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Review

Importance of Fungi in Agriculture

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Abstract

A class of eukaryotic creatures known as fungi is a source of food, organic acids, alcohol, antibiotics, compounds that promote growth, enzymes, and amino acids. Microorganisms like mould, yeast, and mushrooms are among them. They feed on the tissue of living or dead plants or animals. In contrast to other living things, fungi are the main decomposers of materials in the ecological system. Fungi are excellent decomposers of organic waste and target cellulose, lignins, gums, and other complex organic materials most quickly. Moreover, fungi can function in a variety of soil reactions, from acidic to alkaline soil responses. Additionally, fungi play a fundamental role in a variety of physiological processes, including mineral and water uptake, chemical alterations, stomatal movement, and the biosynthesis of auxins, lignans, and ethylene, which help plants better detect and adapt to environmental stresses like drought, salinity, heat, cold, and heavy metals.

Keywords: Fungi, Agriculture, Mycorrhiza, Plant growth and microorganism

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Introduction

The microbe was used in agriculture and industrial activities from the very dawn of civilization. Traditional processors have been in use since the dawn of civilization for the production of fermented drinks, bread, and vinegar. Recent improvements in our knowledge of the genetics, physiology, and biochemistry of fungus have prompted the use of fungi in the creation of several agricultural and commercial goods that are significant economically. The location of the soil's fungi is influenced by all environmental conditions.

In the soil, filamentous fungus mostly breaks down organic matter and aid in soil aggregation. In addition to having this property, bound species of Alternaria, Aspergillus, Cladosporium, Dematium, Gliocladium, Humicola, and Metarhizium produce chemicals that resemble organic substances in soil and may therefore be required for the preservation of soil organic matter.

Crop productivity has been increased using chemical fertilizers and plant growth regulators. The use of chemical fertilizers on crop plants has a severe impact on the environment and human health. Current research has concentrated on finding alternate strategies to improve plant yield and safeguard the soil. Although many plant-associated fungi are widely known for their ability to support plant growth, the interaction between these microorganisms and plants is still unknown. Soil-borne bacteria can penetrate roots and establish their population in plants as endophytes. Microorganisms have the capacity to synthesize phytohormones, dissolve insoluble phosphate, and simplify complicated chemical compounds. It has also been demonstrated that endophytic fungus gives plants a tolerance to salt, drought, heat, and diseases. The capacity of the four endophytic fungi (GM-1, GM-2, GM-3, and GM-4) to enhance soybean plant development under salinity stress conditions was examined. In comparison to controls, seeds prepared with endophytic fungal cultures had increased seed germination and plant growth rates. Gibberellins study of culture filtrate (CF), which revealed a vast diversity and varied amounts of Gibberellic acids, confirmed the beneficial influence of fungi on plant growth.

Rhizospheric fungus application is an efficient and sustainable way to improve plant growth and manage a variety of plant diseases. For their ability to stimulate growth in sesame seedlings, three dominant fungi (PNF1, PNF2, and PNF3) isolated from the rhizospheric soil of peanut plants were tested. PNF2 significantly boosted the shoot length and fresh weight of seedlings across these isolates as compared to controls. PNF2 had a larger quantity of indole acetic acid than the other isolates, according to an analysis of the fungal culture filtrate. The fungal interactions with plants influence the primary and secondary metabolism of plants at all developmental stages. The principal mechanism of photosynthesis and the source of energy for plants. Chlorophyll and carotenoids are examples of photosynthetic pigments that are connected to this efficiency. More so than in the controls, plants treated with fungus showed an increase in leaf chlorophyll.

Fig: Importance of medicinal fungi in agriculture

Role of soil fungus

In low pH or slightly acidic soils, where soils are more likely to be undisturbed, fungi predominate. Several different types of bacteria will start to degrade and transform the organic residues into useable products as a result of fungi breaking down the organic residues. Around 90% of all plants develop hyphae networks that symbiotically connect them to mycorrhizal fungus. The plant mostly receives phosphate and other minerals from the soil through mycorrhizae, including zinc and copper. The plant root serves as a source of nutrition for the fungus, including sugars. A mycorrhizae network is the name given to this cooperative interaction.

