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Potential Application Of Mycorrhiza As A Biofertilizer: A Review

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ABSTRACT

Mycorrhiza, a beneficial association between plant roots and specific soil growths, is crucial for enhancing biological system cycling and protecting plants from environmental and social pressures. Mycorrhiza can be created by many important plant species, with the arbuscular mycorrhizal (AM) association being the most prevalent form used in agricultural systems. As with green frameworks, AM biotechnology is feasible for crops using a transplant organization. The possibilities of AM's beneficial involvement in green practices are evaluated using current advancements and bits of knowledge. It is acknowledged that a proper administration of this favorable interaction would allow a good decrease in concoction given the effects of AM immunization on plant development and wellbeing as biofertilizers and guardians. Compost and pesticide inputs, two essential aspects for creating practical agricultural plants, are becoming closer. The greatest benefits can obtain by immunizing with effective AM parasites and carefully selecting suitable have/organism/substrate mixtures. By ensuring an appropriate mycorrhizal foundation at our planting, we may significantly reduce the display of micro-propagated plants or fake seeds. In particular, immunization with AM growths seems to improve the endurance rate and quality of woody green plants, which are challenging to develop in vitro. Rhizobacterial interactions with AM organisms can be a useful biotechnological tool for promoting plant growth and health through an integrated management strategy. Mycorrhizal inoculum production techniques should be improved for the optimum possible use of AM biotechnology in commercial agricultural plant formation.

Keywords: Mycorrhiza, Biofertilizer, arbuscular mycorrhizal

1. Introduction

The term "mycorrhiza" alludes to the relationship between fungi and roots. This association is typically considered an advantageous mutualistic interaction due to their exceptional relationship, where the host plant receives mineral supplements through contagious mycelium. At the same time, the heterophilic organisms get carbon from the host photosynthesis (Teste *et al.*, 2020). During the procedure of mycorrhiza development in which, the plant 'acknowledges' the contagious colonization without any significant dismissal response. A progression of root parasite communications gives way to the integration of both living organisms. This thus leads to the improvement of an all-around adjusted 'solidarity' inside the setting of the soil-plant biological system. Regardless of the shortage of exploratory data, it has acknowledged that the foundation of the symbiosis must be the result of a continuous molecular 'exchange' between plant and organism, as applied through trading both acknowledgment signals. The parasite turns into a fundamental piece of the framework. The advantageous interaction is considered the most metabolically active component of the fascinating organs of the autotrophic host plant. In addition, furnishing the heterotrophic contagious partner with natural supplements is an environmentally ensured living space for the organism. Mycorrhiza can found in practically any sort of soil. Everything except a couple of vascular plants. (those belonging mainly to the families Cruciferae, Chenopodiaceae, Cyperaceae,) can shape mycorrhiza. The physiology of the plant is exceptionally influenced by the presence of contagious symbiosis (Smith *et al.*, 2010).

The universality of this symbiosis implies a great diversity in the taxonomic features of the fungi and the plants involved. There are significant differences in the mycorrhizal type morphology, which is reflected in the resulting physiological relationships (Barea *et al.,* 2000). About 3% of the higher plants, Betulaceae, Pinaceae, eucalyptus, and some woody vegetables, structure ectomycorrhiza. The parasites are generally higher basidiomycetes and ascomycetes, colonizing the cortical root tissues. An absence of intracellular entrances is a trademark. By and large, the parasite boils up a sheath or mantle around the feeder roots. Three different kinds of mycorrhiza can gather as endomycorrhiza, in which the organism can colonize the root cortex intracellularly (Kumari *et al.,* 2013). One of these is confined to a few species in the Ericaceae ('ericoid mycorrhiza'), the second to the orchidaceous ('orchid mycorrhiza'), and the third the arbuscular mycorrhizas, which is by a wide margin the most across the board type.

There is a fifth gathering, the ectendomycorrhiza. Made out of plant species I families. Other than Ericaceae. However, in the Ericales and the Monotropaceae. They have a sheath; what's more, they produce intracellular infiltrations (arbutin and monostrophic mycorrhiza). The environmental and conservative estimation of arbuscular mycorrhiza can straightforwardly deduce that around four, the fifth of all land plants, including the agronomically significant yields, structure this kind of mycorrhiza, as expressed previously, the arbuscular mycorrhiza are by a wide margin the commonest in plants. Consequently, from here on, this study will be concerned distinctly with the 'arbuscular' type, which will be avoided in paper similar to 'advantageous interactions or just 'mycorrhiza' (Milleret *et al .,* 2009).

