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Review Article

Fungal Microbes that promote plant growth in the rhizosphere promote the growth of plants

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Abstract

Fungi that live in the rhizosphere of crops and have functions aimed at plant sustainability are collectively called "plant growth promoting fungi" (PGPF). These are bioinducers that benefit agricultural sustainability and perform important functions. Today, the challenge in agricultural systems is to meet the needs of the population based on crop yield and protection, without endangering the environment or human and animal health through crop production. PGPF including *Trichoderma spp., Gliocladium virens, Penicillium digitalatum, Aspergillus flavus, Actinomucor elegans, Podospora Bulbillosa,* Arbuscular mycorrhizal fungi, etc. has proven its eco-friendly properties and improves crop production by improving crop shoot and root growth, seed germination, and seed production. Chlorophyll is necessary for photosynthesis and the production of abundant crops. The potential mechanisms of action of PGPF include: Mineralization of major and trace elements necessary to support plant growth and productivity. In addition, PGPF produces plant hormones, -induced resistance enzymes, and defense-related enzymes that inhibit or eradicate the invasion of pathogenic microorganisms, in other words, help plants under stress. This review demonstrates the potential of PGPF as an effective biotic factor to promote and promote crop production, plant growth, resistance to disease invasion, and various abiotic stresses.

INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO) estimates that, due to today's challenges such as high birth rates, the world population is expected to increase to approximately 9.7 billion people by 2050. Population growth is expected to increase by 3 % within the next few years, impacting food prices. From another perspective, we cannot expect food crop production to increase to this extent. Therefore, there is a need to improve agricultural production to address the socio-economic challenges that may arise from population growth. To feed the world's population, the production of food and other agricultural products will need to increase by 70% over current food production. To achieve this goal, plant diseases must be suppressed or eradicated to promote food security. Crops such as tomatoes, cucumbers, and carrots are the major vegetables consumed by humans and animals around the world because they contain essential vitamins, carotenes, and minerals. However, these crops, including tomatoes, cucumbers, carrots, oranges, etc., are affected by plant pathogens such as powdery mildew caused by *Oidium neolycopersici* on tomato, downy mildew caused by *Pseudoperonospora cubensis* on cucumber, and powdery mildew *Erisyphe heraclei* on carrots. Soft rot of oranges is caused by *Penicillium digitatum* and *Fusarium oxysporum* and has reduced their production worldwide. Plant pathogens are microorganisms that produce plant pathogenic toxins which destroys crops, thereby reducing crop production for human consumption. In addition, they cause a variety of diseases, and the microbial pathogens responsible include soft rot (*Fusarium neolycopersici*). *oxysporum, Aspergillus niger*), early late blight (*Alternaria solani*), and powdery mildew (*Oidium* Apart from the effects of plant pathogens, certain chemical derivatives intended to suppress the occurrence of pests and diseases or to increase the fertility of agricultural soils are potentially harmful to human and animal health when ingested by crops to which they have been applied, resulting in reduced yields. Because of these problems, researchers have devised alternative agents that potentially inhibit the growth of plant pathogens and could replace pesticides when applied to agricultural land.

