MYCORRHIZA: THE ASSOCIATION BETWEEN PLANT AND FUNGI

Introduction

Plants associate with other life forms (animals, bacteria or fungi) to complete their life cycle, to fight against pathogens or to thrive in adverse environments. The plant root and its associated living organisms are together called 'rhizosphere'. Rhizosphere is the place where associated microbes, fungi and other living forms live together with the root environment. There are mutualistic associations found in rhizosphere. 'Mycorrhiza', the best example of mutualistic and symbiotic association between plant and fungi, is an amazing phenomenon observed in nature. The mycorrhizal association is one of nature's boons for sustainable agriculture. each benefits from the other: the plant supplies the fungus with photosynthetic products such as sugars, and the fungus supplies the plant with minerals and water. Mycorrhizal associations help the host plants to thrive in adverse soil conditions and drought situations by increasing the root surface and mineral uptake efficiency. Environmental threats like increased temperature, changing climate and associated drought, soil infertility etc. are some of the major challenges. In today's changing environment, indiscriminate use of pesticides and chemicals pose a great threat to the existence of mycorrhizal species.

In nature, more than eighty percent of angiosperms, and almost all gymnosperms are known to have mycorrhizal associations. In such associations the fungal hyphae may develop either intracellularly inside the plant cortex cells, as in arbuscular mycorrhizae, or intercellularly around the cortex cells, as in ectomycorrhizae (Gutie ́rrez et al. 2003). The fungi that produce arbuscular mycorrhizae belong to the division Glomeromycota, while ectomycorrhiza-forming fungi may belong either to the Ascomycota or to the Basidiomycota. Truffles are mycorrhizal fungi belonging to the Ascomycota (Smith and Read 2008). It has been established that ectomycorrhizal fungi are capable of producing endomycorrhizas with underdeveloped intracellular hyphal structures, as well as ectendomycorrhizas with both intra- and intercellular hyphae, in response to particular mineral levels There are mainly two types of mycorrhizal associations found in nature, namely endomycorrhizae or arbuscular-mycorrhizae (AM), eg., *Endogone, Rhizophagus*, etc. and ectomycorrhizae (EM), eg., *Laccaria bicolor, Amanita mascaria*, etc. There are seven types of mycorrhizae. These are endo (arbuscular), ecto, ectendo, arbutoid, monotropoid, ericoid, and orchidaceous mycorrhizae, as described by the scientists. Among them, endomycorrhizae and ectomycorrhizae are the most abundant and widespread.

In endomycorrhizal association of the vascular-arbuscular (VA) type, the fungi penetrate the cortical cells of roots and form clusters of finely divided hyphae which ultimately develops into arbuscules(small ellipsoidal structures). VA fungi forms a mutualistic association with around 80% of vascular plants. It belongs to the phylum Glomeromycota. The ectomycorrhizal fungi invade a partial region of the host root without penetrating the cortical cells and form a thick mantle around the roots. Ectomycorrhizal associations are present in 3% of vascular plants and the fungi belong to the phylum Ascomycota and Basidiomycota. The beneficial association of two different species are sustainable to agriculture practices. AM fungi are obligate biotrophs, solely dependent on the host plants for their survival. The symbiotic mechanism comprise many steps. The first step is the search for the host root which is an important step in fungal-root-colonization process. Most of the present-day plants have a mutualistic symbiosis with micorrhizal fungi. The second step is penetration of fungi into the host root for colonization and final establishment of mycorrhizal symbiosis. These steps are described in detail as follows.

Formation of Mycorrhizae

Hyphae are long thread-like fungal filaments and mycelium is the intertwined mass of hyphae. And the host root interacts with each other, and the hyphae gradually start its propagation into the host root by forming the 'hyphopodium'. Many genes get activated subsequently, owing to hyphopodium formation. This is the primary step of colonization. These are special type of hyphal branch composed of lobed cells with which the fungi attach to the cell wall of the plant partner. Then a pre-penetration apparatus (PPA), which is indispensable for fungal penetration is developed. This structure allows the fungi to grow inside the plant without breaking the integrity of the cells. The final step of this symbiotic process is the formation of arbuscules, which are small tree-like structures. These arbuscules accommodate the fungi into the host cell cytoplasm. The arbuscular cells function as machines for nutrient transport and acquisition. Numerous genes and proteins are involved in the process of nutrient uptake which finally help in the accomplishment of symbiosis. The molecular mechanism adopted by EM fungi is almost similar but not identical to that of AM fungi. Further research is awaited to unravel the details of the processes underlying EM fungal associations.

Nutritional value of mycorrhiza

The photosynthetic product hexose is transported to the arbuscular part of fungal cytoplasm, and gets converted into glycogen and TAG (triacylglycerol). These are suitable forms 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. Phosphate acquisition takes place through the fungal part and is transported to the plant through the phosphate transporter Pht1. Nitrogen is transported through the nitrogen transporter AMT1 to the plant partner. In return, the plant provides carbon sources to its mycorrhizal fungi partners for their nutrition.

Therefore, plants with mycorrhizal associations are more efficient in the absorption of nutrients like nitrogen, phosphorus, potassium, and calcium. Phosphorus is an extremely immobile element present in the soil. The major role of vascular-arbuscular (VA) fungi is to supply phosphorus to plant roots via phosphate transporters. Mycorrhiza increases the surface area of plant roots for improved uptake of water and nutrients. present in the hyphal membrane. Then 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. Fungi provide phosphorus as poly-P pool to the plants. In soil with low phosphate content, mycorrhizae also help plants absorb copper and zinc by similar mechanisms. The networks of mycorrhizal hyphae help plants absorb freely available phosphates. Nitrogen uptake is also very important for plant growth. Nitrogen is available in the soil as ammonium and nitrate. 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, arginine synthesis takes place with help of the enzyme arginosuccinate 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 stomatal 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 demonstrated to protect host plants from diseases like root rot, collar disease, etc. 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. 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 for storage of toxic compounds. Thus, mycorrhizal fungi help in improving soil health by phytoremediation. The efficient use of plants for removal, degradation or detoxification of chemicals present in the soil surface or groundwater.

Importance in agriculture

Mycorrhizae are major components of soil ecosystems and thus are essential for the survival of plant species. They also act as indicators of plant health and soil toxicity. Agricultural practices largely impact the activity of mycorrhiza. Soil tillage breaks up AM hyphal networks leading to a significant reduction in colonization of roots and phosphorus absorption from the soil. The genetic approach to improve crop plants may expedite the loss of AM fungal diversity if the selected hybrid plant genotype is unable to associate with the previous fungal partner. Indiscriminate use of fertilizers and pesticides can inhibit the formation and growth of both endo- and ectomycorrhiza. Land and air pollution, mining, deforestation, etc., are some of the non-agricultural activities that have severe impacts on mycorrhizal survivability. Decomposition of excessive ammonia present in the atmosphere cause physiological alterations such as cellular acidosis in plants and mycorrhizal species. Terrestrial pollutants such as polyaromatic hydrocarbons also have an adverse impact on mycorrhizal species.

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. But present day practices of agriculture may lead to the destruction of these beneficial associations. Anthropogenic activities like slash and burn cultivation, mining, waste disposal, and clear-cutting of forests are also detrimental to mycorrhizae. The fundamental importance of mycorrhizal associations is evident in restoration and revegetation of unfertilized/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 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. 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 for our future generations.