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9. Plant and Plant Growth Promoting Fungi (PGPF) Interaction for Susteinable Agriculture

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9.1 Information:

In 1904 the German agronomist and plant physiologist Lorenz Hiltner first coined the term "rhizosphere" to describe the plant-root interface, a word originating partly from the Greek word "rhiza", meaning root (Hiltner, 1904; Hartmann *et al*., 2008). Hiltner described the rhizosphere as the area around a plant root that is inhabited by a unique population of microorganisms influenced by the chemicals released from plant roots. Rtfed The rhizosphere can be defined as the soil region where processes mediated by microorganisms are specifically influenced by the root secreted chemicals.

This area includes the soil connected to the plant root system being an important environment for the plant and microorganism interactions (Lynch, 1990; Gray and Smith, 2005) because plant roots release a wide range of chemicals involved in attracting microorganisms which may be beneficial (i.e. antagonistic), neutral (i.e. nonpathogenic) or detrimental (i.e. pathogen) to plants (Lynch, 1990; Badri and Vivanco, 2009). The plant growth-promoting fungi (PGPF) belong to a beneficial and heterotrophic group of organisms that can be found in the rhizosphere on the root surface or associated to it and capable of enhancing the growth of plants and protecting them from disease (Glick, 2012). The mechanisms by which PGPF stimulate plant growth involve the availability of nutrients originating from genetic processes, such as phosphate solubilisation, production of phytohormones, siderophores, etc.

Root colonizing nonpathogenic, soil-borne filamentous fungi is generally called as plant growth promoting fungi (PGPF) which are also reported to be suppressed disease incidence by triggering induced systemic resistance and effectively controls soil-borne diseases like damping-off caused by *Fusarium, Rhizoctonia* and *Sclerotium*. PGPF has three dimensional roles in plant interaction which may trigger induced systemic resistance (ISR) in plant, promoting growth of plants and antagonistic activity against soil borne pathogens. Some common plant growth-promoting fungi (PGPF) are reported as *Fusarium* sp., *Penicillium* sp., *Phoma* sp. and *Trichoderma* sp. Species of *Trichoderma*, *Aspergillus*, *Penicillium* and some endophytes have been harnessed PGPF in agriculture.

PGPF in the rhizosphere trigger plant growth through production of hydrolytic enzymes for antagonistic activity against soil borne pathogens and plant hormones and mineral solubilization (N, P, and Fe) for plant growth promotion.

Agricultural production currently depends on the large-scale use of chemical fertilizers (Wartiainen *et al*., 2008; Adesemoye *et al*., 2009). These fertilizers have become essential components of modern agriculture because they provide essential plant nutrients such as nitrogen, phosphorus and potassium.

However, the overuse of fertilizers can cause unanticipated environmental impacts (Shenoy *et al*., 2001; Adesemoye *et al*., 2009). To achieve maximum benefits in terms of fertilizer savings and better growth, the PGPF-based inoculation technology should be utilized along with appropriate levels of fertilization. Moreover, the use of efficient inoculants can be considered an important strategy for sustainable agriculture and for reducing environmental problems by decreasing the use of chemical fertilizers (Alves *et al*., 2004; Adesemoye *et al*., 2009; Hungria *et al*., 2013).

9.3 The Major Mechanisms Of PGPF For Sustainable Agriculture Are:

A. Phosphate Solubilisation:

Next to nitrogen (N), phosphate (P) is a vital nutrient for plant growth and productivity. Its concentration in plants ranges from 0.05% to 0.5% of total plant dry weight. The concentration of phosphate in soil is 2000-fold higher than aluminium/iron or calcium/magnesium phosphates but it is unavailable to uptake by plants due to its insoluble form. Under such conditions, Phosphate solubilizing microorganisms (PSM) offer a biological rescue system capable of solubilising the insoluble inorganic P of soil and make it available to the plants through the secretion of various organic acids and enzymes.

B. Production of Growth Hormone:

Beneficial fungi can produce plant growth hormone like Indole-3-acetic acid (IAA) which mediates an enormous range of growth and development in plants including embryo symmetry establishment, initiation of cell division, promote vascular differentiation, root initiation and apical dominance.

