact, there is a significant pressure to feed the world by agriculturists. Demand for growth of major agriculture commodities is imperative. One major component that militate against achieving this objective is the effort by pests and diseases to reduce yield of agriculture crop production. The impact of both biotic and abiotic stress on production has a greater effect on our aim of increasing agricultural productivity. Many management practices especially pesticides application to mitigate pests and diseases incidence have directly negative influence on the surrounding environment [1, 2].

Pesticides use is regarded as one of the major and common agricultural management practices with a growing evidence of negative impacts on the ecosystem for their application. Any form of synthetic pesticides used ends up creating environmental as well as health concerns. These products may find their way contaminating water bodies resulting in contamination to human and aquatic lives, residual in agricultural produce, causing metabolic disorders to humans when contaminated foods are consumed. They also pose high financial cost to farmers with serious financial burden on output due to their expensive nature.

Many natural resources conservatives have called for reduction in the application of these pesticides and resort to natural, environmentally friendlier and healthy alternatives/practices that require reduction, if not complete their elimination [3, 4]. Many biological, chemical and physical factors also influence soil quality, among these are the microbial communities in the rhizosphere that contribute to soil quality thereby enhancing plant growth and health [5, 6]. The extent of microbial interaction among members have great significance. Among these microorganisms are the Plant Growth Promoting Rhizobacteria (PGPR) and the Arbuscular Mycorrhizae (AM). The later lives symbiotically with the plant in the rhizosphere due to its extensively hyphal network development thereby protecting the crop from pathogen attack [7], decreases biotic and abiotic stress and reducing disease incidence [6, 8]. Therefore, if the potentials of AM are properly harnessed in agriculture, it should be able to reduce sustainably the cost and use of synthetic pesticides in agriculture systems. This is because many soils contain the indigenous AM fungi that colonize the root systems [9], even though not all plants are dependent on Mycorrhizae, most increase yield when AM fungi are applied [10]. This is sure way to attain agricultural sustainability with the reduction in the pesticides and at the same time protecting the crops from pathogen attack and ensuring high yield. Therefore, this chapter tries to detail the role Mycorrhizae fungi play not only in protecting the plant as a biocontrol agents/bioprotectants of soil-borne pathogens but also promoting plant growth thereby realizing its full potential and ensuring maximum yield.

## 2. Importance of mycorrhizal fungi as a biocontrol agent in suppressive soils

The management of plant disease by chemical approach has been one of the classical methods in agriculture that has sustained productivity for ages. As much as this has been helpful, it has also resulted in nearly an uncontrollable levels of pesticide resistance among many plant pathogens. Also, their direct and indirect impacts have led to the destruction of non-target and beneficial soil organisms as well as raising various health concerns among human and animal populations [4, 11]. To manage this, an appreciable number of studies in recent times have focused on identifying and engineering micro-organisms (i.e., mycorrhiza, bacteria, fungi, and nematodes) that are naturally antagonistic to various plant disease causing pathogens. This approach comes as a more environmentally friendly approach to the application of synthetic pesticides [12, 13]. Among all the organisms, the mycorrhizal fungi are the commonest, largest in biomass and the most important beneficial fungi group. They also combine this with a target specific inhibitory or antagonistic reaction on various soil-borne phytopathogens [3]. By means of changing both the anatomical and morphological structures of plant roots, mycorrhizal fungi improves both the chemical and physical properties on the root-zone environment, hence activating various defensive and disease resistance systems in the plant [14]. Furthermore, they have the abilities to minimize the damage infringed by bacteria, fungi, nematode, as well as other phytopathogens of crops such as *Musa nana*, *Fragaria ananassa*, *Medicago truncatula*, *Cucumis sativus*, *Lycopersicon esculentum, Cucum ismelo*, *Olea europaea*, *Zea mays*, *Citrus reticulata*, *Solanum tuberosum*, among other plants [3, 4, 15].