Fertilizer nitrogen will continue to serve for increasing grain production into the foreseeable future, but efforts should also oriented towards augmenting biological nitrogen fixation mediated by microorganisms. The annual turnover of nitrogen in the biosphere varies from100 to 200 million tons. The ratio between chemically fixed and biologically fixed nitrogen ranges from 1:4 to 1:2.5 and within biologically fixation

(Davey *et al.,* 1984). The amounts of nitrogen fixed by grains of legumes have been made by the International Atomic Energy Agency (IAEA), Vienna, using labeled nitrogenous fertilizers. Some of the results were obtained by the collaborating scientists in the agency's network of experiments in different countries. The demand for chemically fixed nitrogen is bound to increase, and the nitrogen gap would be difficult to bridge in the wake of the energy crisis.

Furthermore, no breakthrough in chemical fixation is yet visible to minimize the energy requirements of the conventional Haber-Bosch process for ammonia production. In developing countries, the construction of new nitrogen fertilizer plants is not only expensive but time-consuming. Formers in many parts of Africa do not use inorganic nitrogenous fertilizers because they are imported and expensive. Therefore, the strategy for improving agricultural production in developing countries should consider inexpensive, realistic, and pragmatic programs to augment biological nitrogen fixation (Vonderembse *et al.*, 1997).

2. Properties of AM (arbuscular mycorrhizal)

A few of the properties innate in every unified framework are especially pertinent in AM affiliations, particularly reliance, similarity, explicitness, etc. It appears that specific growth assumed an essential job in the advancement of 'plants' as they colonized the land in the late Silurian and early Devonian period (400 $\times 10^2$) in that they seem to have become related to such 'plants' therefore encouraging the supplement take-up forms (Nicolson *et al.,* 1975) these affiliations might be considered mycorrhiza. The plant/mycorrhiza coevolution may represent the around-the-world spread of AM beneficial interaction and its harmonious properties. These properties are resolved by:
(1) the ability of the plant to supplement through a growth

(2) the challenges of the growth to finish its life cycle autonomously of the host plant since it is a physiologically committed symbiont

(3) the qualities of the plant as communicated by how much it is reliant on mycorrhizas for its proper development (mycorrhizal reliance of a plant) (Janos *et al.*, 2007).

This reliance on mycorrhizas changes starting with one plant animal group and then onto the next. Some need the AM beneficial interaction to endure, others to improve their development, and others to accomplish their most significant advancement. This shows the plant genotype controls the measure of root tissue that would become mycorrhizal. Since the parasites likewise contrast in the degree to which they colonize the root arrangement of a given host plant, it follows that a particular kind of 'explicitness' can be perceived in the advantageous interaction in which they participate. Here, the idea of 'similarity' emerges, which must be related to 'cooperative viabilities to build up that of 'utilitarian similarity' (Morandi *et al.*, 1984). The last alludes to the phenotypic articulation of the AM status because of the ecological effects on the declaration of the genotypic gear of both the plant and the parasite. There is proof of organism plant 'acknowledgment' forms at a few phases. Such proof incorporates (Azcón *et al.*, 1994).

3. Classification of biofertilizer

Classification of Biofertilizers Several microorganisms and their association with crop plants are being exploited in the production of biofertilizers. They can grouped in different ways based on their nature and function.

Rhizobium

Rhizobium is a bacteria that lives in soil habitats and colonizes legume roots to fix atmospheric nitrogen symbiotically. Rhizobium’s appearance and physiology range from free-living environments to the bacteroid seen in nodules. Regarding the number of nitrogen-fixed concerns, they are the most effective biofertilizer. They are known as the cross-inoculation group and contain seven genera. They are very specialized in developing nodules in legumes. In Bergey’s Manual of Determinative Bacteriology, Rhizobium has been grouped into various families, including *Azotobacteriaceae*, *Mycobacteriaceae*, *Myxobacteriaceae*, and *Pseudomonadaceae*. The cataloging of data for identifying bacteria was initially described in Bergey’s Manual of Determinative Bacteriology. Such references are followed by Bergey’s Manual of Systematic Bacteriology (Bergey *et al*., 1994), which was revised extensively by the American Society of Bacteriology (now known as the American Society for Microbiology). Rhizobium is classified based on the cross-inoculation grouping provided by Fred’s historical studies. The capacity of an isolate of Rhizobium to develop nodules on the roots of a few closely related species of legumes serves as the foundation for cross-inoculation grouping. This idea has led to the classification of Rhizobia, which may produce nodules on the roots of specific legumes as a species (Fred *et al*., 2002)

Azotobacter

Of the several species of *Azotobacter*, *A. chroococcum* is the dominant inhabitant in arable soils capable of fixing N2 (2-15 mg N2 fixed /g of carbon source) in culture media. The bacterium produces tremendous slime, which helps in soil aggregation. The number of *A. chroococcum* in Indian soils rarely exceeds 105/g soil due to the lack of organic matter and the presence of antagonistic microorganisms in the soil (Asoegwu *et al*., 2018).