Although soil fungus can thrive in a wide variety of pH levels, they are more prevalent in acidic circumstances due to intense competition with bacteria at neutral pH levels. Most fungi prefer to thrive at the ideal soil moisture level and are aerobic in nature. These organisms barely have a role in the metabolic changes caused by high wetness. The area near to the ground where various chemicals and organic chemistry processes take place is known as the rhizosphere. It is dominated by soil bacteria. Up to 10–30% of the soil rhizosphere is made up of soil fungi. Due to their capacity to create a wide range of extracellular enzymes, fungus can decompose many types of organic materials, consequently controlling the balance of nutrients and carbon to maintain healthy soil.

Table 1: Agricultural application of medicinal fungi

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

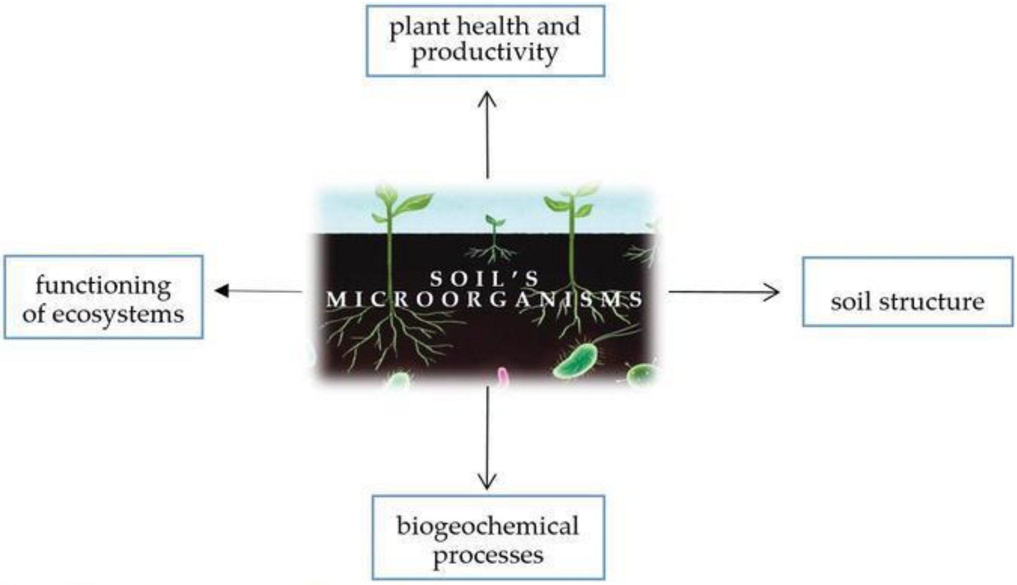
Functions of the soil microbiome

One gram of healthy soil usually contains a microbiome comprising many millions of microbes, including archaea, bacteria and fungi. It is estimated range from 1 g of soil, contain about 4000–6000 bacterial genomes can be isolated (Torsvik et. al., 1996). Some microbes colonize the area around plant roots, known as the rhizosphere, forming mutually beneficial associations (symbioses) with plants.

These symbiotic microbes, and other free-living soil microbes, contribute to crop growth and soil health by:

- Cycling nutrients, including nitrogen and phosphate, which are essential for plant growth. These microbial processes are also important for global biogeochemical cycles.
- Improving soil structure and increasing organic matter content, which are important for fertility, water retention, and minimizing erosion and flood risk.

- Conferring disease resistance to crops by out-competing pathogenic microbes and stimulating biochemical plant defenses.
- Microbes are improving the resilience of plants to environmental stresses, viz. temperature and moisture.
- Enhancing the root growth and nutrient uptake capacity of soil.