Plant growth-promoting fungi (PGPFs) are resident microorganisms that live in the rhizosphere soil of various crops, including tomatoes, and are one of the effective and environmentally friendly derivatives that scientists have studied to suppress or eradicate plant diseases. These are known to improve plant defense mechanisms and growth. Application of PGPF curbs the use of pesticides and protects plants from biotic and abiotic stresses. Various studies have reported the following PGPF genera (Gliocladium, Penicillium, Phoma, Phytophthora, Rhizoctonia, Talaromyces, Trichoderma) for improving tomatoes, oranges, apples, pears, cucumbers, carrots, etc. Plant growth is promoted, which further promotes plant innate immunity and the production of various secondary metabolites required by plants. PGPF serves the following functions in plants: potential for antagonistic or biological control through competition for space and nutrients, growth hormone production, solubilization of minerals in plants, mycoparasitic and saprophytic resistance, root colonization and -induced systemic resistance (ISR). Apart from the above roles, PGPF suppresses the invasion of plant pathogens in tomato plants and other crops, contributes to improving soil nutrition, and reduces ethylene production in plants by producing 1- aminocyclopropane-1-carboxylate (ACC) deaminase and other phytohormones. Low-yield production of tomatoes and other crops is achieved by biotic and abiotic stresses, which cause serious problems and reduce soil fertility. Drought, high and low temperatures, strong winds, and soil salinity are important abiotic stresses that affect crop production. Destructive environmental pressures that lead to the loss of arable land and agricultural products are soil salinity and soil consolidation. Biotechnology techniques are sustainable and effective in stimulating the interaction of PGPF with plant root exudates, which is necessary to improve crop abundance production and also promote soil health. PGPF present in the rhizosphere improves plant response to environmental stress and promotes crop production. In this study, crop plants are observed as superorganisms that are highly dependent on PGPF for their targeting roles and properties. However, various studies have reported an association between PGPF and improving crop growth, health status, and healthy crop production. Therefore, crop plants could utilize PGPF according to its benefits by selectively stimulating PGPF, which could induce the growth and development of in tomato plants.

Beneficial associations of microbial communities in crop rhizosphere soil:

PGPF can change the physiological properties of bacteria in soil. The population of Pseudomonas spp. in the rhizosphere depends on the role played by the rhizosphere and the activity of the ectomycorrhizosphere. Bacteria can survive on fungal hyphae, especially if they can produce biofilms or secrete a type III secretion system (ITSS), as survival mechanisms on hyphae are other than motility. The exudate produced by mycorrhizal roots is a substrate for conventional bacterial growth, and bacteria activate the changes and availability of both arbuscular mycorrhizal fungi and tomato plants to nutrients. The interaction of AMF with *Bradyrhizobium japanicum* has been shown to help stimulate proper growth of most tomato plants. AMF and PGPF were also reported to improve cucumber growth and inhibit the decay of PGPF (*T. Viride and P. Chrysogenum*) has been reported for its effectiveness in preventing post-harvest diseases in oranges. Endosymbiosis is an association between bacteria and Basidiomycota, but interactions rarely occur in Ascomycota. Intracellular associations have challenging benefits for plants because they involve a variable number of growth-promoting enzymes. The symbiotic relationship that occurs between fungi and bacteria is not limited to the benefits obtained in tomato plants, nor is it limited to the possibility of protecting bacteria from the activity of antibiotics, as in Piriformospora indica. In the presence of bacteria, the ability of fungi to participate in endosymbiosis helps some of the phyla to complete their life cycles.

Crops establish beneficial microorganisms in the rhizosphere:

Crop roots secrete primary metabolites such as amino acids, carbohydrates, organic acids, glucosinolates, and vitamins, as well as secondary metabolites such as known alkaloids, flavonoids, phenols, sulfur-containing compounds, and terpenoids. It signals and interacts with the rhizosphere microbiota. These excreta in the root zone soil consist of a rich mixture of extracted chemicals with important proportions of carbon and nitrogen for crop growth and health. The exudate has the great advantage of attracting and multiplying the beneficial microbial community while simultaneously destroying pathogens by inhibiting their growth and invasion. The rhizosphere microbiota also helps plants adapt to their specific environment and the colonization of a specific microbiota in the rhizosphere is called niche colonization. The importance of the rhizosphere microbiome, also called the rhizosphere biome, is thought to depend on chemical exudates, which also promote mutual activity through signaling molecules stimulated and secreted by plants and microorganisms. Scientific research has focused on PGPR, but has also highlighted the potential of PGPF and protists, providing scope for the production of additional nodule biomes in the future. The chemical effects of plant signaling and rhizome biome are still not well understood. Researchers may refer to this point using a number of terms, including: B. Complex interactions between plants and microorganisms, the chemical language of the rhizosphere, interactions in the rhizosphere, and plant signaling. Rhizosphere chemistry recruitment and colonization of rhizobiotic communities occurs through two general processes. First, it is done by derivation from root deposits or root exudates produced by the microbial biomass living in the rhizosphere of the crop. It is a specific way of forming, recruiting, and regulating the microbial community that is the source of microorganisms in the soil, and represents a way to prevent, support, or terminate it. However, we believe that this important function of chemicals in the study of rhizosphere organisms cannot be considered as signal transduction. The second process that affects the nodule biome occurs through the recognition and response of low molecular weight plant or microbial compounds, resulting in one or more cellular responses that are limited by sensing the substances through the following processes: catabolism, transformation, resistance, etc. This represents a restrictive cascade that ultimately leads to transcription of a genetic locus in response to specific compounds. The main types of signaling can be divided into three mechanisms that are known to occur in the rhizosphere. PGPR or PGPF exchange information about cell biomass or density and control gene expression. Signaling molecules allow types of microorganisms to multiply and change their behavior. Signal transduction from plants to microorganisms via plant secretions. This has been demonstrated in a number of special symbiotic relationships, and is likely to occur frequently in other interactions as well. Signal transduction from microbial communities to plants. Previously mentioned by compounds produced by microorganisms involved in plant defense responses, plant gene expression, and root development.