Azospirillum

Azospirillum lipoferum and *A. brasilense* (Spirillum lipoferumin in earlier literature) are primary inhabitants of soil, the rhizosphere, and intercellular spaces of the root cortex of *graminaceous* plants. They develop an associative symbiotic relationship with *graminaceous* plants. Apart from nitrogen fixation, growth promoting substance production (IAA), disease resistance, and drought tolerance are some of the additional benefits of inoculation with *Azospirillum*. Cyanobacteria: Both free-living and symbiotic cyanobacteria (blue-green algae) have been harnessed in rice cultivation in India. Once so much publicized as a biofertilizer for rice crop, it has not presently attracted the attention of rice growers all over India. The benefits of legalization could be to the extent of 20-30 kg N/ha under ideal conditions. Still, the labor-oriented methodology for preparing BGA biofertilizer is a limitation (Gebrewold *et al*., 2018).

Azolla

Azolla is a free-floating water fern that floats in water and fixes atmospheric nitrogen in association with nitrogen fixing blue green alga *Anabaena azollae*. Azolla is either an alternate nitrogen source or a supplement to commercial nitrogen fertilizers. Azolla is used as a biofertilizer for wetland rice, and it is known to contribute 40-60 kg N/ha per rice crop (Lumpkin *et al*., 1980).

Phosphate solubilizing microorganisms (PSM)

Several soil bacteria and fungi, notably Pseudomonas, Bacillus, Penicillium, and Aspergillus species. Secrete organic acids and lower the pH in their vicinity to dissolve bound phosphates in soil. Increased yields of wheat and potato were demonstrated due to inoculation of peat-based cultures of *Bacillus polymyxa* and *Pseudomonas striata* (Rodríguez *et al*., 1999).

AM fungi

The transfer of nutrients, mainly phosphorus and also zinc, and sulfur, from the soil milieu to the cells of the root cortex is mediated by intracellular obligate fungal endosymbionts of the genera *Glomus*, *Gigaspora*, *Acaulospora*, *Sclerocysts*, and *Endogone* which possess vesicles for storage of nutrients and arbuscles for funneling these nutrients into the root system. The commonest genus appears to be Glomus, which has several species distributed in soil (IJdo *et al*., 2011).

Silicate solubilizing bacteria (SSB)

Microorganisms are capable of degrading silicates and aluminum silicates. During the metabolism of microbes, several organic acids are produced, which have a dual role in silicate weathering. They supply H+ ions to the medium and promote hydrolysis and the organic acids like citric, oxalic acid, Keto acids, and hydroxy carbolic acids, which form complexes with cations, promoting their removal and retention in the medium in a dissolved state (Raturi *et al*., 2021).

4. Plant growth promoting rhizobacteria (PGPR)

Rhizobacteria, known as “plant growth promoting,” infiltrate soil around roots or the rhizosphere and are helpful to crops (PGPR). The PGPR inoculants stimulate growth by inhibiting plant disease (termed “bioprotectants”), enhancing nutrient uptake (termed “biofertilizers”), or producing phytohormones (termed Biostimulants). Phytohormones or growth regulators that enable crops to have more fine roots increase the porous surface of plant roots for uptake of water and nutrients. Species of Pseudomonas and Bacillus can create these substances. However, they are still poorly understood. These PGPR, also known as biostimulants, generate phytohormones, including indole-acetic acid, cytokinins, gibberellins, and inhibitors of ethylene synthesis.) Numerous and varied interactions among these components contribute to the soil ecosystem’s complexity.

its biological, chemical, and physical elements (Datta *et al*., 2015). As such, bacteria are thought to be potent forces for certain enzyme-mediated core metabolic processes, and their varied genetic and functional activities have a crucial impact on soil functioning (Muneese *et al*., 2009). The expanded microbial variety, as well as the increased numbers and activity of the microorganisms in the rhizosphere, are caused by the specific Physico-chemical and biological features of the soils connected with the roots as compared to the soils away from the root and root surface (Zahir *et al*., 2004). When plants and microbes interact, plant roots produce organic substances consumed as nutrients by root-associated microorganisms. Additionally, organic substances are given to the soil microbiota by decomposing dead plant matter, such as growth substrates, structural elements, signal chemicals, and decomposing plants. The rooting pattern and nutrition availability of the plants are impacted by microbial activity in the rhizosphere (Gryndler *et al*., 2000). Beneficial, rhizosphere-colonizing bacteria: Growth of Plants A kind of bacteria known as “promoting bacteria” colonizes the roots and thrives in the microhabitats found on the surface of the roots to support plant growth and defense. These are naturally occurring, soil-borne bacteria that, when added to seeds, soil, or crops, promote plant growth by supplying nutrients and lessening the harm caused by soil-borne pathogens (Zablotowicz *et al*., 1991). Plant interactions with rhizosphere microorganisms impact the overall crop yield and commercial agricultural productivity. as growth substrates, structural elements, signal chemicals, and decomposing plants. The rooting pattern and nutrition availability of the plants are impacted by microbial activity in the rhizosphere. Beneficial, rhizosphere-colonizing bacteria: Growth of Plants A kind of bacteria known as “promoting bacteria” colonizes the roots and thrives in the microhabitats found on the surface of the roots to support plant growth and defense. These are naturally occurring, soil-borne bacteria that promote plant growth by supplying nutrients and lessening the harm caused by soil-borne pathogens when added to seeds, soil, or crops. Plant interactions with rhizosphere microorganisms impact overall crop yield and commercial agricultural productivity (Shaw *et al*., 2006).