Benefits of Microbes in Soil

- Decompose organic matter
- Foster soil aggregate stability
- Recycle and regulate carbon, nitrogen and phosphorous
- Fix nitrogen for plant uptake
- Increase the available plant root area for nutrient uptake
- Degrade pesticides
- Improve soil structure
- Help control diseases

Nutrient Recycling

The soil's microorganisms contribute significantly to increased agricultural output. In fact, soil-dwelling microbes assist plants in absorbing more nutrients. "Nutrient recycling" is a process that involves plants and these helpful bacteria. The bacteria facilitate the plant's "absorption" of necessary energy sources. In exchange, plants provide the microorganisms access to their waste byproducts for nourishment. Trichoderma for example has the ability to secrete large amounts of cellulolytic enzymes and seed germination factors, the quality that is being utilized in nutrient recycling/production of organic tea (concentrates of nutrients from decomposed organic matter) essentially in soilless/ greenhouse crop production. Organic/ compost tea is brewed using either aerated or nonaerated method, provides water soluble available nutrients for plants, increased soil microorganism population and diversity. A arbuscular mycorrhizal fungus *Glomus iranicum* var *tenuihypharum* which increases the nutrient absorption (nitrogen, phosphorus, calcium, potassium, sodium, iron, manganese, etc.), water use efficiency, photosynthesis rate, biomass increase, productive yield (quantity and quality) is commercialized as biostimulants by Symborg, a biotechnology company for the Bio-agricultural sector found in 2009 and currently operating in 31 countries in Europe, US, South America and Asia.

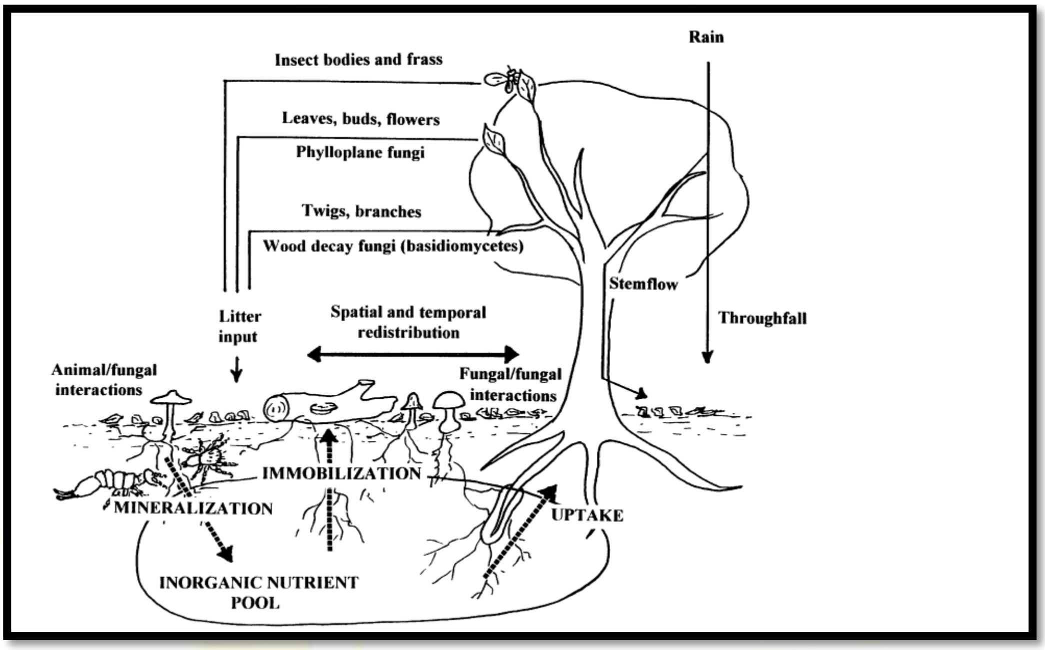


Figure: Nutrient Cycling by Saprotrophic Fungi in Terrestrial Habitats. In: Kubicek, C., Druzhinina, I. (eds) Environmental and Microbial Relationships. The Mycota, vol 4. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-71840-6_16

Sources of Fertilizers (Bio fertilizers)

These are environment friendly, non-bulky, low cost, renewable sources of plant nutrients which supplement chemical fertilizers and play an important role in improving nutrient supplies and their crop availability to crop plants. When applied to seeds, roots, or soil, these helpful microbes in a ready-to-use live formulation mobilize the availability of nutrients through their biological activity. They are simply chosen strains of advantageous soil microorganisms that have been grown in a lab and packaged in a suitable carrier that can be applied to soil or seeds. Through their actions in the soil or rhizosphere, biofertilizers produce plant nutrients like nitrogen and phosphorus and gradually make them available to plants. Due to their potential to preserve soil health, reduce environmental contamination, and reduce the use of chemicals in agriculture, biofertilizers are currently gaining popularity. Due to their low cost and the fact that most farmers in rain-fed agriculture are small and marginal farmers who cannot afford expensive chemical fertilizers, these inputs become even more crucial. Biofertilizers are a perfect addition for organic farming and for lowering crop costs.