Formulation of PGPF, its application and effects on crops:

i. Formulation of PGPF PGPF:

Particularly Trichoderma species, is known to have many advantages as a plant growth promoter and is used in a number of commercial formulations. Various organic and inorganic carrier molecules were examined for their efficient properties in bio vaccines. A talc-based formulation was prepared from *T. harzianum* to provide concentrated conidial biomass of the fungus with an increase of colony-forming units (CFU) over time. Concentrated formulations offer the additional advantage of smaller packages for storage and transportation and lower product costs compared to other products.

Carriers such as charcoal, cow dung, sawdust, and vermiculite. Application of formulation to seeds showed an absolute improvement in growth promotion of chickpea. Corn, cassava husks, peanut husks, and sugarcane bagasse were used as carriers for Trichoderma spp. Used. Vaccines. In contrast to the inoculum introduced with sugarcane bagasse and the control, the maize formulation resulted in dramatic improvements in root length, wet weight and biomass of rice seedlings. For the biostimulants Trichoderma Dry Spray, a formulation in the form of a free-flowing powder in the form of was manufactured. A CO2-generating dispersant system based on citric acid, sodium bicarbonate, and polyacrylic acid was used, with lecithin and polyvinyl alcohol as the adhesive and the former as the wetting agent. Hydrolyzed amino acids have also been reported to be extracted from dead pigs to produce *T. harzianum* and used as biofertilizers. When the produced biofertilizers was used for soil amendment, it contributed to the densification of *T. harzianum* and promoted plant growth. Compost fertilizer was obtained from cow dung, from which, Trichoderma biofertilizers were produced and applied to agricultural fields. Fields treated with biofertilizers had richer harvests and were more productive than fields without biofertilizers. Another effective formulation was prepared from

Piriformospora indica prepared from talcum powder (vermiculite) with 20% water content. In greenhouse experiments of these formulations provided significant improvements as bioinoculants compared to vermiculite-based formulations.These indicate that biofertilizers produced from PGPF have the potential to contribute to the development of agricultural systems and improve crop productivity.

ii. Application and effects of PGPF on crops:

Microbial communities exist in interaction with crop roots. Plant growth-promoting microorganisms (PGPMs), in addition to promoting crop development, are also used to stimulate plant resistance to pathogen invasion. The introduction of these microorganisms is one of the environmentally friendly disease control methods and is permanent as the natural immunity of the plants is stimulated. Few studies have described how PGPF achieves its effectiveness compared to PGPR in stimulating resistance to pathogen invasion. PGPF is non-pathogenic and exists in nature as a saprophyte that feeds on dead organic matter, contributing to the maintenance of soil fertility, thereby promoting plant growth and stimulating defense responses against attack by plant pathogens. The potential of PGPF to colonize roots is considered the first mechanism necessary to prevent the invasion of plant pathogens and also contributes to nutrient uptake, thereby improving plant growth. The potential of PGPF directly or indirectly includes phosphate solubilization, IAA production, siderophore production, enzyme (cellulase and chitinase) production, etc., which not only promotes plant growth and stimulates disease resistance. Due to the beneficial use of PGPF in agricultural systems, scientists have focused on the use of PGPF to stimulate inhibition via ISR and promote plant growth in crops. The ISR produced by PGPF in plants is involved in cell wall modification through the accumulation of callose, lignin, and phenols, which reduces plant income and also impedes the growth and reproduction of invading plant pathogens. Apart from the changes occurring in plant cell walls, PGPF also initiates enhanced accumulation of defense enzymes in crop plants, such as β-1,3- -glucanase, chitinase, peroxidase (POX), and phenylalanine ammonia-lyase (PAL), which are proportionally involved in defense strategies against plant pathogens.

