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Symbiotic Association of Beneficial Fungal Species with Plants to Enhance Agricultural Production and Productivity

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Abstract **– Fungi are diverse organisms in ecosystem establishment in different ways of association with other organisms like Mycorrhizal fungi. Mycorrhizas are associations between fungi and the roots or other underground organs of plants. Therefore, the review was made to point out important fungal species involved in symbiotic fungal-plant interaction and their major roles in agriculture as well as ecosystem. Most land plants form associations with mycorrhizal fungi. The fungal organs are identified as chain, arbuscul, vesicle, supportive cells and spore. Mycorrhiza types are described as arbuscular, ecto, ectendo, arbutoid, monotropoid, ericoid and orchidaceous mycorrhiza. The vesicular arbuscular mycorrhiza and ecto mycorrhiza are the most abundant, widespread and important fungal species involved in symbiotic fungal–plant interactions. They are described as symbiotic organisms because the fungus receives photo synthetically derived carbon compounds and the plant has increased access to mineral nutrients and sometimes water. Mycorrhizal fungi are important fungi species in nutrient exchange that greatly enhanced the ability of plants to take up phosphorus and other trace nutrients those are relatively immobile and exist in low concentration in the soil solution. Fungi can be important in the uptake of other nutrients by the host plant. Mycorrhiza establishes its symbiotic relationships with plants and plays an essential role in plant growth, disease protection, and overall soil quality. The other roles of Arbuscular mycorrhizal fungi involved in alleviation of heavy metal stress and increasing grain production. However, use of mycorrhizal biotechnology engineered establishment of mycorrhizal associations in land reclamation and revegetation is not well-practiced in many parts of the world. It is crucial to recognize and understand the molecular and ecological roles of mycorrhiza for agriculture, horticulture, forestry and soil remediation. Indiscriminate use of fertilizers and pesticides can inhibit the growth of mycorrhiza. Therefore, the development of mycorrhizal may be a better environmentally friendly alternative for agricultural practices like addition of inorganic fertilizers and can go a long way in maintaining a sustainable environment.**

Keywords **– Arbuscular Mycorrhiza, Fungus, Interaction, Mycorrhiza, Plant.**

I. Introduction

Mycorrhizas are important components of ecosystem in which the association with most land plants. Mycorrhizas are associations between fungi and the roots or other underground organs of plants. Wang and Qiu (2006) explained that living things have a complex and multilateral connection with one another and their surrounding whereby the surrounding and the living things form a related collection and this collection creates a complex ecological system.

Mutualism is close relationship which exists between most living things in nature in which the partheners benefit from each other. Various types of peaceful coexistence in nature were suggested by many scientists thus, we can describe the relationship between fungi and alga in lichen, the relationship between bacteria and angiosperm in nodules in the nitrogen fixation and the relationship in plants and fungi in the state of Mycorrhizas to which all have an important role in natural ecosystems (Van der Heijden *et al*., 1998).

Mycorrhizal fungi are diverse and associated with many land plants from lower to higher plants. According to Smith and Read (2008) Vesicular arbuscular mycorrhiza fungi are the most common and abundant coexistent fungi in soil and can coexist with more than 90 percent of plant species to establish a symbiotic relationship. Fungus has the ability to produce and secrete growth hormones, better water absorption and protection against plant pathogens (Ramakrishnan and Bhuvaneswari, 2015).

The mycorrhizal fungi have multi interaction with plants that we can point out as; increase plant resistance to diseases, increased nitrogen fixation, increasing plant resistance to drought, enhance photosynthesis rates, lower concentrations of elements such as cadmium and arsenic in plant tissues. Van der Heijden *et al*., (1998) suggested that Mycorrhiza improve soil physical properties. Mycorrhiza fungi help to alleviate this problem by providing an extensive hypha network for capturing mineral nutrients and transporting them back to the roots (Ramakrishnan and Bhuvaneswari, 2015). The other mutual association is the relationship between lichens and Mycorrhizas are not the only examples of symbiosis. Many plants have been found to harbor symptomless indication like endophytic fungi within the plant walls or intercellular spaces. They are beneficial because they help to activate plant defense genes and produce insect anti-feedant compounds such as the ergot alkaloids.

The world agriculture especially, developing countries highly depends on is the use of chemical fertilizers and inorganic pesticides that have impact on environment and limit the growth of beneficial organisms. The practice of using and attempt to identify important linkage between organisms make relying up on inorganic agriculture that limited the transformation of modern agriculture in many countries. Therefore, the objective is to point out important fungal species involved in symbiotic fungal-plant interaction and their major roles in agriculture as well as in ecosystem.