Types of fungal biofertilizers

Biofertilizers are made up of microbial inoculum or collections of living microorganisms that, through a variety of methods, promote the growth of plants and increase crop yield. Examples include the ability to solubilize phosphorus, break down organic matter, or oxidize sulphur in the soil. Arbuscular mycorrhizal fungi, which are most likely the most prevalent fungi in agricultural soil, are one type of biofertilizer. By increasing the availability, uptake, or absorption of nutrients, stimulating plant growth through hormone action or antibiosis, and decomposing organic wastes, the inoculum increases crop production. For the purpose of promoting plant development and eradicating weeds, pests, and illnesses, men exploit naturally existing organisms to create biofertilizers and biopesticides. These helpful microorganisms are used by scientists to create biofertilizers. Phosphate and nitrogen are important for the growth of plants. These compounds exist naturally in the environment, but plants have a limited ability to extract them. Phosphate plays an important role in crop stress tolerance, maturity, quality and directly or indirectly, in nitrogen fixation.

Penicillium bilaii, a fungus, aids in releasing phosphate from the soil. In order for the roots to use the phosphate in the soil, it creates an organic acid that dissolves it. Many other features of this symbiosis have been noticed and used, in addition to the well-known role of AMF in delivering nutritional advantages. Interspecific rivalry, the course of succession, soil aggregate stabilization, and the encouragement and determination of plant diversity are a few of them. This organism's biofertilizer is applied either by inoculating seeds with the fungus or by putting it straight into the ground. Such organisms can be more effective as biofertilizers by genetic engineering.

Bioherbicide (Mycoherbicides)

Throughout a range of land uses, weeds constitute an annoyance. The need to establish new methods for managing weeds is growing due to the abundance of weeds that are resistant to herbicides as well as restrictions on the use of cosmetic pesticides. Throughout the past few decades, fungi-along with bacteria and viruses have been used to accomplish this purpose with increasing frequency. In comparison to traditional herbicides, this technique is said to have fewer negative effects on the environment, more target specificity, lower development costs, and the discovery of novel herbicidal mechanisms. The well-known genera of fungi that have drawn attention as potential bioherbicide candidates are Colletotrichum, Phoma, and Sclerotinia. A comparison of the genomes of Colletotrichum gloeosporioides and *Colletotrichum orbiculare* revealed that both species *harboured* a number of candidate genes predicted to be involved in pathogenesis, including enzymes that break down plant cell walls and secreted disease effectors like small secreted proteins (SSPs), the latter of which was shown to be expressed differently in plants depending on the stage of infection, indicating that some of these proteins may have sparked the development Additionally, there is proof that both of these Colletotrichum species are capable of producing indole acetic acid, a plant hormone with well-known herbicide templates as its derivatives. The control of parasitic weeds is another area where mycoherbicide development and application have made considerable strides. *Striga hermonthica* was reported to be successfully controlled by the arbuscular mycorrhizal fungus (AMF) *Glomus mossea* mutant due to its improved downregulation of striga lactones and phosphorus mobilization. Furthermore, mycoherbicide efficacy of parents and mutants of Fusarium *oxysporum* sp.f *strigae* (pathogenic to *striga hemontheica*) has been thoroughly and intensively studied.