PGPF as an alternative to chemical derivatives in crop plantations:

Chemical derivatives, including fungicides, herbicides, and insecticides, can be classified based on their chemical properties and their use for controlling organisms that cause diseases and plant infestations. These derivatives are used in agriculture to protect crops from pests, insects, and undesirable plants (weeds). These chemicals are also used in public health to eradicate diseases and vectors, and to kill insects such as cockroaches, mosquitoes, aphids, and termites. Chemical derivatives are classified into different groups based on their potential effects. For example, chemical derivatives that act against insects are called insecticides, chemical derivatives that act against fungi and the various mycotoxins they produce are called fungicides, those used to control weeds are herbicides, and those used against rodents (rats) are called rat poisons. Fumigants are used to control insects such as beetles, aphids, and other pests, and mothballs are most often applied to the skin and clothing to ward off insects. Based on the chemical properties, they can be classified into benzoic acid derivatives, benzonitriles, carbamates, dipyrides, organochlorines, organophosphates, phenoxyalconates, phenylamides, phthalimide derivatives, thorazines, and pyrethroids. While these chemicals are effective in their primary role of eradicating undesirable microorganisms, they also pose a risk to crops, humans, animals, and the environments in which they are used. As a result, they pose various hazards and affect health due to the accumulation of toxic toxins in the tissues of crops, humans, and animals that eat them. For this reason, scientists are working on developing affordable and environmentally friendly means to combat plant pathogens and various plant diseases.

Trichoderma formulations are manufactured as granular or wettable powders. Mainly 90% of Trichoderma strains are used for plant protection to fight plant diseases through the antagonistic properties that the fungi produce against plant pathogens. Their application potential as BCAs in agricultural land is estimated based on input costs and share in crop production. Application of BCA is not expensive and easy to handle in contrast to synthetic chemical derivatives. Farmers can rely on cheap synthetic chemicals, but they cannot achieve bumper harvests or healthy crop production like BCAs. Therefore, it has been observed that huge economic losses occur when the balance between crop production costs and input costs is disrupted. Therefore, Trichoderma spp. and other PGPFs are known to increase crop productivity, which corresponds to an increase in sales of , spp. Proper application of BCA (PGPF) on agricultural land can reduce and replace chemical fertilizers . To maintain soil health, the application of PGPF contributes to a sustainable approach. As discussed in this review, scientists are studying how PGPF inhibits the growth of plant pathogens.

Conclusion:

PGPF and its organizations are intentionally diverse, with a variety of factors contributing to plant health activities. This scientific result highlights the importance of plant growth-promoting bacteria in the rhizosphere and indicates their potential to promote crop growth and development. The application of PGPF biologics has helped to alleviate problems encountered in crop production and efforts to grow pest-free crops with no or minimal use of chemical fertilizers and pesticides. This review shows how rhizosphere microbiota (PGPF) can improve agricultural sustainability and soil fertility. However, comprehensive research on the properties of PGPF that contribute to crop growth and productivity is still in its infancy. Therefore, it is important to investigate some of the activities carried out by PGPF in plant-microbe interactions in order to include the microbiota in the improvement of sustainable agriculture for crop production and plant protection. Recent advances and reliable improvements in biotechnological equipment may aid in the production of PGPF to impart beneficial properties to crops. Genetic modification and upregulation of growth-promoting traits in plants that carry out synergistic activities could lead to improved inoculum functionality. Studies may be conducted periodically to determine the genetic stability and ecological conservation of genetically modified strains. Therefore, PGPF points out that it can contribute to plant growth through comprehensive improvement of the basic process operation industry.

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