II. The Meaning of Mycorrhiza and Fungal Organs

2.1. *The Definition of Mycorrhiza*

The term mycorrhiza can be defined as fungus root. According to Omid Alizadeh (2011**)** fungi form many types of symbiotic association with the roots or other underground organs of plants. They are estimated to occur in at least 80% of all vascular plants, including angiosperms (the flowering plants), gymnosperms (the cone-bearing plants), many pteridophytes (ferns and their allies), and some bryophytes especially liverworts (Jim Dacon, 2007). Many of these associations are thought to be mutualistic, because the fungus typically absorbs mineral nutrients from the soil and channels these to the plant, while the plant provides the fungus with sugars. However, there are several different types of mycorrhiza, with different properties and feature that fossils from the Rhynie Chert deposits in Scotland contain fungal structures similar to those of the most common mycorrhiza fungi today the arbuscular mycorrhiza fungi. So, it seems that some of the earliest land plants had already established mycorrhiza associations, and these might even have been a prerequisite for life on land (Jim Dacon, 2007).

Fungi are involved in a wide range of intimate symbiotic associations with other organisms. In several cases the fungi and their partners have become so intimately dependent on one another that they have lost the ability to live alone. In other cases the fungi can be cultured in laboratory media but they are, in effect, ecologically obligate symbiosis because they seldom if ever grow as free-living organisms in nature. The many thousands of species of lichen are classic examples of this. They grow in some of the most inhospitable environments on earth, where no other organisms can grow, including cooled lava flows and arid desert sands, where they literally hold the place in place.

Agrios (2007) indicated that the below-ground networks of fungal hyphae provide potential links between several different types of organism. There is every reason to believe that further examples remain to be discovered. Symbiotic associations are also significant in economic terms. The fungal entophytes of pasture grasses produce toxic alkaloids such as lolitrem B and ergovaline, which are now known to be responsible for several diseases of horses, sheep, and other grazing animal.

2.2. *Fungal Organs*

The fungi morphology in symbiotic system includes chains outside of root and inside, support cells, vesicle inside the root between the cellular and intracellular and intracellular Arbusculs (Wang and Gui, 2006). Considering that most of these organs can start a new colonization of plant roots are, a profile for each were described below.

2.2.1. *Chain*

Outside root chains that originated from germination spores present in the rhizosphere are of different morphology and functioning. Some participate in the colonization of roots, some are responsible for material absorption from the environment (soil), and some are spore producers. These chains have no lateral wall and where surface root cells contact, they are derived and from the end of each branch after forming aspersorium on the root surface, a thin chain penetrates inside the roots. Intracellular chains are always in plasma membrane surrounding the cell. In pot culture studies have shown that the outward root chain in Glomaceae family and Acaulosporaceae have great ability for root colonization, but in the Gigosporaceae family the ability is very low (Alizadeh, 2011).

2.2.2. *Arbuscul*

This shrub looking organs from divergence of successive and bifurcate branches of inner root chains, after passing through the cellular wall and in an enclosed case in plasmatic membrane are formed within the root skin cells with a high level of contact with plant cells, Arbuscular plays the role of an exchange organ for limbs and nutrient exchange between fungus and host plants. Studies have shown that in the chain's core of an Arbuscul a lot of seed, mitochondria, glycogen particles, fat cells and dense granules made of poly-phosphate exist in vacuoles (Goss and Varennes, 2002; Alizadeh, 2011). In the final fine branches, the number of vacuoles are high and the granules inside disappear.

2.2.3. *Vesicle*

Vesicle are spherical or oval bodies with a thin wall, and contain lipid cells which in terms of swollen chain ends or some of its' middle parts, are created inside or between roots' skin cells, and in the case of intercellular they are confined with plasma membrane similar to Arbuscul. These organs are only formed in fungal species belonging to the order of the *Glomineae* (Dickison, 2000; Wang and Gui, 2006).

2.2.4. *Support Cells*

Various forms of bulged cells with thin walls, which are sourced from the outer root chains in funguses under the order of Gigasprineae, are called support cells. The level of these cells is in the barbed Gigasprineae genus, but in the Schatele spore they are seen as small bulges with an almost flat surface. Before mycorrhiza colonization begins the support cells appear on the Germination tube resulted by the spores. In pot culture, the number of support cells reaches its' peak point shortly after the start of spores, but after four months onwards, their number is reduced or they completely disappear (Smith and Read, 2008).

2.2.5. *Spore*

Except the Gigapora genus which forms its' spores only in soil, all other spores are produced in the soil or in the roots. Although members of the order Glomal are categorized in Zygomycetes category, but none of them produce Zygospore and their non-genus spores are in the form of Chlamydospore or Azygospore. Inner root sporisation are formed in some famous genus types of *Glomus intraradices* and *Glomus diaghanum*. The time for sporisation, often starts three to four weeks after the onset of root colonization, unless the growth context is of high absorbable phosphorus which in that case all the fungus growth stages will be limited. It is thought that spores of all arbuscular mycorrhiza fungi have the ability to colonize the root by forming a germinant pipe. However, if the *Giga spora gigantea* spores are healthy, they have more ability to colonize the root (Dalpe and Monreal, 2004; Smith and Read, 2008).