Products	Fungi	Companies
AgBio-Endos	Ectomycorrhizal fungi	AgBio Inc, Westminter, USA
AgBio-Ectos	Endomycorrhizal fungi	Agbio-inc.com
AM120	Mycorrhizal fungi	Reforestation Technologies International, USA www.reforest.com
Bioorganic Plus	*Trichoderma harzianum* *Trichoderma hamatum*	NovaScience Co. Ltd, Thailand.
BioVam	Mycorrhizal fungi *Trichoderma* spp.	T&J Enterprises, USA www.tandjenterprises.com
BuRize	AM fungi	BioScientific Inc, Arizona, USA www.biosci.com
Diehard™ mycorrhizal inoculant	Mycorrhizal fungi *Trichoderma* spp.	Horticultural Alliance, Inc, Fl, USA www. horticulturalalliance.com
Endomycorrhizal inoculant (BEI), inoculant micronized (BEIM), Mycorrhizal root dip	Endomycorrhizal fungi	Bio-Organics, Oregan, USA www.bio-organics.com
MycoApply® Endo MycoApply® Endo/Ecto MycoApply® Maxx Plant Success ™	Ectomycorrhizal fungi Endomycorrhizal fungi	Mycorrhizal application Inc, Oregon, USA www.mycorrhizae.com
Mycogrow™	Ectomycorrhizal fungi Endomycorrhizal fungi	Fungi perfecti, LLC, WA., USA www.fungi.com
Mycomax	AM fumgi (*Glomous intraradices*)	JHBiotech Inc. California, USA www.jhbiotech.com
Myke Myke® Pro Mycorise®	Mycorrhizal fungi	Premier Tech Biotechnologies, Canada www.premiertech.com
PLantmate®	*Trichoderma* spp.	Agrimms Technologies Ltd, www.vinevax.com
Promote®	Ectomycorrhizal fungi (*Pisolithus tinctorius*)	JHBiotech Inc. California, USA www.jhbiotech.com
Rhizanova	Mycorrhizal fungi	Becker-Underwood Inc., USA www.beckerunderwood.com
Rootgrow, Rootgrow Professional	Mycorrhizal fungi	PlantWorks Ltd., United Kingdom www.plantworksuk.co.uk
SoilMoist™	Ectomycorrhizal fungi Endomycorrhizal fungi	JRM chemical, Inc. Ohio, USA www.soilmoist.com
Superzyme	*Trichoderma* spp.	JH Biotech, Inc., Ventura, CA. USA www.jhbiotech.com
Tricho®	*Trichoderma* spp.	Agrimms Technologies Ltd, www.vinevax.com

Table-2: Fungal Biofertilizers (https://www.fungaldiversity.org/fdp/sfdp/FD38-2.pdf)

Food Production

Humans have used microbes for centuries to produce food. Wine, bread and cheese are common examples of foods that depend on microbial ingredients and activities. Today, microorganisms play even more significant roles in food production. They serve primary and secondary roles in food fermentation and in preventing food spoilage and they can produce enzymes or other metabolites used in food production and processing. Yeast (in particular Saccharomyces cerevisiae) is the most widely used fungi aside lactic acid bacteria (LAB).

Microorganisms relevant for food and feed production are also those which form complex microbial communities (microbiomes) tightly associated with animal and plant organisms (hosts). For instance, the microbiomes of both the animal gut and of plants are known for their importance for the host's nutrient uptake, protection against biotic (pathogens) and abiotic stress, as well as for providing metabolic capabilities. Macro fungi (members of many genera) due to their nutrient contents and their roles on the health of their consumer are cultivated as high valued crops. The cultivation of mushrooms (commonly referred as royal meat) has emerged one of the most economical/ profitable agricultural value chains specifically because of its ease of production (limited space and inputs requirements; good price).

Beneficial Fungal-Crop Symbioses

Genetically change agricultural crops, or their symbiotic fungi, in order to enhance this link as most plant species are capable of developing advantageous symbiotic partnerships with soil fungi. In order to create a biotechnological strategy to promote the contact, it is necessary to first discover the genes in fungi or plants that are responsible for the symbiotic relationship. For example, in barrel clover (*Medicago truncatula*), only some genes appear to be involved in plant-fungal interactions since 29 of these genes were increased during mycorrhizal association, but 11 of these genes were not upregulated in plants during bacterial colonization.