C. Endophytic Growth:

Beneficial PGPF can grow in an endophytic way in plant and supports plant growth. Endophytic activity (i.e. growth inside plant tissue without any harm) of many microorganisms may useful to host plant by stimulating of plant growth, drought stress and the obstruction to pathogens. Endosymbiotic species are capable of establishing colonies in plant roots and triggers the expression of many plant genes affecting stress responses.

9.4 Antagonistic Activity:

Soil inhabiting nonpathogenic fungi play antagonistic activity for protection of plant against pathogen by several mechanisms is stated as bellow.

A. Competition:

Beneficial fungi may grow faster or use its food source more efficiently than the soil borne pathogen, thereby decreasing the population of pathogens, called as nutrient competition. The most common reason for the death of many microorganisms growing in the vicinity of beneficial fungal strains is the starvation and scarcity of limiting nutrients source. This can be effectively used in biological control of phytopathogens using *Trichoderma* sp.

B. Antibiosis:

Beneficial fungi may release some antimicrobial compound that slows down or completely inhibit the growth of pathogenic microorganism in the rhizosphere is called antibiosis. *Trichoderma*, a beneficial fungi release a small size diffusible compounds or antibiotics that inhibit the growth of other microorganisms (Benitez et al., 1998).

C. Mycoparasitism:

Some beneficial fungi feed on pathogenic microbes directly which is called as mycoparasitism. Mycoparasitism is one of the main mechanisms involved in the antagonisms of *Trichoderma*. The process apparently include, chemotropic growth of *Trichoderma*, recognition of the host by the mycoparasites, secretion of extra cellular enzymes, penetrations of the hyphae and lysis of the host (Zeilinger et al., 1999). *Trichoderma* recognizes signals from the host fungus, triggering coiling and host penetrations.

D. Siderophore Production:

Iron is one of the most important micronutrient used by microorganisms and is essential as cofactor for their metabolism in a large number of enzymes and iron-containing proteins. Siderophores are low molecular weight, iron chelating ligands synthesized by microorganisms that restrict the growth of pathogenic microorganisms by limiting the iron availability as it bind to the available form of iron ($Fe2+$) in the rhizosphere Under iron limiting conditions, Plant Growth Promoting Fungi (PGPF) produce siderophores to competitively acquire ferric ions (Ahmed and Holmström, 2014).

E. HCN Production:

Hydrogen Cyanide (HCN) is released as product of secondary metabolism by several microorganisms (fungi and Bacteria) and affects sensitive organisms by inhibiting the synthesis of ATP-mediated cytochrome oxidase led to biological control of pathogenic microorganism.

9.5 Secondary Metabolites:

Some fungi like *Trichoderma* is well known for production of secondary metabolites (SMs) such as Pyrones, Koninginins, Viridins, Azaphilones, Harzianopyridone Butenolides, Diketopiperazines, Peptaibols and Hydroxy-Lactones that are toxic for phytopathogenic fungi (Naziya et al., 2019). Different fungi produce different metabolites.

9.6 Plant Defense Mechanism:

Induced systemic response- Plant Growth Promoting Fungi (PGPF) exerts an indirect control against pathogens through the induced systemic response (ISR) in plant cells that results in an enhanced defense mechanism in plant. Systemic acquired resistance (SAR) and induced systemic response (ISR) are two forms of induced resistance, wherein plant defenses are preconditioned by prior infection or treatment that results in resistance against subsequent challenge by a pathogen or parasite (Choudhary *et al*., 2007). ISR activation is mediated through the jasmonate (JA) and ethylene (ET) pathways in direct contact with non-pathogenic rhizospheric fungi which are called as PGPF that protect plant with the accumulation of defense chemicals and structural barrier. Whereas, Systemic acquired resistance (SAR) is mediated in response of Salicylic acid (SA) in response of necrotizing pathogen which is resulted in the production of pathogenesis-related proteins (PR-Proteins) (Kauffmann et al., 1987). SAR is directly linked with hypersensitive reaction with the generation of Reactive Oxygen Species (ROS) in response to the necrotizing pathogens.

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