Most mycorrhizal fungi, usually being present as a biotrophic symbiotic microorganisms in the soil rhizosphere usually have a common invasion and ecological niche as most soil-borne pathogens. This could mean that under fair conditions, there must be a spatial competition between pathogens and most mycorrhizal fungi. In this, mycorrhizal fungi, eg., the Arbuscular mycorrhizal fungi (AMF) have been reported to have the potential of reducing the initial and reinfection rates of most pathogens that infects the root epidemics. For example, various studies have reported some competitive relationships between the AMF and an array of plant pathogens. i.e., bacteria, fungi, and nematodes [16–19].

Mycorrhizal fungi played some significant roles in regulating plant growth and development. For example, cucumber plants were found to have some higher levels of zeatin, GA, and IAA when it was inoculated with *G. terrestris*. This increment was further observed to have a bearing with an enhancement in the plant's resistance ability to *Rhizoctonia solanacearum*. In general, mycorrhizal fungi proves significant in the development of plants by inducing synthesis of various plant signaling substances, and improving and enhancing activities of enzymes.

## 3. Mechanism of suppression of mycorrhizae bioprotectants

The production of healthy and disease-free plant and plant products with corresponding higher yield can directly or indirectly be linked with microorganisms in the soil rhizosphere. Due to the number of environmental concerns regarding the use of different biological control agents, and increasing pathogens resistant to pesticides, more stable and environmentally friendly alternatives are now been considered. AM fungi are not only useful as biofertilizers, but also as bio-stimulants due to their antagonistic capabilities against plant pathogens [20]. They are known to established symbiotic relationship with more than 80% of the plant species [21, 22]. In plant disease management, AMF has been considered as one of the reliable and available options as it is found to serve as a bioprotectant and plant stimulant in sustainable food production and ensure reduction in plant pathogen population to acceptable level without harmful effect to the environment. AMF has been used as a biological control agent in the reduction of incidence and severity of bacteria such as *Pseudomonas syringae, Erwinia carotovora* [23] and fungi such as *Fusarium* spp. [24], *Pythium* sp. [25], *Verticillium* sp. [26], *Sclerotinia* sp., *Phytophthora* sp., *Macrophomina* sp. [27], and nematodes such as *Radophulus* sp. [28].

There are numerous pathogens in the soil that cause diseases to plants and result in substantial reduction in plant yields. These pathogens have to be controlled to ensure food security around the world. Among the new and sustainable control alternatives is biological control that involve the use of antagonistic organisms to suppress damage activities of other organisms that cause diseases to plants [29]. Among the most promising biological control agents is the rhizosphere-competent fungi called mycorrhizae, which is capable of suppressing the activity of disease-causing organisms both major and minor beside their role in stimulating plant growth response. The roots of most plants are in symbiotic association with certain soil fungi and this association is called mycorrhiza [30]. The mycorrhiza has number of functions that include enhancement of nutrient uptake, improvement of soil structure and plant establishment, protection of plants against environmental stresses and suppression of plant diseases [31].

Plant roots colonization by AMF usually results in the decrease of the incidence and severity of the diseases caused by pathogens. The reduction in damage by AMF maybe as a result of changes in the morphology and plant root growth, biochemical and physiological changes in the plant, histopathological changes in the plant root, mycorrhizosphere effects that results in the modification of microbial population density, activation of host defense mechanisms, parasitism of nematodes by AMF and competition for photosynthetic products and colonization sites [32]. Among the various proposed biocontrol mechanisms for the plant diseases, the most effective biocontrol scheme could either be the result of all the mechanisms working together or as a separate entity. The major limitation in the use of AMF as a biocontrol agent could culminate from its obligate nature, the role of environmental influence on the various mycorrhiza symbiotic associations and limited understanding of the mechanism involved in the interaction processes. The objective of this chapter is therefore to throw more light on the mechanism of suppression of mycorrhizae bioprotectants.