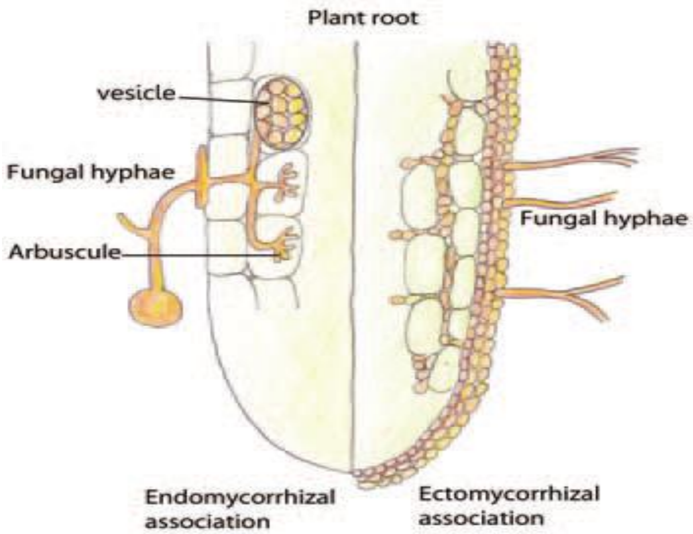

Fig. 1. Schematic representation of endo and ectomycorrhizal association between plant and fungus. Source: Johanson *et al*., (2016).

III. TYPES AND CLASSIFICATION OF MYCORRHIZA

3.1. *Ectomycorrhizal Fungus*

These fungi are of the class Basidiomycets and some are from Ascomycets and few imperfect funguses and only of type of Zygomycetes called Andogon. These funguses do not enter into root cells and that's why they are referred to as Ecto (external). Through the space between the root skin cells the rows of this fungi provide a dense network called the Hartic network for exchange of metabolites with the host plant. In addition by forming a rather thick layer of sheath or a pod on the surface of short and feeder roots, which often by changing the color, the shape of the roots follows frequent branches of two or more. Detection of ectomycorrhizal is easily done through morphological changes of the root sheath (Duponnois and Plenchette, 2003; Ramanankierana *et al*., 2007).

Ectomycorrhizal fungi are also found in natural environments, mainly in forests ecosystems. These fungi can form visible reproductive structures (mushrooms) at the feet of trees they colonize. Ectomycorrhizal fungi grow between root cells without penetrating them. Their hyphae grow externally, forming dense growth known as a fungal mantle. These fungi form symbiotic relationships with most pines, spruces and some hardwood trees including beech, birch, oak and willow, 5 to 7% of plants belong to this association (Ramakrishnan and Bhuvaneswari, 2015).

3.2. *Endo Mycorrhiza Fungus*

The association of these kids of fungi are with in fungus root. Endo Mycorrhizas form associations with most plants approximately 80 percent of all plant species. These fungi are entirely classified as Zygomycets. These types of mycorrhiza are called Endomycorrhize fungi because the fungus penetrates into the root skin cells of host plants (Ramakrishnan and Bhuvaneswari, 2015). The basic principles of naming VAM mycorrhiza is producing specific fungus organs named Arbuscul and Vesicle within the host plants root. In some types of Endomycorrhize fungi, vesicle are not formed; of this type we can refer to the mycorrhiza fungus which belong to the genus *Gigaspora* and *Scutellospora*. Vesicle appear mostly in the mid to late vegetative period, but Arbuscul is the original location for metabolic exchanges between the fungus and plant. Arbusculs are usually formed in the inner part Skin stem cells. The fungus roots, after penetrating into the chain of successive cell divisions, while producing bifurcate branches, become progressively thinner and subtle and in total create an organ which looks like small shrubs which facilitate the exchange of metabolites between the two can coexistent, because of the very large contact surface with the host cell. Vesicle or organs that are similar looking to bag or sacks, often result in swelling on the end of fungi and form within or between the root and are gradually accumulated by Lipid droplets and form like storage and resting organs (Duponnois and Plenchette, 2003; Johansson, *et al*., 2004).

Endo Mycorrhizas form associations with most plants (approximately 80 percent of all plant species). These fungi cannot be grown in pure culture but must be grown in association with plant roots. They form branched structures called arbuscules within the host's root cells and thus they are known as arbuscular mycorrhiza fungi. The arbuscules are sites of nutrient exchange between the fungus and the host. This manual focuses on arbuscular mycorrhiza fungi. Fungi of the Endomycorrhize consist of a septet hyphae are members of the Phycomycetes and Basidiomycetes. The hyphae of these fungi penetrate the cells of the root cortex forming an internal hyphae network. Some hyphae also extend into the soil. For many plant species including most agricultural crops the predominant type of fungal infection is vesicular arbuscular mycorrhiza (Ramakrishnan and Bhuvaneswari, 2015).

