Chapter

Role of Fungi in Agriculture

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Abstract

Fungi are a group of eukaryotic organisms and source of food, organic acids, alcohol, antibiotics, growth-promoting substances, enzymes, and amino acids. They include microorganisms like molds, yeasts, and mushrooms. They live on dead or living plants or animals' tissue. Fungi are very different from other living organisms; they are the primary decomposers of substances in the ecological system. Fungi are tremendous decomposer of organic waste material and most readily attack cellulose, lignins, gums, and other organic complex substances. Fungi can act also under a wide range of soil reaction from acidic to alkaline soil reactions. Fungi conjointly play a basic role in different physiological processes as well as mineral and water uptake, chemical change, stomatal movement, and biosynthesis of compounds termed biostimulants, auxins, lignan, and ethylene to enhance the flexibility of plants to ascertain and cope environmental stresses like drought, salinity, heat, cold, and significant metals.

Keywords: fungi, mycorrhiza, plant growth

1. Introduction

The microorganism was used from the very beginning of the civilization in the agriculture and industrial processes even before their existence was well known. Production of fermented beverages, bread and vinegar are traditional processers practiced from the time of early civilization. Recent advancement in our understanding about the genetics, physiology, and biochemistry of fungi, has led the exploitation of fungi for preparation of different agriculture and industrial products of economic importance. All the environmental factors influence the distribution of the fungal flora of soil [1, 2].

The primary functions of filamentous fungi in the soil are to degrade organic matter and help in soil aggregation. Besides this property, bound species of *Alternaria, genus Aspergillus, Cladosporium, Dematium, Gliocladium, Humicola* and *Metarhizium* manufacture substance like organic compounds in soil and therefore could also be necessary for the maintenance of soil organic matter. Plant growth regulators and chemical fertilizers have been used to increase crop production [3, 4]. Application of chemical fertilizers to crop plants negatively affects human health and environments. Recent studies have focused on identification of alternative methods to enhance plant productivity and protect the soil. Soil borne microbes can enter roots and establish their population in plants as endophytes, and many plant-associated fungi are well known for their capacity to promote plant growth; however, the relationship between these microbes and plants is still uncertain [5]. Microorganisms have the ability to produce phytohormones, solubilize insoluble phosphate and convert complex organic substances to simple forms. Endophytic fungi have also been shown to impart plants with tolerance to salt, drought, heat and diseases [6].

The four endophytic fungi (GM-1, GM-2, GM-3, and GM-4) were tested for their ability to improve soybean plant growth under salinity stress conditions. The seed germination and plant growth were higher in seeds pretreated with endophytic fungal cultures than their controls. The positive influence of fungi on plant growth was supported by gibberellins analysis of culture filtrate (CF), which showed wide diversity and various concentrations of Gibberellic acids [7].

Application of rhizospheric fungi is an effective and environmentally friendly method of improving plant growth and controlling many plant diseases. Three predominant fungi (PNF1, PNF2, and PNF3) isolated from the rhizospheric soil of peanut plants were screened for their growth-promoting efficiency on sesame seedlings. Among these isolates, PNF2 significantly increased the shoot length and fresh weight of seedlings compared with controls. Analysis of the fungal culture filtrate showed a higher concentration of indole acetic acid in PNF2 than in the other isolates [8].

The fungal associations with plants influence the primary and secondary metabolism of plants at all developmental stages. Photosynthesis is an important primary mechanism, and the main source of energy for plants. Its efficiency is related to photosynthetic pigments such as chlorophylls and carotenoids. Leaf chlorophyll a was increased in fungi-treated plants more so than in the controls [9].

2. Role of soil fungus

The fungi dominate in low pH or slightly acidic soils where soils tend to be undisturbed [10]. Fungi break down the organic residues so many alternative sorts of microbes will begin to decompose and method the residues into usable merchandise. Approximately 90% of all plants form symbiotic mycorrhizae fungi relationships by forming hyphae networks. Through mycorrhizae the plant obtains mainly phosphate and other minerals, such as zinc and copper, from the soil. The fungus obtains nutrients, such as sugars, from the plant root. This mutually beneficial relationship is called a mycorrhizae network [11].