Protection of plants by mycorrhizal fungi against disease causing organisms involves multiple mechanisms that include: production and changes in the exudation pattern, formation of physical barrier (fungal mantle) around the roots and synthesis of anti-fungal compounds by the plant roots in response to mycorrhiza symbiotic association [33]. For example, *Paxillus involutus* (Ectomycorrhizal fungi) was reported to successfully controlled *Fusarium moniliforme* and *Fusarium oxysporum* causing rot disease in *Pinus resinosa* as well as *Pisolithus tinctorius* (Ectomycorrhizal fungi) in controlling *Phytophthora cinnamomi* causing disease in sand pine [34]. Specific form of disease suppression may result from the activity of one or few antagonistic microbes.

The symbiotic association of AMF has been reported to induce plant host defense response both at early and later stage of invasion by the pathogen [35]. There have been reports of quick response in terms of plant host defense to pathogens by the mycorrhizal associated plants compare to those devoid of this symbiotic relationship and for that matter, AMF colonization has been proposed to act as a priming scheme for the pathogen resistance process [36, 37].

In a related defensive mechanism against plant pathogens, AM fungi have been involved in the activation of the plant defense response against pathogens and this include the expression of number of genes with their matching proteins (e.g., phenolics, cellulose deposition, chitinases, hydroxyproline-rich glycoproteins, phytoalexins, peroxidases and proteins relating to pathogenicity) [38, 39]. Both localized and systemic resistance to *Phytophthora parasitica* has been reported in tomato root system [40], Pathogenesis-related proteins are involved in triggering of the Systemic acquired resistance (SAR) defense mechanism [41]. The pathogen *Aphanomyces euteiches* causing disease on garden pea was biologically controlled after pre gene activation of the host defense response by mycorrhiza-related chitinolytic enzymes [38].

Mycorrhization have been recorded to change plant root exudation pattern and these alterations could indirectly affect the pathogen through alteration of the pH of soil environment or through production of inhibitory products. In a study involving symbiotic association of strawberry with mycorrhiza fungi, exudates released by the roots of the strawberry had shown to suppress the growth and sporulation of *Phytophthora fragariae* [42], as well as affect the germination of microconidia produced by *Fusarium oxysporum* in a related experiment [43, 44]. There is also evidence of direct antagonistic action by AMF against pathogens in the soil rhizosphere [45, 46].

In terms of improvement in the nutritional status or reduction of plant root damage by the pathogen, the increase supply of nutrient by mycorrhiza fungi to plants have been suggested to enhanced their tolerance level to pathogen damage and carbon drain from plants to the pathogen. AMF absorb nutrient via the external network of fungi hypha by solubilizing both macro and micro elements like Mn, Ca, Zn, Cu, N and P [47–49]. This nutrient uptake ensures healthy growth of the plant due readily or available nutrients supply to the plant that enhances the tolerance or resistance level of the plant to the pathogens [50]. The mycorrhizal fungi increase the rate at which phosphorous is absorbed by increasing the surface area, number of roots, growth and development of plant root hairs. The increase in phosphorous uptake in plant-mycorrhizal symbiotic relationship constitute the major mechanism for the AMF-mediated biocontrol [51].

With regards to the morphological alteration of the plant roots, mycorrhization has been reported to cause some changes in the morphology of the roots in spatial, structural, temporal and quantitative way [52, 53]. The AM produce arbuscles and vesicles both inter and intracellularly within plant root. Any pathogen that encounters with ectomycorrhizal fungus has to first of all deal with the external and multilayer network of hyphae known as mantle and inner cortical cells which serve as physical barrier to invasive pathogens and play a critical role in enhancing the population of the useful microorganisms in the soil with corresponding production of growth promoting elements by PGPRs that increase the plant resistance to pathogens [54–56]. In aromatic plant (e.g., basil), the root length and toot tip numbers, level of branching and fresh weight of the plant have been reported to be altered independently based on the type of AMF involving in the colonization process [53].