3.3. *Ectendo Mycorrhiza Fungi*

This type of fungus the fungal sheath is reduced or it doesn't exist, the Hartic network has not expanded, but the roots penetrate inside (Brundrett, 2004). Ecto mycorrhiza fungi can form Ectendo mycorrhiza mode on different hosts and in good conditions. In the first step of classifying, we can find the type of fungi related to each mycorrhiza according to the transverse wall. Those that have no walls are Fecomistic End fits and those that have fungi with transverse walls are Ascomycets or Basidiomycetes. In the first grown where Fecomistic fungi have no transverse walls, they belong to Endogonaceae and are Zygomycetes genus (Assigbetse *et al*., 2005). These fungi are rarely seen freely. They are dispersed around the roots and they penetrate in the spaces between cells and into the host plant cells and have particularly formed split suction organs (Arbuscular) inside the cell and the vesicle are inside or outside the host tissue, and mostly form spores or sporocarps with complex structures. In this case, this type of mycorrhiza is called VAL which is short for Vesicular Arbuscular mycorrhiza walls of fungi contain Ectomycorrhiza, ectendo mycorrhiza and Ericoid Mycorrhizas which can often establish a symbiotic relationship with the root of the tree or Shrubs. Until 1974, VAM fungi was limited only to genus Endogone, but now the fungi are in four genus *Glomuse*, *Sclerocystis*, groups of Endogonaceae family fungi was performed which used isolated spores (Bedini*et al*., 2008).

IV. Classification of Mycorrhiza Based of Function

4.1. *Arbuscular Mycorrhizas (Am)*

Arbuscular Mycorrhizas are the most common type of mycorrhiza and are found world-wide on crop plants, wild herbaceous plants, trees, many pteridophytes, and some bryophytes. Until recently, the AM fungi were classified as members of the Zygomycota. But analysis of the genes encoding the small subunit (18S) ribosomal RNA shows clearly that AM fungi are not related to Zygomycota and probably share common ancestry with Ascomycota and Basidiomycota. So they have been assigned to a new monophyletic group, the Glomeromycota (Schubler *et al*. 2001). Seven genera are recognized within this, based primarily on features of the spores: *Acaulospora*, *Entrophospora*, *Archaeospora*, *Glomus*, *Paraglomus*, *Gigaspora*, and *Scutellospora* (Agrios, 2005).

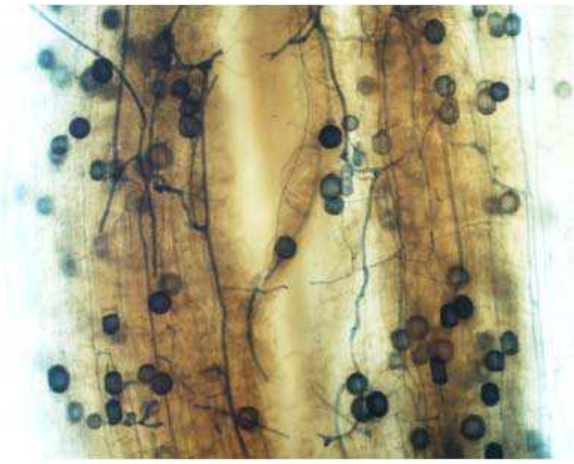

Fig. 2. Roots of *Prunus* rootstocks with hyphae and spores of *Glomus intraradices.* Source: Calvet *et al*. (2004).

4.2. *Ectotrophic Mycorrhizas*

Ectotrophic Mycorrhizas, or ectomycorrhizas, are found mainly on woody plants, including many species of coniferous and broad-leaved trees outside of the tropics. For example, ecto mycorrhiza has been typically found on trees such as pine, spruce, larch, oak, beech, birch, and eucalypts but tropical trees and even some temperate trees (sycamore, ash, poplars) have arbuscular mycorrhizas, and some trees (e.g. willows) can have both types. The fungi involved in ectomycorrhizal associations are principally members of the Basidiomycota that produce many of the common toadstools of the forest floor (e.g. *Amanita, Boletus, Cortinarius, Hebeloma, Lactarius* spp. but ectomycorrhizas also are formed by some Ascomycota, including the truffle fungi. Given the range of plants and fungi involved in this type of symbiosis, it is thought that ectomycorrhizal associations evolved independently on several occasions in the last 130-180 million years (Weber and Webster, 2007).

The characteristic feature of ectomycorrhizas is the presence of a substantial sheath of fungal tissue that encases the terminal, nutrient-absorbing rootlets and the rootlets themselves are often short stumpy with no root hairs. An extensive network of individual hyphae or aggregated mycelia cords radiates from the surface of the root sheath, while beneath the sheath the fungus invades between the root cortical cells to form a "Hartignet. Although the fungus is in close contact with the root cells in this region, there is no penetration of the host cells, hence the name of these mycorrhizas-ectotrophic (outside-feeding) mycorrhizas (Agrios, 2005). Because of the lack of root hairs and the encasement of the feeder roots by a fungal sheath, virtually all the mineral nutrients that enter the root must be channeled through the fungus. The uptake of mineral nutrients from soil is facilitated by the mass of fungal hyphae that radiate into the soil and transport nutrients back to the mycorrhiza sheath. The fungus benefits from these associations by obtaining sugars from the plant. Trees invest a considerable amount of photosynthate to support the fungal network conservatively estimated at 10% or more of the annual photosynthetic production of a tree (Bonfant and Genre, 2010).