Soil fungi can grow in a wide range of soil pH but their population is more under acidic conditions because of severe competition with bacteria at neutral pH. A majority of fungi are aerobic and prefer to grow at optimum soil moisture. The contribution of these organisms in biochemical transformation under excessive moisture is negligible [12].

The rhizosphere is a locality next to the basis dominated by soil microbes wherever several chemicals and organic chemistry methods occur. Soil fungi form up to 10–30% of the soil rhizosphere. The fungi ability to produce a wide variety of extracellular enzymes, they are able to break down all kinds of organic matter, decomposing soil components and thereby regulating the balance of carbon and nutrients for maintain soil health. This allows fungi to bridge gaps in the soil to transport nutrients relatively far distances back to the plants [13] (**Tables 1** and **2**).

Soil is a primary source of fungal growth, and is associated with the roots of all plant species. Fungi produce a wide range of bioactive metabolites, which can improve plant growth [14]. In addition, fungi supply inorganic nutrients to plants, such as ammonium, nitrate, and phosphate [15] and they are used as biofertilizers. Rhizosphere microorganisms can overcome competition with other soil factors and survive under variable environmental conditions [16].

Fungal species/ strain	Plant type	Fungi-mediated response	Beneficial effects on plant species	References
AM fungi	Dead vegetation in soil	Degrade of dead organic	Nutrient mobilization	[43] Hodge et al. (2001)
Phanerochaete velutina	Wood	Decomposing wood	Phosphorus translocation	[44] Wells et al. (1998)
Pleurotus sp.	Wood	Wood decay	Nutrient mobilization	[45] Cohen et al. (2002)
Perisporiopsis lateritia	Leaves of *Hevea* sp.	Leaves decay	Nutrient mobilization	[46] Chaverri and Gazis (2010)
Navisporus floccosus	Wood	Wood decay	Nutrient mobilization	[47] Phillips et al. (2012)
M fungi	*Pinus taeda*	Decomposing organic matter	Carbon and nitrogen cycling	[48] Hoorman (2011)
AM fungi	*Vigna unguiculata*	Mineral uptake	Improved nutritional status	[49] Yaseen et al. (2011)
M fungi	*Allium cepa*	Plant growth	Improved nutritional status	[50] Albrechtova et al. (2012)
Trichoderma sp.	*Arabidopsis sp.*	Auxins dependent mechanism	Higher biomass production and increased lateral roots formation	[51] Contreras-Cornejo et al. (2009)
Trichoderma sp.	Agriculturally important crops	Biocontrol	Crop management	[52] Chalot and Brun (1998), [53] Harman and Mastouri (2010)
Ectomycorrhizal fungi	Higher plant species	Phenolic compounds degradation	Plant protection	[54] Ha (2010)
Ectomycorrhizal fungi and AM fungi	Agricultural crops	Stomatal physiology and water relation	Improved water potential status and increased photosynthesis rate	[55] Arnold and Engelbrecht (2007)

Table 1.
Soil-beneficial fungi on different physiological and catabolic processes in various host plant species.

Product	Microorganism used	Agriculture application
Gibberellins	*Fusarium moniliforme*	Plant growth hormone
Zearalenone	*Fusarium graminearum*	Growth promoter in cattle
DeVine	*Phytophthora palmivora*	Control of milkweed vine
Collego	*Colletotrichum sp*	Control of northern jointvetch
Chontral	*Chondrostereum purpureum*	Control of hardwoods
Rotstop	*Phanerochaete gigantea*	Control of butt rot of conifers

Table 2.
Agricultural application of fungi.

3. Ecological plant-microbe interactions

The microbes and plants along regulate several soil processes as well as the carbon cycle and nutrient utilization. Plant diversity and abundance might modification the complete soil scheme through the discharge of root exudates that attract or inhibit the expansion of specific organisms [17].