Plant roots colonized by AM fungi have enlarged length and diameter with profuse branches [57, 58]. Plant roots were found to accumulate an increased deposition of lignin and chitinases content [59] as well increase the resistance of plant root system to pathogens when in association with AM fungi. Incidence and severity of diseases caused by *Phytophthora parasitica* were found to decrease in AMF association with plant as compare with non-mycorrhizal roots [22]. AMF associated plants produced a lot of arginine that were found to suppress Thielaviopsis spore formation and large amount of proteins, phytoalexins and peroxidases [58, 60, 61] that induce plant resistance to pathogens.

AMF is found to prevent infection of the root during root colonization by decreasing the access sites to the pathogen as well as stimulate plant host defense mechanism as it was reported in reducing the incidence and severity of root-knot nematodes [62]. Number of mechanisms have been reported to increase stress tolerance of plants by AM fungi and this include the formation of a complex network hypha by AM fungi around the plant roots that block intruding pathogens. In an apple seedling trial, an apple replant disease triggered by phytotoxic myxomycetes has been successfully suppressed by AM fungi such as *Glomus fasciculatum* and *G. macrocarpum* [63]. AMF are also known to provide protection to plants against pathogenic bacteria that affect roots in the soil. Disease caused by *P. syringae* on tomato plant have been drastically reduced in plant-mycorrhiza symbiotic association [23, 33]. The various protective and suppressive mechanisms involve in this include: indirect effects (chemical interactions; physical protection); and indirect mechanisms e.g., isoflavonoids, increase nutrition uptake by plants; changes in the morphology of the plant roots by increased lignification.

Competition by AMF with pathogens for infection site on the plant root is well documented. In the competition for the site, AMF usually inhabit the location on the plant root surface where the pathogen require to penetrate the root or it pre-establishes itself in the cells so that the site cannot be occupied by any new invasive pathogen [40, 64]. In other cases, Mycorrhizal fungi and pathogens causing plant diseases, more often than not live in the same niche that bring them into physical contact to compete for the limited resources (nutrient and space) in the rhizosphere [65]. AMF is also known to compete with the other pathogens for carbon. The AMF colonize the roots of the plants and make use of the carbohydrate from the plant, thereby leaving limited amount of carbon to be utilized by the competing pathogen and this explains the rationale behind the biocontrol strategy implore by AM fungi [36, 66, 67]. There are diverse AMF species that show different carbon sink strength in the roots of plants associated with mycorrhiza and thus have shown different inhibitory or antagonistic effect against plant pathogens [68, 69]. For example, in nematode trial, *Meloidogyne incognita* reproduction factor was found to be reduced when in association with AMF prior to inoculation [70]. Elucidation and protective capability of the mycorrhizal symbiotic association with variable expression of the traits in relation to their ability to protect plants have been well documented [16]. AM fungi in association with plants results in biochemical changes in host tissues, reduction in plant stress, uptake of phytonutrients, changes in plant root anatomy and morphology, trigger systemic resistance, and competition for the limited resources such as nutrient and space [40].

## 4. Action of AM fungi against plant pathogens

With increasing cost of pesticides and the negative effect of this on human health and the environment as well as pathogen resistance, AM fungi offers potential for more sustainable and environmentally friendlier alternative for sustainable agriculture. These fungi are nevertheless most important habitat of the rhizosphere and their activity has direct influence on disease incidence and severity especially on root diseases [71]. There are several reports of possible use of AM fungi in the biocontrol of plant diseases [72–74]. One communality among all these reported evidence are that, AM interactions with plant pathogens tends to reduce their damage to plants caused by fungi and nematodes; a symbiotic association with these plants enhances resistance or tolerance.