5. Microbial Biofertilizers: Types and Applications

5.1 Sources of biofertilizers

As a result of the referenced disadvantages of synthetic manures, it is basic to diminish the utilization of compound composts and pesticides in farming without having any unfriendly impact on crop creation by the consolidation and utilization of innocuous, sustainable contributions of composts. The most appropriate options for synthetic composts are biofertilizers that incorporate natural waste and dead creatures, just like living creatures, For instance, excrement and manure are reasonable for pretty much every assortment of plants, and eggshells have high calcium and Stellaria media (chickweed), *Equisetum sp*. (horsetail), *Azolla pinnata*, *Arctium sp.* (burdock), *Rumex Crispus* (yellow dock), *Symphytum officinale* (comfrey). *Urtica dioica* (brambles) have high nitrogen content. Network waste and sewage slop give a reasonable wellspring of plant sustenance; however, these may contain overwhelming metals and may effectively affect harvests, buyers, and soil microorganisms (Giller *et al*., 1998). All the more significantly, biofertilizers can create effective microbial strains that, by their connections in the rhizosphere, advantage crop plants by taking supplements.

By certain known and obscure components, numerous microscopic organisms distinguished as plant development advancing rhizobacteria (PGPR) can animate plant development. The significant realized instruments showed by PGPR that advance

plant development is barometrical nitrogen obsession, phosphorus solubilization, supplement take-up improvement, or plant development hormones (Bashan *et al*., 1990).

Achromobacter, a PGPR, was found to upgrade the length just as the number of root hairs and expanded nitrate and potassium take-up in Brassica napus (oilseed assault), which was apparent through the expanded dry loads of shoot (from 22% to 33%) and root (from 6% to 21%) (O'Brien *et al.*, 2016). In this manner, different sorts of biofertilizers are ideal supplements to trim the plant, prevent immediate ostensible harm to the condition, and improve the biodiversity of the soil(Sharma *et al*., 2021). Their utilization, later on, is expected to increment because of by and large increment in the interest of manures to produce more nourishment on constrained arable land and further because of depleting feedstock/ petroleum products (vitality emergency), expanding concoction manure cost, draining soil fruitfulness, worries about natural dangers, and an expanding risk to maintainable agriculture (FU *et al*., 2016).

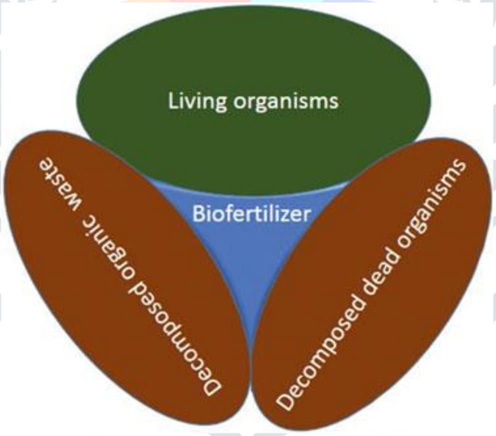

Figure 1: Source of biofertilizer

5.2 Microbial Biofertilizers

When applied to plant surfaces, seeds, or soil, a biofertilizer of chosen effective living microbial cultures can colonize the rhizosphere or the interior of the host plant, thereby promoting plant development by increasing the availability, supply, or uptake of primary nutrients to the host. Additionally, marginal and small farmers have easier access to biofertilizers than chemical fertilizers. Most of the bacteria, fungus and cyanobacteria employed in manufacturing microbial biofertilizers belong to these three effective microbes and have symbiotic relationships with plants. Based on their origin and function, microbial fertilizers that supply nitrogen and phosphorus are the most significant varieties (Banerjee *et al*., 2006).