3.1 Economic advantage of fungi

- The saprophytic fungi of decay maintain the never-ending cycle of greenhouse emission that could be the most significant staple for plant chemical processes in nature. They additionally cause rot, decay, and decomposition of animal and plant remains emotional plant nutrients in an exceedingly type offered to inexperienced.

- There are types of fungi they serve to suppress fungi inflicting the sickness disease of the seedlings and thereby influence favorably the expansion of crops.

- Some fungi like *Empusa sepulchrasis, Metarhizium anisopliae,* and *Cordyceps melothac* can be used to control some insect pests. Others parasitic to some insects particularly, some spore-forming ones. The fungi spores sprayed on the crop cuss to regulate them. Colorado potato beetles, citrus rust mites, and spittle-bugs of insect cuss that may be controlled exploitation fungi. These types of fungi form loops on their mycelium which traps and strangle nematodes as the attempt to pass through. They later absorb nutrition from the nematodes.

3.2 Vesicular arbuscular mycorrhiza

Vesicular arbuscular mycorrhiza (VAM) fungi belong to the *Glomeromycota*. They are primitive fungi at the base of the tree for higher fungi (basidiomycetes). They turn out microscopic structures, or comparatively tiny sporocarps (truffle-like). Just over 200 species of these fungi are described, yet they are capable of forming mycorrhizal associations with the majority of plants. The word mycorrhiza is derived from the classical Greek word for "mushroom" and "root." In a mycorrhizal association, the underground mycellium is in contact with plant roots, but without causing any harm to the plant.

Mycorrhizal fungi accountable in the rising growth of host plant species because of raised nutrient uptake, production of growth-promoting substances and tolerance to drought, salinity and synergistic interactions with other beneficial microorganisms [18]. The soil conditions prevalent in sustainable agriculture are likely to be more favorable to AM fungi than are those under conventional agriculture [19]. The AM fungi are widely distributed in natural and agricultural environments and have been found associated with more than 80% of land plants, ferns, woody gymnosperms and angiosperms and grasses [20].

Arbuscular mycorrhiza fungi (AMF) are beneficial fungal organisms that share symbiotic association with many land plants. The arbuscular mycorrhiza fungi have the potential to improve soil characteristics, thereby promoting plant growth in normal and stressful environments [21]. The arbuscular mycorrhiza fungi colonization enhances plant growth [22] and changes the morphological, nutritional and physiological levels of plants to improve resistance against different abiotic stresses [23]. The arbuscular mycorrhiza fungi inoculation protects *Ocimum basilicum* against salinity stress by improving mineral uptake, chlorophyll synthesis and water use efficiency [24]. Tomato plants inoculated with arbuscular mycorrhiza fungi show an increase in the leaf area, nitrogen, potassium, calcium and phosphorous contents to enhance the plant growth rate compared to controls [25].

3.3 Edible fungi

Fungi can be used to produce material of nutritive value such as vitamins, amino acids, and lipids to make it more nutritious and palatable. Mushrooms are cultivated to yield fruit bodies directly consumed as food and yeast cells, mold mycelium is grown in fermenters to produce single-cell protein which may be used as food.

3.4 Plant response to AM Fungal inoculation

Soil phosphorus is a critical factor in plant response and responses are generally better under low phosphorus levels. Host genotypes and fungal strains seem to influence the response of plants to inoculation. The worldwide field experiment has provided evidence to show that under marginal P-deficiency soils lacking in effective AM fungal endophytes increase in yield of wheat, maize, barley, potatoes, and cowpea. Increased uptake of zinc has also been shown in AM fungus inoculated peach, maize, wheat and potato in zinc deficiency soils. The AM associations related to increased uptake of sulfur and calcium, improved water absorption and tolerance of plants to water stress in citrus and avocado seedlings have also been noticed. There are also reports of increased levels of cytokinins and chlorophyll by AM fungus- infected plants [26]. Therefore, many researchers were trying to use alternative approaches based on either manipulating or adding microorganisms to enhance plant protection against pathogens. The useful microorganisms (antagonistic bacteria) (e.g., bacteria genus visible radiation, *Bacilli subtilis*) and fungi (e.g., AMF, Trichoderma) contend with plant pathogens for nutrients and house, by manufacturing antibiotics, by parasitizing pathogens [27].