4.3. *Ericoid Mycorrhizas*

The cold, nutrient-poor, acidic upland soils of the northern hemisphere tend to be dominated by heath land plants of the family Ericaceae, such as *Calluna* (ling), *Erica* (the bell heathers), and *Vaccinium* (bilberry, cranberry, etc.). Equivalent soils in the southern hemisphere support a different family the Epacridaceae. All these heath land plants have a distinctive type of mycorrhizal association with Ascomycota that produce coils of hyphae in the thin lateral roots termed "hair roots. "The coils develop within the root cells but outside of the host plasma membrane and nutrient exchange is thought to occur primarily through this interface. The fungi that produce ericoid mycorrhizas are unusual because they seem to be free-living saprotrophs in soil. They grow in laboratory culture, producing septate hyphae with a fragmented, zigzag growth form, but only one of them (*Hymenoscyphu ericae*) has been studied in detail. DNA and RNA profiles indicate that there is considerable genetic diversity between isolates that are similar in colony appearance (Brundrett, 2004).

There is strong evidence that a primary role of the ericoid mycorrhizas is to provide the host plants with nitrogen. This was shown initially in laboratory conditions, by supplying plants with 15N-labeled ammonium, when the label was taken up and incorporated into the plants. But when 15N-ammonium was added to natural, acidic health and soils the mycorrhizal plants actually took up less label than the non mycorrhizal control plants, even though the mycorrhizal plants had accumulated more total nitrogen. Evidently, in these conditions the fungus was obtaining nitrogen and supplying it to the host from a different (unlabeled) source, while the uptake of ammonium was simultaneously suppressed. This led to the discovery that the fungus secretes a proteinase with optimum activity at about pH 3, releasing amino acids from the soil organic matter. All members of the Ericaceae are strongly mycorrhizal, consistent with a major role of the mycorrhizal fungi in supplying mineral nutrients (Bonfant and Genre, 2010).

4.4. *Orchid Mycorrhizas*

Orchid mycorrhizas are entirely different from any of those above, because orchids are parasitic on a fungus for at least the early part of an orchid's life. The seeds of orchids are extremely small, consisting of an embryo and only a few nutrient reserves. When orchid seeds are triggered to germinate they produce a few root hairs and these must be colonized by a fungus at an early stage or the seedling will die (Rasmussen, 1995).

The fungi in these cases are species of Rhizoctonia (Basidiomycota) or closely related fungi, which grow on soil organic matter, degrading cellulose and other polysaccharides. The fungus penetrates the orchid embryo and produces hyphal coils, called peletons, which are surrounded by the host cell membrane. These coils last only a few days, before they degenerate and are replaced by further coils in other cells. Presumably, this repeated production and degeneration of the coils provides the main source of sugars to the developing orchid. These sugars are likely to include trehalose or other fungal carbohydrates. Consistent with this orchid seedlings can be raised artificially in commercial conditions by supplying them with trehalose in a culture medium. In natural conditions the mycorrhizal fungi provide orchids with their sole source of carbohydrates during the early years of life. Most orchids do not emerge above ground and produce chlorophyll until they are 3-5 years old and about 200 species do not produce chlorophyll at all throughout life (Jim Dacon, 2007).

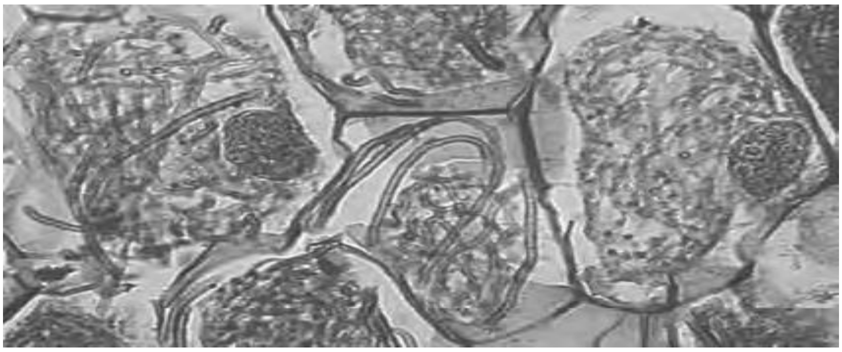

Fig. 3. Section through part of the protocorm (basalstem region) of an orchid, *Neottia*, showing coils of hyphae (peletons) within the orchid cells. Source: Jim Dacon (2007).