5.3 Nitrogen-Fixing Microbes

Nitrogen is most abundant and ubiquitous in the air yet becomes a limiting nutrient due to the difficulty of its fixation and uptake by the plants. However, certain microorganisms, some of which can form various associations with plants, are capable of considerable nitrogen fixation. This property allows for the efficient plant uptake of the fixed nitrogen and reduces losses by denitrification, leaching, and volatilization. These microbes can be:

(a) Free-living in the soil. Assessing nitrogen fixation by free-living bacteria is difficult, but in some plants like Medicago sativa, it has been estimated to range from 3 kg N ha^{-1} to 10 kg N ha^{-1}. *Azotobacter chroococcum* in arable soils can fix 2–15 mg N ^{1} of carbon source in culture media, and it further produces abundant slime which aggregates soil. However, free-living cultures of nodulating bacterial symbionts (e.g., Frankia) have been found to fix atmospheric nitrogen in the rhizosphere of their host and even non-host plants. For *Beijerinckia mobilis* and *Clostridium spp*., inoculation methods of leaf spray and seed soaking stimulated growth in cucumber and barley plants by significant nitrogen fixation and other mechanisms of bacterial plant growth hormone synthesis. Free-living cyanobacteria (blue-green algae) have been harnessed in India's rice cultivation, providing up to 20–30 kg N ha^{-1} under ideal conditions.

(b) Having symbiotic and other endophytic associations (of rhizobia, Frankia, and cyanobacteria) with plants. The nitrogen-fixing efficiency of rhizobia bacteria is an important group of biofertilizers that contains organisms like Rhizobium, *Bradyrhizobium*, *Sinorhizobium*, *Azorhizobium*, *Mesorhizobium*, and *Allorhizobium*, can vary till 450 kg N ha^{-1} among different strains and host legume species, in which root nodules are formed. The *rhizobial* biofertilizers can be in powder, liquid, and granular formulations, with different sterilized carriers like peat, perlite, mineral soil, and charcoal. Like rhizobia, Frankia, a nitrogen-fixing actinomycete, can also form root nodules in several woody plants (Thomas *et al*., 2019)

(c) Living in the rhizosphere (associative/associated) without endophytic symbioses. Compared to endophytic symbionts, these nitrogen-fixing microbes have a less intimate association with roots. These include *Acetobacter diazotrophicus* and Herbaspirillum spp. with sugarcane, sorghum, and maize Azoarcus spp. with *Leptochloa fusca* (taller grass) species of *Alcaligenes*, *Azospirillum*, *Bacillus*, *Enterobacter*, *Herbaspirillum*, *Klebsiella*, and *Pseudomonas* with rice and maize and *Azospirillum* with great host specificity comprising a variety of annual and perennial plants. Several studies have shown that due to nitrogen fixation and production of growth-promoting substances, *Azospirillum* increased the growth and crop yield of wheat, rice, sunflower, carrot, oak, sugar beet, tomato, eggplant, pepper, and cotton. The inoculum of *Azospirillum* can be inexpensively produced and applied by a simple peat formulation. The biofertilizer of *Acetobacter diazotrophicus* was found to fix and make available up to 70% of sugarcane crop nitrogen requirement of about 150 kg N ha1 annually (Boddey *et al.*, 1995).

5.4 Phosphorus-Solubilizing Microbes

Phosphorus is the second most restricting nutrient for plants after nitrogen in soil due to its high concentration and the fact that most of it are contained in inaccessible forms. By relocating phosphorus from the inaccessible forms in the soil, phosphorus-solubilizing bacteria (PSB) like *Bacillus* and *Pseudomonas* can boost the availability of phosphorus to plants. (Richardson *et al.*, 2001). These microorganisms, along with specific soil fungi like Penicillium and Aspergillus, cause the soil's bound phosphates to dissolve by secreting organic acids that have a lower pH near them. *Bacillus megaterium* var. phosphatic, and inexpensive rock phosphate with a PSB, were applied to sugarcane and increased sugar yield and juice quality by 12.6%. It also decreased the amount of phosphorus needed by 25%, which resulted in a further 50% decrease in the use of expensive superphosphate. (Sundara *et al.*,2002).