Moreover, certain plant genes were activated before coming into touch with the fungus physically. There is an increase in plant defensive mechanisms during the early phases of fungal contact with plants, particularly the jasmonic acid (JA) and salicylic acid (SA) biosynthesis pathways. The SA pathway is typically thought to be upregulated in response to biotrophic infections. Yet, equilibrium is reached and the activity of this pathway decreases to a lower steady state during continuous symbiosis. In the absence of this, the plant defense mechanism would continue to operate and might even succeed in eradicating the fungus symbiont. This shows that advantageous fungi block the SA route, which is necessary for long-lasting interaction. The SA route cannot be suppressed by harmful phytopathogens, revealing a unique channel of communication between the plant and helpful fungi symbionts.

The interaction might be improved by locating and manipulating the genes involved in communication between fungus and plant. Symbiosis-related genes in both plants and fungi have been discovered. For instance, MtScp1, a plant gene that encodes a carboxypeptidase important in the transmission of fungal-specific signals, has been discovered. Since they manage the regulation of molecules secreted from the fungus prior to association that stimulate root development and expression of plant genes necessary for intercellular fungal interaction, fungal genes involved in plant adherence, such as mad2 and myc, are essential to fungal-plant association. To encourage fungal-root interactions, these genes may be molecularly modified. Mycorrhizal fungi could be genetically evaluated utilizing proteome analysis and next generation sequencing in order to elucidate the full set of genes engaged in this complicated, commutative, and advantageous collaboration between plant and fungus, plants with and without. After gaining a better understanding of the genes involved in plant-fungal communication, other relationships might be examined, such as those with the insect pathogenic, endophytic fungus Metarhizium, which is a suitable test organism for genetic engineering. Arbuscular mycorrhizal fungi are known as helpful plant fungus, however the majority of them are obligate biotrophs that are challenging to cultivate in pure culture and resistant to conventional transformation techniques. Contrarily, Metarhizium is a picky fungus that is simple to genetically modify.

Fungal Symbiosis, Agriculture Can Survive in Drought or Salinity

Drought and salinity in the soil and irrigation water have an impact on agricultural productivity. Under drought situations, mycorrhizal fungi can enhance the uptake and storage of water by crops. It is hypothesized that soil fungi colonizing plant roots enhance stomatal effectiveness in plants. Moreover, extra radical mycelia increase the efficiency of mycorrhizal related roots in absorbing water from the soil, widening the water depletion zone and giving plant roots access to previously inaccessible water. With the increased accumulation of reactive oxygen species produced during extended exposure to stress, soil salinity can harm plants.

Antioxidants like glutathione can be produced as a result of endophytic interactions. 30 As an illustration, soybean with fungal symbionts has increased proline concentration in its roots, which is necessary for preserving cellular osmotic equilibrium in salty environments. Under saline conditions, it has been demonstrated that Metarhizium forms an endophytic relationship with soybean roots. Another strain of Glomus iranicum var tenuihypharum, (product of Symborg) was applied singly or in other microbial complexes in saline water/ soils or industrial waste channels, the Ca/Na ratio in the leaf of Viburnum Tinus L. increased and the Cl content reduced. Inoculation had a positive effect on the mineral content of the plants and improved the water potential of the stems and the relative chlorophyll content. The use of biotechnological approach in order to establish or strengthen this fungal partnership with other crop plants can in a great way contribute to the improvement of agricultural productivity.

Conclusion

As the fungus modifies the architecture of the roots, a larger root surface becomes available for nutrient absorption, leading to an increase in the uptake of nutrients from the soil. In addition to serving as an absorption surface, fungi also increase nutrient availability by solubilizing insoluble nutrients like phosphorus, making them available to plants. They also increase nutrient mobility facilitating faster intracellular nutrient movement and mobilizing nutrients from soil masses that are not reached by roots but are instead travelled by mycorrhizal hyphae. By increasing the activity of antioxidant enzymes and osmolytes and controlling the synthesis of phytohormones, which may conceivably connect the multiple tolerance mechanisms for cumulative stress response, arbuscular mycorrhizal fungi protected plants. It was demonstrated that arbuscular mycorrhizal fungi have a strong effect on salt.

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