3.5 Exploitation of AM fungi for nutrient uptake and exchange

The fungi form a symbiotic association with roots of higher plants, facilitating uptake of plant nutrients, particularly of those which are less mobile this association is known as mycorrhizal association [28].

There are two types of mycorrhizal association (i) Ectotrophic mycorrhizae and (ii) Endomycorrhizae.

i. Ectotrophic mycorrhizae

Ectotrophic mycorrhizae, where the fungus forms a mantle or sheath around the root surface and where the mycelium develops intracellularly. The fungi which forms this types of association are species of *Boletus, Amenita*, etc.

ii. Endomycorrhizae

Endomycorrhizae, where the fungus develops intracellularly in the root without forming Hartig net. In this association the penetration of roots cells is characterized by the formation of terminal spherical structure called vesicular, which contain oil droplets and phosphorus. This type of mycorrhiza is called vesicular arbuscular mycorrhizae.

The management of AM fungi is very vital for organic and low-input agriculture systems wherever soil phosphorus is, in general, low, although all agroecosystems can benefit by promoting arbuscular mycorrhizae establishment. Some crops that poor at seeking out nutrients within the soil passionate about AM fungi for phosphorus uptake. For example, flax, which has poor chemotaxis ability, is highly dependent on AM-mediated phosphorus uptake at low and intermediate soil phosphorus concentrations. Proper management of AMF in the agroecosystems can improve the quality of the soil and the productivity of the land. Agricultural practices like reduced tillage, low phosphorus fertilizer usage and perennialized cropping systems promote functional mycorrhizal symbiosis [29].

3.6 Function of AM fungi in soil quality and phytoremediation

The use of arbuscular mycorrhizal fungi in ecological restoration comes (phytoremediation) has been shown to modify host plant institution on degraded soil and improve soil quality and health. There is evidence to suggest that this enhancement of soil aggregated stability is due to the production of a soil protein known as glomalin [30]. The arbuscular mycorrhizal fungi and is of agricultural significance particularly in the Phosphorus deficient soils where the where the phosphorus in the vesicle diffuses out into the cytoplasm and is taken up by the plant. Fungi belonging to the genera *Glomus, Endogene* form this association [31].

3.7 Role of AM fungi in salinity problem

The mycorrhizas can be used to help plants overcome extreme environmental conditions, such as saline environments [32] and several AM species have been found living in saline habitats [33]. According to some estimates, around 50% of plants living near shorelines possess mycorrhizal associations in their root systems [34]. Similarly, several species of AM were discovered in salt marsh plants [35]. Even in very saline sites reaching more than 150 dS/m of electrical conductivity, there are species of AM that can survive such hostile conditions [36].

There are different mechanisms by which AM fungi can help plants cope with salt stress. For example, they can enhance soil nutrient absorption by plants [37, 38] showed that the addition of AM fungi to lettuce and onion plants resulted in increased accumulation of phosphorus under conditions of salinity stress. Furthermore, AM can affect the ionic balance of plants, especially about Na^+ and Cl^- [39].

Furthermore, the addition of AM to tomato (*Lycopersicon esculentum*) under conditions of salinity improved anti-oxidant enzyme production, thus protecting cell membranes from damage. AM fungi can also improve the secretion of different types of hormones, one of them being abscisic acid. Mycorrhizal effects on hormones are important, as these hormones can enable plants to overcome many environmental stressed [40]. For example, inoculation of lettuce (*Lactuca sativa*) with Glomus intraradices induced enhanced levels of hormones in these plants under conditions of salinity stress and this, in turn, affected the regulation of stomatal closure. Salinity may also induce drought conditions for plants, so AM fungi may also help plants increase water uptake. The addition of mycorrhizas to leek (*Allium porrum*) increased the surface area of the roots, thereby increasing water absorption by the plants. The efficiency of water use in lettuce plants improved significantly with the addition of mycorrhizas under salt stress [41].