5.5 Compost Biofertilizers

Compost is a disintegrating, brittle, murky substance that creates a symbiotic food web in the soil. It contains microbes, earthworms, dung beetles, and around 2% (w/w) of nitrogen, phosphate, and potassium. In addition to providing crops with beneficial minerals and increasing soil microbial diversity, microbial oxidation of solid organic residues by microorganisms results in the formation of humus-containing material, which can be used as an organic fertilizer to sufficiently aerate, aggregate, buffer, and keep the soil moist (Said *et al.*, 2007). Composting is created from various materials, including straw, leaves, bedding from cow stalls, fruit and vegetable wastes, slurry from biogas plants, industrial wastes, rubbish from city factory waste, sewage sludge, etc. These components are used to create the compost, and several microorganisms that break down, including *Trichoderma viridae*, *Aspergillus niger*, Several Gram-negative bacteria, including *A. terreus*, *Bacillus* species, and Pseudomonas and Serratia. Those bacteria (such as Klebsiella and Enterobacter), etc., exhibit cellulolytic or, in addition to proteolytic activity and antibiosis, exhibit ligninolytic and other activities. (Through the creation of antibiotics) that suppresses other parasitic or pathogenic microorganisms. Another important type (vermicompost) contains earthworm cocoons, excreta, microorganisms (like bacteria, actinomycetes, and fungi), and different organic matters, which provide nitrogen, phosphorus, potassium, and several micronutrients, and efficiently recycle animal wastes, agricultural residues, and industrial wastes cost-effectively and uses low energy (Boulter *et al.*, 2002).

5.6 Mycorrhizal Biofertilizers

These are phosphate absorbers or phosphorus-mobilizing biofertilizers. More than 80% of all land plants have functioning mutualistic symbioses with mycorrhizal fungi, in which the fungus relies on its host for photosynthates and energy while offering various benefits to it. (Thakur *et al.*, 2018). The mycelium of the fungus grows from the root surfaces of the host plant into the soil, increasing the surface area for the plant to more effectively access and acquire nutrients, especially from sources of insoluble phosphorus and other elements like calcium, copper, zinc, etc. (Singh *et al.*, 2017). Furthermore, mycorrhizal fungi improve plant resistance to root diseases and herbivores, soil quality, soil aeration, water dynamics, heavy metals, and drought. (Rillig *et al.*, 2002). This indicates that these fungi have great potential for use in agriculture, land reclamation, or vegetation restoration. Basidiomycetes' ectomycorrhiza produces a mantle on the root surface of various trees, including Eucalyptus, Quercus, peach, pine, and others, penetrating internally into the intercellular spaces of the cortical region, where it acquires the sugars and other nutrients generated by the plant. These fungi perform several crucial tasks, including expanding the surface area of roots to absorb water and minerals, solubilizing soil humus organic matter to release and absorb inorganic nutrients, and secreting enzyme compounds with antibacterial properties that shield plants from different root diseases. Tree plantations have been shown to benefit from ectomycorrhizal symbiosis regarding the growth and nutrient uptake, particularly when large-scale inoculum procedures are used in nursery or forestry cultivated areas. Glomus and other arbuscular mycorrhizal (AM) fungi are non-specific, intercellular, obligatory endosymbionts with unique root vesicles and arbuscular structures. Compounds with antibacterial properties that shield plants from different root diseases. Tree plantations have been shown to benefit from ectomycorrhizal symbiosis regarding the growth and nutrient uptake, particularly when large-scale inoculum procedures are used in nursery or forestry cultivated areas. Glomus and other arbuscular mycorrhizal (AM) fungi are obligatory endosymbionts that are intercellular and non-specific with special structures of vesicles and arbuscules in roots (Mikola *et al.*, 1970).

Regarding a suitable replacement for chemical fertilizers, which are linked to several environmental risks, biofertilizers are a crucial part of sustainable organic farming in contemporary agricultural practices. Biofertilizers can produce hormones and antimetabolites to support root growth, decompose organic matter for soil mineralization, fix and make atmospheric nitrogen available in the soil and root nodules, solubilize phosphate (from insoluble forms like tricalcium, iron, and aluminum phosphates into available forms), sift phosphates from soil layers, and sift phosphates from soil layers. Increased harvest yields and improved soil structure result from this. Unpolluted water sources induced drought tolerance in plants and altering soil particle aggregation for better water relations (by enhancing leaf water and turgor potential, maintaining stomatal functioning, and increasing root development). However, a greater demand for and understanding of the usage of biofertilizers among farmers and planters might open the door for new entrepreneurs to enter the biofertilizer production industry, which also needs government assistance and encouragement. As a necessary component of sustainable agriculture, biofertilizer technology must be appropriate for the social and infrastructure needs of the users, economically feasible and viable, renewable, applicable to all farmers equally, stable in the long run, accepted by various societal segments, and adaptable to local conditions and different cultural patterns, of society, workable in practice, and fruitful. Thus, it is clear that thorough practical training of dealers and farmers is necessary to improve knowledge of the importance and economic viability of applying biofertilizer technology.

References:

1. Teste, F. P., Jones, M. D., & Dickie, I. A. (2020). Dual-mycorrhizal plants: their ecology and relevance. *New Phytologist*, *225*(5), 1835-1851.