4.5. *Monotropoid Mycorrhizas*

Plants of the family Monotropaceae lack chlorophyll throughout their lives and depend on mycorrhizal fungi for all their nutrient requirements (Read, 1997). These plants are found in the deep shade beneath forest trees sometimes broadleaved trees such as oak and beech, but more commonly coniferous trees such as pine, spruce, and fir. The fungi involved in these associations are Basidiomycota, such as Boletus edulis, that produce typical ectomycorrhizas attached to the roots of forest trees. From the tree host, these fungi radiate into the soil as hyphal networks or mycelial cords, and they forma hyphal sheath around the roots of Monotropa and related genera. So, in effect, the monotropoid plants are simply parasitic on ectomycorrhizal fungi, which in turn draw their sugars from the tree. This transfer of nutrients has been demonstrated by supplying 14CO2 to the leaves of trees and following the label as it moves down to the roots as sucrose before entering the mycorrhizal sheath as labeled sugar alcohols or trehalose, and thence through the mycelialcords and ultimately into the flowering spikes of Monotropa. The sheath that develops around the roots of Monotropa is typical of an ectomycorrhizal sheath, with a Hartignet. But the fungus also produces small pegs that project into the root cells and then expand, surrounded by the plant cell membrane. This three membered symbiosis, involving a direct nutritional connection between a tree host, mycorrhizal fungus and parasitic higher plants (Bonfant and Genre, 2010).

Table 1. Major categories of mycorrhiza and their attributes. Source: Barman *et al*., (2016).

Mycorrhizal Type	Fungal taxa	Plant taxa	Intracellular Colonization	Fungal Sheath	Vesicle
Arbuscular	Glomeromycota	Bryophyte Pteridophytes	Present	Absent	Present or absent

Mycorrhizal Type	Fungal taxa	Plant taxa	Intracellular Colonization	Fungal Sheath	Vesicle
		Gymnosperms angiosperms			
Ecto	Basidiomycota Ascomycota Zygomycota	Gymnosperms Angiosperms	Absent	Present	Absent
Ectendo	Basidiomycota Ascomycota	Gymnosperms Angiosperms	Present	Present or Absent	Absent
Arbutoid	Basidiomycota	Ericales	Present	Present or absent	Absent
Monotropoid	Basidiomycota	Monotropoideae	Present	Present	Absent
Ericoid	Ascomycota	Ericales Gymnosperms	Present	Absent	Absent
Orchidaceous	Basidiomycota	Orchids	Present	Absent	Absent

4.6. *The Mutual Benefits of the Partners*

Plants provide carbon to their fungal partners. The photosynthetic product hexose is transported to the arbuscular part of fungal cytoplasm and gets converted into glycogen and TAG (triacylglycerol). These are suitable firms of carbohydrates that are easily transported to long distances within the fungal network. In the case of plants, mycorrhiza increases the surface area of roots for improved uptake of water and nutrients. Immobile nutrients are absorbed by the plants through diffusion. In nutrient depleted, tropical regions with excessive rainfall where essential nutrients are leached from soil surfaces, mycorrhizal fungi can extend their external hyphae beyond the depleted zones. As a result, more volume of soil becomes accessible to plant roots. Therefore, plants with mycorrhizal associations are more efficient in the absorption of nutrients like nitrogen, phosphorus, potassium, and calcium (Brundrett, 2004).

Phosphorus is an extremely immobile element present in the soil. The major role of vascular-arbuscular (VA) fungi is to supply nutrient. Mycorrhiza increases the phosphorus to plant roots via phosphate transporters surface area of plant roots for improved uptake of water and nutrients present in the hyphal membrane (Bucher, 2007). The networks of filamentous, extra radical hyphae of AM fungi help in the uptake of freely available phosphates. Extension of fungal hyphae generally begins beyond the host root so that greater soil volume can be used for phosphate acquisition. AM fungi can hydrolyze organic phosphates present in the soil and provide soluble phosphates to their host plant. Phosphate transporter of the Pht1 family of fungi helps in the uptake of inorganic phosphate into the cytosol. Then the phosphate gets transferred to the fungal vacuole where polymerization occurs to form polyphosphate chains (poly-P). The poly-P is transferred to the intra radical hyphae, where hydrolyzation takes place by liberating free phosphate for transfer to the interfacial apoplast of the AM fungi. Fungi provide phosphorus as poly-P pool to the plants. In soil with low phosphate content, mycorrhizas also help plants absorb copper and zinc by similar mechanisms. The networks of mycorrhizal hyphae help plants absorb freely available phosphates (Barman, *et al.*, 2016).