3.8 Potential of AM fungi in drought condition

Rice is mostly cultivated under rain-fed conditions. The yield can be severely reduced when the water supply is insufficient, therefore drought is one of the major

Product	Fungus	Target
Mycotal	*Verticillium lecanii*	Whitefly and thrips
Vertalec	*Verticillium lecanii*	Aphids
Biogreen	*Metarhizium anisopliae*	Scarab larvae on pasture
Cobican	*Metarhizium anisopliae*	Sugarcane spittle bug
Conidia	*Beauveria bassiana*	Coffee berry borer
Ostrinil	*Beauveria bassiana*	Corn borer
CornGuard	*Beauveria bassiana*	European corn borer

Table 3.
Mycoinsecticide.

constraints for rice production. Rice has its mechanisms to drought stress, and they are also assisted by living soil organisms. Arbuscular mycorrhizal (AM) fungi are among one of the soil microorganisms that may enhance drought resistance of rice. It assists plants in uptake water and nutrients. It also plays roles in regulating plant hormones, as well as stomatal behavior under drought stress. Apart from that, intercropping is likely contributing to the improvement of drought resistance and AM fungi activity. Intercropping can enhance AM fungi colonization and improve the root morphology of rice which beneficial for drought resistance. Thus, this analysis aims to achieve a lot of insight regarding the mutuality between AM fungi and rice beneath drought stress. The study will focus on the effects of AM fungi on the growth of rice, rice hormones, water potential and the contribution of AM fungi and intercropping on drought resistance of rice. The mycorrhizal development still strongly stimulated the improvement of plant growth and increased plant survival under drought stress. AMF had shown to reinforce drought tolerance in numerous plants [42].

3.9 Mycoinsecticides

The fungi have been utilized for controlling insect pests. The microbial control of insect pests emerged 100 years ago. Insect is infected by fungi through the body surface and this property is different from the infection caused by bacteria, viruses, and protozoa. Fungi attacking insect are called entomogenous. The conidia of the insect attacking fungi are attached to the insect integument where they germinate and the germ tubes penetrate in insect body under optimum temperature and humidity. The fungus proliferates in the insect body and the insect body gets covered with mycelia and conidia. The newly formed conidia are dispersed and cause subsequent infections and the cycle is continued (**Table 3**).

3.10 Myconematicides

Based on the nature of fungal biocontrol agents the nematopathogenic fungi are of three types, nematode, trapping fungi (*Arthrobotrys, Dactylella*), endoparasites (*Hirsutella, Meria*) and highly specific egg parasites (*Datylella*). The common and commercialized myconematicide are Royal 300 R (*Arthrobotrys robata*), Royal 350 R (*Arthrobotrys suporba*).

4. Conclusions

The increased absorption of available nutrients from soil as the fungus changes root morphology, which result in the larger root surface available for nutrient absorption. Fungal filaments also act as the absorption surface and increasing the nutrient availability by solubilizing insoluble nutrients like phosphorus, which thus become available to plant and increasing the nutrient mobility due to faster intracellular nutrient mobility and mobilizing nutrients from the soil mass not visited by the roots system but traversed by the mycorrhizal hyphae. The arbuscular mycorrhizal fungi protected plants by up-regulating the activity of antioxidant enzymes and osmolytes and by regulating the synthesis of phytohormones, which might possibly interconnect the various tolerance mechanisms for cumulative stress response. The prominent effect of arbuscular mycorrhizal fungi against salinity was proven to be due to a restriction in sodium uptake by roots and to the homeostasis of nutrient uptake.

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