2. Smith, S. E., & Read, D. J. (2010). *Mycorrhizal symbiosis*. Academic Press.
3. Barea, J. M. (2000). rhizosphere and mycorrhiza of field crops. In *Biological resource management connecting science and policy* (pp. 81-92). Springer, Berlin, Heidelberg.
4. Kumari, R., Prasad, R., Pham, G. H., Garg, A. P., & Varma, A. (2013). Biotechnology—an overview. *Biotechnological Applications of Microbes: Volume II*, *2*, 1.
5. Milleret, R., Le Bayon, R. C., & Gobat, J. M. (2009). Root, mycorrhiza and earthworm interactions: their effects on soil structuring processes, plant and soil nutrient concentration, and plant biomass. *Plant and Soil*, *316*(1), 1-12.
6. Nicolson, T. H. (1975). Evolution of vesicular-arbuscular mycorrhizas. In *Endomycorrhizas; Proceedings of a Symposium*.
7. Davey, M. R., & O'hara, G. W. (1984). In vitro systems for studying nitrogen fixation. In *Applications of genetic engineering to crop improvement* (pp. 25-52). Springer, Dordrecht. Davey, M. R., & O'hara, G. W. (1984). In vitro systems for studying nitrogen fixation. In *Applications of genetic engineering to crop improvement* (pp. 25-52). Springer, Dordrecht.
8. Vonderembse, M. A., Raghunathan, T. S., & Subba Rao, S. (1997). A post-industrial paradigm: to integrate and automate manufacturing. *International Journal of Production Research*, *35*(9), 2579-2600.
9. Janos, D. P. (2007). Plant responsiveness to mycorrhizas differs from dependence upon mycorrhizas. *Mycorrhiza*, *17*(2), 75-91.
10. Morandi, D., Bailey, J. A., & Gianinazzi-Pearson, V. (1984). Isoflavonoid accumulation in soybean roots infected with vesicular-arbuscular mycorrhizal fungi. *Physiological Plant Pathology*, *24*(3), 357-364.
11. Azcón-Aguilar, C., & Bago, B. (1994). Physiological characteristics of the host plant promote an undisturbed functioning of the mycorrhizal symbiosis. In *Impact of arbuscular mycorrhizas on sustainable agriculture and natural ecosystems* (pp. 47-60). Birkhäuser, Basel. Azcón-Aguilar, C., & Bago, B. (1994). Physiological characteristics of the host plant promote an undisturbed functioning of the mycorrhizal symbiosis. In *Impact of arbuscular mycorrhizas on sustainable agriculture and natural ecosystems* (pp. 47-60). Birkhäuser, Basel.
12. Bergey, D. H. (1994). *Bergey's manual of determinative bacteriology*. Lippincott Williams & Wilkins.
13. Fred, E. B., Baldwin, I. L., & McCoy, E. (2002). *Root nodule bacteria and leguminous plants* (No. 5). UW-Madison Libraries Parallel Press.
14. Asoegwu, C. R., Awuchi, C. G., Nelson, K., Orji, C. G., Nwosu, O. U., Egbufor, U. C., & Awuchi, C. G. (2020). A review on the role of biofertilizers in reducing soil pollution and increasing soil nutrients. *Himalayan Journal of Agriculture*, *1*, 34-38.
15. Gebrewold, A. Z. (2018). Review on integrated nutrient management of tea (Camellia sinensis L.). *Cogent Food & Agriculture*, *4*(1), 1543536.