Nitrogen uptake is also very important for plant growth. Nitrogen is available in the soil as ammonium and ni-

-trate. Ammonium, nitrate, and amino acids are absorbed by the extra radical mycelium of fungi. Nitrogen is generally taken up in the form of ammonium through a protein transporter named AMT1 (fungal origin). Among amino acids, arginine is typically involved in the translocation of nitrogen. Within the extra radical mycelium, ammonium combines with glutamate to form glutamine due to the activity of glutamine synthetase. After glutamine synthesis, synthesis takes place with help of the enzyme argino succinate synthetase. Arginine is the final product utilized by plants. There are several ways by which AM fungi help plants to absorb water from the soil. AM fungal hyphae grow into the soil matrix, and create a skeletal structure to hold primary soil particles together by physical enlargement. Soil structure and its porosity are important factors for water retention, especially during the dry season. AM fungi can also change the hormonal flow of information from plant roots to shoots, and affect stomata responses when soil water potential is lowered. It has been reported that mycorrhizal associations help plants increase nutrient uptake during water-stressed conditions by increasing hydraulic conductivity in roots. The rhizosphere is the site where microorganisms interact with both plant roots and soil constituents. The higher carbon demand of AM fungi competitively inhibits the growth of plant pathogens. Furthermore, the mycorrhizal fungal partner can also improve the nutrient status of the host plant by compensating the loss of root biomass due to pathogen attack by increasing its tolerance. With AM formation, production of plant defense chemicals like phenolic substances, phytoalexins, and chitinases are increased. Symbiotic processes are not affected by these chemicals but systemic plant defense mechanisms are turned on Mycorrhizal associations also protect plants against heavy metal toxicity which in turn defend host plants from other harmful pathogens. Competitive inhibition of pathogens by endo and ectomycorrhizal fungi is demonstra-
-ted to protect host plants from diseases like root rot, collar disease, etc. (Askar and Rashad, 2010).

Mycorrhizal associations also protect plants against heavy metal toxicity. Ectomycorrhizal fungi protect trees from high concentration of toxic heavy metals like copper, zinc, iron, manganese, cadmium, nickel, etc., by accumulating and immobilizing them in the mycorrhizal mantle. The plants associated with mycorrhizal fungi also benefit from fungal detoxification systems. The detoxification mechanisms include extracellular heavy metal chelation by root exudates (eg., glycoprotein glomalin), binding of heavy metals to rhizodermal cell walls, and avoidance of heavy metal uptake. The large surface area of fungal hyphae is an important sink point for heavy metals. Fungal vesicles are also sites forstor age of toxic compounds. Thus, mycorrhizal fungi help in improving soil health by phytoremediation (Brundrett, 2004).

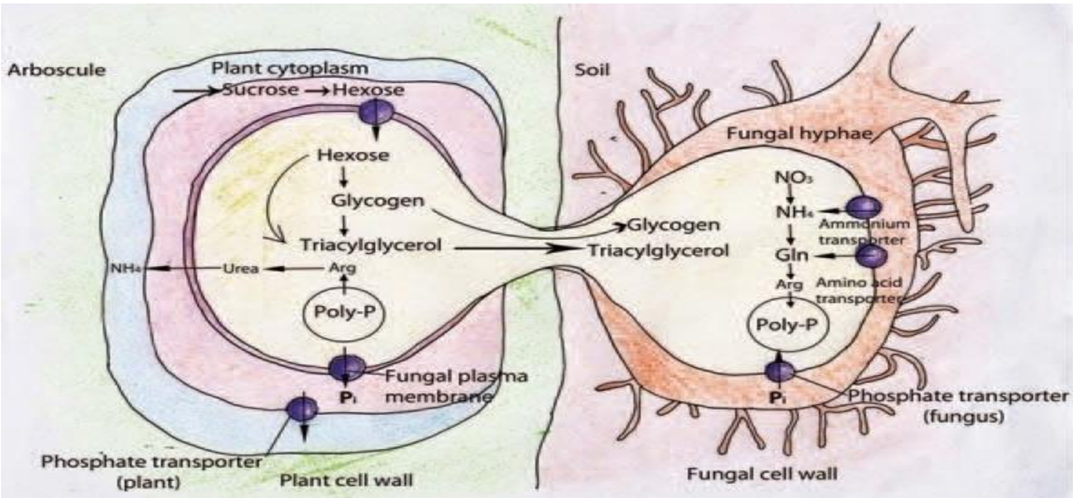

Fig. 4. The process of nutrient transportation across the plant and fungus. Source: Parniske (2008).

4.7. *Lichen*

Many fungi form symbiotic associations with plants, in which both of the partners are likely to benefit. The two most important examples are lichens and mycorrhizas. Lichens are intimate associations between two organisms' photosynthetic partner (a green alga or a cyan bacterium) and a fungus which together produce a thallus that can withstand some of the most inhospitable environments on Earth. Typically, the fungus encases and protects the photosynthetic cells, and also absorbs mineral nutrients from trace levels in, while the photosynthetic partner provides the fungus with carbon nutrients. There are about 13,500 lichen species across the globe, and they play essential roles as pioneer colonizers of habitats where no other organisms can grow, including rock surfaces and unstable, arid mineral soils (Agrios, 2005).