In the interaction between AM fungi and plant parasitic nematodes (PPM), for instance, the PPM are known to be very common agricultural soil inhabitants world over and cause extensive damages to many crop species. By their actions, they can be ectoparasites or endoparasites (semi-endoparasites and migratory endoparasites), sedentary endoparasites and causes about 50–60% yield losses and many often these damages are aggravated when other pathogens capitalize on them to cause severe diseases.

Both the nematodes and AM fungi tend to stablish relationship in the rhizosphere due to their common interest in nutrient provided by the host plant. The interaction between these two would have opposite effect on growth and yield that will tend to favor the host plant [75].

Also, plant pathogenic fungi are one of the common occupants of the soil matrix and causes wide range soil-borne diseases. The soil serves as host to these pathogens and cause severe damages to the roots of susceptible hosts. Soil-borne diseases caused by phytopathogenic fungi are also difficult to control due to their ability to develop over seasoning structures such as chlamydospore, sclerotia, rhizomorph, etc. The presence of AM fungi and their interaction with these plant pathogenic fungi in the rhizosphere gives the advantage to the AM fungi to exert its s opposite effect/influence on the plant pathogenic fungi thereby protecting the plant from their attacks, promoting plant growth and enhancing yield of the plant [76, 77].

Finally, there also reports on several other plant pathogens establishing opposite relationship with the AM fungi such as the bacteria, mycoplasma, plant viruses etc. thereby reducing disease incidence and severity in their interactions with AM fungi [78, 79].

## 5. Use of mycorrhizal fungi in plant growth and disease suppression

Plants are major source of energy for both human and animals providing about 80% of food consumed by humans and primary source of nutrition for livestock. Production of adequate food to feed the ever growing global is threatened by the high prevalence of diseases caused by biotic agents such as bacteria, fungi, nematodes, viruses and oomycetes. Plant diseases reduces quantity and quality of yield, thereby affecting food security and safety of produce for consumption. It is estimated that diseases account for yield loss ranging from 13 to 22% with billions in economic losses due to inputs purchase for their management [80]. Yield and storage losses attributed to diseases have significantly been linked to global starvation and malnutrition millions of people [80, 81]. Diseases reduce yield of plants by altering several physiological process such as the absorption and transportation of water and nutrients needed for plant use, photosynthesis, flower and fruit development [82].

Plant diseases results from positive interactions of host, pathogen and environment. To overcome the negative impact of diseases on plant growth, multiple strategies have been developed and successfully used to manipulate host-pathogen interactions to favor growth of the host whilst suppressing reproduction, establishment and transmission of the pathogen. Some of the approaches to controldiseases include the use of chemicals, physical, genetic and cultural means. Host resistant approach is economical, effective and environmentally friendly, however, rapid breakdown due to continuous pathogen evolution limits its use in commercial and modern crop production tilted towards intensification and mono-cropping which provides ideal environment for pathogen evolution. In situations where reliance on resistant varieties to suppress diseases has not been achieved, utilization of chemicals have become inevitable. Chemicals are highly effective but its harsh effect on human and animal health, non-target organisms and the environment resulting from excessive use has unfortunately defeated its mass promotion and utilization. An alternative to chemical pesticide is the use of biological control. According to [83, 84], biological control limits diseases causing pathogen, improves plant immunity, modifies environment through efficient cropping systems. Biological control agents offer advantages over chemical control agents by being antagonistic to specific pathogens with less risk compared to chemical pesticides. Contrary to its benefit, application of BCAs is heavily challenged by several biotic and abiotic factors as well as frequent pathogen evolution which makes field application frequently inconsistent [85]. Notwithstanding this, recent reports have shown that application of mycorrhizal fungi strains as biological control agents is an important option to reduce threats posed by diseases.

