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Functional Role of Plant Growth Promoting Endo- and Rhizobacteria in Major Cereal Crops

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In recent decades, the endo- and rhizobacteria have been exploited as potential biofertilizers and biocontrol agents for sustainable production and productivity of non-leguminous crops. The present article highlights the functional role of PGPR (phytoharmone production, nitrogen fixation, phosphate solubilization, antibiotic production, siderophore production etc) in major crops viz., rice, wheat, maize and sugarcane.

Introduction

Rhizobacterial strains are found to increase plant growth after inoculation of seeds and therefore called "Plant growth promoting rhizobacteria (PGPR)". The mechanisms of growth promotion by these PGPRs are complex and appear to comprise both changes in the microbial balance in the rhizosphere and alterations in host plant physiology. PGPR has a significant impact on plant growth and development in both direct and indirect ways. The direct promotion of plant growth by PGPR generally entails providing the plant with compound that is synthesized by the bacterium or facilitating the uptake of nutrients from the environment. On the other hand, indirect promotion of plant growth occurs when bacteria prevent some of the deleterious effects of a phytopathogenic organism by one or more mechanisms. Different functional traits of a typical PGPR are as follows:

PGPR	Plant growth promoting traits
Rhiozobium leguminosarum	IAA, HCN, ammonia and siderophore
Mesorhizobium sp.	IAA, HCN, ammonia and siderophore
Rhizobium sp.	IAA, HCN, ammonia and siderophore
Azospirillum amazonence	IAA and nitrogenase activity
Mesorhizobium sp.	IAA, HCN, ammonia and siderophore
Proteus vulgeris	Siderophore
Mesorhizobium ciceri	IAA and siderophore
Pseudomonas, Bacillus	IAA, phosphate solubilization and siderophore
Klebsiella oxytoca	IAA, phosphate solubilization and nitrogenase activity
Bacillus spp., Pseudomonas spp.	IAA and ammonia production
Azotobacter spp., Bradyrhizobium spp.	IAA ,Siderophore and ammonia production
Rhizobium sp.	IAA, HCN, ammonia and siderophore
Pseudomonas fluorescens	Induced systemic resistance and antifungal activity
Bacillus subtilis	Antifungal activity
Gluconacetobacter diazotrophicus	Zinc solubilization
Bravibacillus spp.	Zinc resistance and IAA
Pseudomonas putida	ACC deaminase, Pb and Cd resistance and siderophore
Pseudomonas fluorescens., Azospirillum bracilense	IAA, siderophore and antifungal activity
Azospirillum amazonence	IAA, phosphate solubilization, nitrogenase activity ,antifungal activity
Pseudomonas fluorescens	IAA, phosphate solubilization
Kluyvera ascorbata	ACC deaminase, IAA, siderophore, metal resistance
Paenibacillus polymyxa strain HKA15	Antifungal activity

Plant growth benefits due to the addition of PGPR, include increase in germination rates, root growth, yield including grain, leaf area, chlorophyll content, magnesium, nitrogen and protein content, hydraulic activity, tolerance to drought and salt stress, shoot and root weights and delayed leaf senescence.

Functional Role of PGPR

Indole-3-Acetic Acid (IAA) Production: IAA is a phytohormone which is known to be involved in root initiation, cell division and cell enlargement. This hormone is very commonly produced by PGPR. However, the effect of IAA on plants depends on the plant sensitivity to IAA and the amount of IAA produced from plant associated bacteria and induction of other phytohormones. The bacterial IAA from *P. putida* played a major role in the development of host plant root system.

Phosphate Solubilization: Use of co-inoculants of *Pseudomonas, Azotobactor* and *Bacillus* with Mussoorie Rock Phosphate (MRP) could make phosphorus availability to equivalent 50 kg of P_2O_5 /ha applied in the form of Single Super Phosphate (SSP). The efficient phosphate solubilizers are *Pseudomonas species viz., Pseudomonas aeruginosa, Pseudomonas cepacia, Pseudomonas fluorescence and Pseudomonas putida*.

Siderophore production: Siderophores are low molecular weight, extracellular compounds with a high affinity for ferric iron, that are secreted by microorganisms to take up iron from the environment and their mode of action in suppression of disease are thought to be solely based on competition for iron with the pathogen. Rhizobacteria produce various types of siderophores (pseudobactin and ferrooxamine B) that chelate the scarcely available iron and thereby prevent pathogens from acquiring iron.