Lichens are remarkable organisms, unique in many ways. They represent a symbiosis between at least two separate organisms - a fungus and a photosynthetic partner, which can be either a green alga or a cyan bacterium. When the two (or more) partners come together they produce an entirely different type of organism, with a distinct morphology, leading to a long term symbiotic relationship. But sooner or later, in many lichens, this relationship breaks down, and then the partners have to re-establish the relationship from the separately dispersed fungal spores and photosynthetic cells (Bonfante and Genre, 2010).

Lichens are extremely common and can even be the dominant organisms in some environments, such as arctic tundra and semiarid desert regions. Because of their unique symbiotic relationship, lichens are able to grow in conditions that no other organisms can tolerate. In the following sections we will look at the structure and physiology of lichens, and their environmental significance (Webster and Weber., 2007).

4.8. *The Lichen Partners*

There are estimated to be between 13,500 and 17,000 species of lichen, but we must begin with a note on taxonomy. Because lichens are "dual organisms" composed of at least two separate species, there has always been a difficulty in naming them (Galun and Bubrick, 1984). This issue was resolved by formally assigning lichens to the fungal kingdom. So, for example, the common orange-yellow coloured lichen *Xanthoria parietina* which grows on rocks in coastal areas, is classified as a fungus (*Xanthoria*) that contains a photosynthetic partner in this case, the green alga *Trebouxia*. In many lichens the fungus were termed the mycobiont (the fungal symbiont) is a member of the Ascomycota (cup fungi) but in a few cases it can be a member of the Basidiomycota. The photosynthetic partner (the photobiont) can be either a green alga or a cyano bacterium. However, a few lichens contain both a green alga and cyanobacteria representing a symbiosis of three kingdoms of organisms. Almost all of the lichen fungi seem to be ecologically specialized, because they are found only in lichen partner ships and very rarely in a free-living state (Bonfante and Genre, 2010).

Table 2. The major types of mycorrhiza and their ecological significance. Source: Barman *et al.*, (2016).

Mycorrhizal type	**Typical host plant**	**Fungi involved**	**Major significance**
Arbuscular Mycorrhiza	Many	Glomeromycota	Phosphorus uptake from soil
Ectomychorrhiza	Forest tree mainly template	Basidiomycota, Ascomycota	Nitrogen uptake from soil
Ectendomychorrhiza	Many pines, spruce	Ascomycota of genus wilcoxina	Mineral nutrient uptake from soil

Mycorrhizal type	Typical host plant	Fungi involved	Major significance
Arbutoidmychorrhiza	Arctostaphylo Arbutus, Pyrota	Basidiomycotasuch As Boletus edulis	Mineral nutrient uptake from soil
Monotropoid Mychirriza	Healthy land plant	Ascomycota	Plants obtain sugars from ectomycorrhizal fungi attached to trees
Ericoidmyhorrhiza	Erica, calluna, etc.	Mitosporic fungi hymnoscyphus ericae	Nitrogen uptake from soil
Orchidmychorrhiza	Orchids	Rhizoctonia like fungi	Fungi supply the plant with sugars

V. Conclusion

Mycorrhizas are associations between fungi and the roots or other underground organs of plants ranging from lower to higher plants. Many fungi form symbiotic associations with plants, in which both of the partners are likely to benefit. The two most important examples are lichens and mycorrhizas. Lichens are intimate associations between two organisms a photosynthetic partner a green alga or a cyano bacterium and a fungus which together produce a thallus that can withstand some of the most inhospitable environments on Earth. The other associations are rhizobium bacteria with root nodules of legumineous plants. Mycorrhiza types are described as arbuscular, ecto, ectendo, arbutoid, monotropoid, ericoid and orchidaceous mycorrhizae.

Mycorrhizal fungi are important to alleviate the problem of nutrient uptake by providing an extensive hyphal network for capturing mineral nutrients and transporting them back to the roots. Mycorrhizal symbiosis is one of the crucial factors that determine plant and soil health. In addition, mycorrhiza enhances mineral uptake ability and tolerance to drought stress. It also induces resistance against soil pathogens, and reduces sensitivity to toxic substances in their host plants.

Anthropogenic activities like slash and burn cultivation, mining, waste disposal, and clear-cutting of forests are also detrimental to mycorrhiza. The other importance of mycorrhizal associations is evident in restoration and revegetation fallow lands. However, use of mycorrhizal biotechnology engineered establishment of mycorrhizal associations in land reclamation and revegetation is not well-practiced in many parts of the world. It is crucial to identify and understand the molecular and ecological roles of mycorrhiza for agriculture and allied activities. The continuous use of chemical fertilizers and pesticides can inhibit the growth of mycorrhiza. Thus, development of mycorrhizal biotechnologies may be a better nature-friendly alternative for agricultural practices like addition of inorganic fertilizers and can go a long way in maintaining a sustainable environment.

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