Mycorrhizal fungi exists closely with over 80% of plants species on land offering plethora of benefits to its host. These fungi may reside within the cortex of plant roots. Mycorrhiza fungi-host association contributes significantly to carbon, nitrogen and phosphorus cycling in the ecosystem. In addition to these, mycorrhiza fungal activities improve water uptake by increasing quantity of available soil water [86] thereby improving plant productivity, diversity and contributing significantly to plant growth and fitness. According to [87] these fungi alters root morphology by increasing root branching and growth to favor root vigor due to the high nutrient uptake [88] hence influencing plant growth and yield. Mycorrhizal fungi have successfully been used and reported to increase growth and yield of several crops such as carrot [89], yam [90], maize [91].

Biocontrol by mycorrhizal strains against multiple diseases is achieved by triggering defense mechanisms in the host to improve plant tolerance to pathogens. Earlier studies [92–94] have shown improved tolerance and suppressive ability of plants to vascular diseases caused by Fusarium, Verticillium and Bacteria. Other studies have demonstrated improved tolerance of cucumber, olive, date palm, and tomato seedlings to fusarium and bacteria wilt following application of mycorrhizal strains [95, 96]. Research findings by [21, 97] showed that multiple root branching resulting from root alteration due to interaction with host reduced infection of *Phytophthora fragariae* in strawberry. Root necrosis in cowpea caused by *Rhizoctonia solani* and *Pythium aphanidermatum* in pepper were reported to decrease in the presence of both *Glomus clarum* and *Gnypeta deserticola*. Although most success has been achieved in the use of Mycorrhizal fingi (MF) to manage soil borne fungal pathogens, other works have reported on their biocontrol potential against aerial pathogens like *Alternaria solani* in tomato [37] and other necrotrophic and biotrophic pathogens [98]. Apart from fungal pathogens, suppression of Plant Parasitic Nematodes (PPN) by MF has been reported in plants such as banana, coffee and tomato [99, 100]. Similarly, [101, 102] concluded that AMF can attack soybean cyst nematodes and reduce severity of nematode infection in crops such as soybeans, cotton, cucumbers, tomatoes and citrus. MF antagonizes activities of PPN by reducing infection, reproduction and enhances tolerance. Although many research outputs have concluded on the biocontrol potential of MF, mass application in the field is sporadic due to variability in performance, on host, pathogen isolate and environmental condition [103]. There is the need therefore to improve communication on the efficacy and safety associated with MF application biocontrol agents.

## 6. Mycorrhizal fungi for sustainable agricultural systems

Sustainable agricultural systems use available natural resources to achieve acceptable level of productivity, food quality, and quantity without compromising the environmental impacts [27]. As defined, sustainable agriculture is the use of ecological sound, economic viable and socially responsible practices to obtain higher productivity, numerous plant health practices contribute to sustainable agriculture through the control of soil-borne diseases by increasing soil microbial activity thereby enhancing symbiosis, competition, and parasitism within the rhizosphere [104, 105]. The current research focus has been the search for suitable alternatives to the use commercial synthetic pesticides. Many have been achieved though, but the efficient exploration of microorganisms to improve soil fertility and at the same time enhancing plant growth and protection is being pursued.

To improve crop protection, synthetic pesticides have been used extensively to mitigate effects of pest and diseases, over reliance has been a problem and therefore biological processes that will enhance plant health such as mycorrhizae, earthworm and other symbionts should be encouraged [106, 107]. Mycorrhizae association with plants are beneficial for sustainable agriculture as they reduce pests and diseases infestation [7].

## 7. Conclusion

This chapter has demonstrated that Mycorrhizae fungi especially AM fungi play critical role in plant protection. Apart from making nutrient available for the plant uptake, AM fungi provide protection to the plant thereby enhancing plant growth and yield. The AM fungi live symbiotically with the plant by benefiting from nutrient rich environment provided by the plant in the rhizosphere and the plant also benefit from the AM fungi through deprivation of other pathogen from getting direct contact with the plant thereby enhancing its ability to resist pathogens attack.

## Conflict of interest

The authors declare no conflict of interest.

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