Hydrogen cyanide (HCN) production: The cyanide ion is exhaled as HCN and metabolized to a lesser degree in to other compounds. HCN first inhibits the electron transport and the energy supply to the cell is disrupted leading to the death of the organisms. It inhibits proper functioning of enzymes and natural receptors and it is also known to inhibit the action of cytochrome oxidase. HCN is produced by many rhizobacteria and is postulated to lay a role in biological control of pathogens. Suppression of take-all of wheat by *P. fluorescens* strain CHAO was attributed to the production of HCN.

Potential of Biocontrol Agents in Rice Disease Management

The success of potential biocontrol agents in disease suppression depends on a suitable form for application to the plant system. Biocontrol agents can be applied either by direct inoculation (dipping seeds in culture, aerial spraying or spreading it in sowing furrows by a drip system) or by the use of various solid-phase inoculants. The effects of some of the biocontrol agents on the pathogens and/or plant are summarized in the following:

a. Bacterium *P. fluorescens* applied (prior to pathogen inoculation) against several rice pathogens to the seed and rice plants can reduce disease severity by 20-42% in a greenhouse and the field. Such bacterization of rice plants can enhance plant height, number of tillers and grain yield by 3 to 160%.
b. Seed treatment by antagonistic bacteria can reduce bakanae disease (*Fusarium fujikuroi*) by 72-96%.
c. Different species of *Bacillus* applied to rice plants as a seed treatment before sowing, root dip prior to transplanting and two foliar sprays prior to inoculation can suppress bacterial blight pathogen by up to 59%, resulting in a two-fold increase in plant height and grain yield.
d. Recent laboratory study demonstrated that *P. fluorescens* have insecticidal effect on the rice tungro virus disease vector *Nephotettix virescens*. Bacterial strains of *Pf*7-14 and *Pp*V14i can cause about 90% mortality if they feed on treated rice leaves for 7 days.

Diazotrophs Bacteria and PGPR in Association with Major Cereal Crops

Recently, it is observed that non-leguminous plants like rice, sugarcane, wheat and maize form an extended niche for various species of Nitrogen Fixing (NF) bacteria. These bacteria thrive within the plant, successfully colonizing roots, stems and leaves. During the association, the invading bacteria benefit the acquired host with a marked increase in plant growth, vigor and yield. With increasing population, the demand of non-leguminous plant products is growing. In this regard, the richness of NF flora within non-leguminous plants and extent of their interaction with the host definitely shows a ray of hope in developing an ecofriendly alternative to the nitrogenous fertilizers (Upendra kumar *et al.*, 2012).

During extensive greenhouse and field experiments using non-sterilized soils, Riggs *et al.* (2001) observed that when maize seeds were inoculated with *H. seropedicae* under greenhouse conditions, the yield increased by 49–82% with applied fertilizer N, whereas without fertilization, the increase was only 16%. This indicated the participation of factors other than biological nitrogen fixation, which improved the maize plant's proficiency to use the available fertilizer N. Similarly, Sevilla *et al.* (2001) also suggested the participation of other growth-promoting factors in addition to N fixation as both wild and *nifH* mutants of *A. diazotrophicus* promoted growth of sugarcane in the presence of nitrogen. Most endophytes with plant growth-enhancing properties are producers of phytohormones: indolacetic acid, gibberellins and cytokinins, iron-sequestering, phosphate-solubilising enzymes and 1-aminocyclopropane- 1-carboxylate (ACC) deaminase. Release of auxins and ACC deaminase *in vitro* by the rhizobacteria are linearly correlated with the host plant growth promotion. Subsequently, indole-3-acetic acid and ACC deaminase production is being deployed as tool for identification and screening of endophytes

Conclusion

In overall, the inoculation of PGPRs in major cereal crops may increase plant biomass, root elongation, uptake of NPK and ultimately increase the yield of major cereal crops without deteriorating soil health. Subsequently, they act as potential biofertilizers and antagonistic agents to save synthetic chemical fertilizers and pesticides, respectively and become an ecofriendly alternative in upcoming days.

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