16. Lumpkin, T. A., & Plucknett, D. L. (1980). Azolla: botany, physiology, and use as green manure. *Economic Botany*, *34*(2), 111-153.
17. Rodríguez, H., & Fraga, R. (1999). Phosphate solubilizing bacteria and their role in plant growth promotion. *Biotechnology advances*, *17*(4-5), 319-339.
18. IJdo, M., Cranenbrouck, S., & Declerck, S. (2011). Methods for large-scale production of AM fungi: past, present, and future. *Mycorrhiza*, *21*(1), 1-16.
19. Raturi, G., Sharma, Y., Rana, V., Thakral, V., Myaka, B., Salvi, P., ... & Deshmukh, R. (2021). Exploration of silicate solubilizing bacteria for sustainable agriculture and silicon biogeochemical cycle. *Plant Physiology and Biochemistry*, *166*, 827-838. Raturi, G., Sharma, Y., Rana, V., Thakral, V., Myaka, B., Salvi, P., ... & Deshmukh, R. (2021). Exploration of silicate solubilizing bacteria for sustainable agriculture and silicon biogeochemical cycle. *Plant Physiology and Biochemistry*, *166*, 827-838.
20. Datta, A., Singh, R. K., Kumar, S., & Kumar, S. (2015). An effective and beneficial plant growth promoting soil bacterium “Rhizobium”: a review. *Ann Plant Sci*, *4*(1), 933-942.
21. Munees, A., & Khan, M. S. (2009). Effect of insecticide-tolerant and plant growth-promoting Mesorhizobium on the performance of chickpea grown in insecticide stressed alluvial soils. *Journal of Crop Science and Biotechnology*, *12*(4), 213-222.
22. Zahir, Z. A., Arshad, M., & Frankenberger, W. T. (2004). Plant growth promoting. *Advances in agronomy*, *81*, 97.
23. Gryndler, M. (2000). Interactions of arbuscular mycorrhizal fungi with other soil organisms. In *Arbuscular mycorrhizas: physiology and function* (pp. 239-262). Springer, Dordrecht.
24. Zablotowicz, R. M., Tipping, E. M., Lifshitz, R., & Kloepper, J. W. (1991). Plant growth promotion is mediated by bacterial rhizosphere colonizers. In *The rhizosphere and plant growth* (pp. 315-326). Springer, Dordrecht.
25. Shaw, L. J., Morris, P., & Hooker, J. E. (2006). Perception and modification of plant flavonoid signals by rhizosphere microorganisms. *Environmental Microbiology*, *8*(11), 1867-1880.
26. Giller, K. E., Witter, E., & Mcgrath, S. P. (1998). Toxicity of heavy metals to microorganisms and microbial processes in agricultural soils: a review. *Soil biology and biochemistry*, *30*(10-11), 1389-1414.
27. Bashan Y, Harrison SK, Whitmoyer RE (1990) Enhanced growth of wheat and soybean plant inoculated with Azospirillum brasilense is not necessary due to general enhancement of mineral uptake. Appl Environ Microbiol 56:769–775
28. O’Brien, F., & Mary, J. (2016). *The role of the rhizosphere microbial community in plant chemistry and aphid herbivory in Brassica oleracea* (Doctoral dissertation, University of Southampton).
29. Sharma, P., Sharma, M. M. M., Malik, A., Vashisth, M., Singh, D., Kumar, R., ... & Pandey, V. (2021). The rhizosphere, rhizosphere biology, and rhizospheric engineering. In *Plant growth-promoting microbes for sustainable biotic and abiotic stress management* (pp. 577-624). Springer, Cham.

30. FU, D. H., JIANG, L. Y., Mason, A. S., XIAO, M. L., ZHU, L. R., Li, L. Z., ... & HUANG, C. H. (2016). Research progress and strategies for multifunctional rapeseed: a case study of China. *Journal of Integrative Agriculture*, *15*(8), 1673-1684.
31. Banerjee, M. R., Yesmin, L., Vessey, J. K., & Rai, M. (2006). Plant-growth-promoting rhizobacteria as biofertilizers and biopesticides. *Handbook of microbial biofertilizers. Food Products Press, New York*, 137-181.
32. Thomas, L., & Singh, I. (2019). Microbial biofertilizers: types and applications. In *Biofertilizers for sustainable agriculture and environment* (pp. 1-19). Springer, Cham.
33. Richardson, A. E. (2001). Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants. *Functional Plant Biology*, *28*(9), 897-906.
34. Sundara, B., Natarajan, V., & Hari, K. (2002). Influence of phosphorus solubilizing bacteria on the changes in soil available phosphorus and sugarcane and sugar yields. *Field Crops Research*, *77*(1), 43-49.
35. Boulter, J. I., Trevors, J. T., & Boland, G. J. (2002). Microbial studies of compost: bacterial identification, and their potential for turfgrass pathogen suppression. *World Journal of Microbiology and Biotechnology*, *18*(7), 661-671.
36. Said-Pullicino, D., Erriquens, F. G., & Gigliotti, G. (2007). Changes in the chemical characteristics of water-extractable organic matter during composting and their influence on compost stability and maturity. *Bioresource Technology*, *98*(9), 1822-1831.
37. Thakur, P., & Singh, I. (2018). Biocontrol of soil-borne root pathogens: an overview. *Root Biology*, 181-220.
38. Singh, I., & Giri, B. (2017). Arbuscular mycorrhiza mediated control of plant pathogens. In *Mycorrhiza-Nutrient uptake, biocontrol, eco-restoration* (pp. 131-160). Springer, Cham.
39. Rillig, M. C., Wright, S. F., & Eviner, V. T. (2002). The role of arbuscular mycorrhizal fungi and glomalin in soil aggregation: comparing effects of five plant species. *Plant and Soil*, *238*(2), 325-333.
40. Mikola, P. (1970). Mycorrhizal inoculation in afforestation. In *International review of forestry research* (Vol. 3, pp. 123-196).