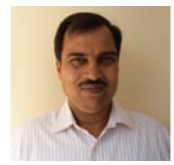
Plant Growth Promoting Rhizobacteria

Potential Microbes for Sustainable Agriculture

Jay Shankar Singh

Plant Growth Promoting Rhizobacteria (PGPR) are a group of bacteria that enhances plant growth and yield via various plant growth promoting substances as well as biofertilizers. Given the negative environmental impact of artificial fertilizers and their increasing costs, the use of beneficial soil microorganisms such as PGPR for sustainable and safe agriculture has increased globally during the last couple of decades. PGPR as biofertilizers are well recognized as efficient soil microbes for sustainable agriculture and hold great promise in the improvement of agriculture yields.



Jay Shankar Singh is an Assistant Professor in the Department of Environmental Microbiology, BB Ambedkar (Central) University, Lucknow, Uttar Pradesh, India. He is working on the environmental problems related to ecology of methane (CH_4)-consuming bacteria (methanotrophs), environmental remediation and sustainable agriculture development. He also has a strong devotion to teaching and is always available to share with others the ever-growing enthusiasm for his research field.

Agriculture contributes to a major share of national income and export earnings in many developing countries, while ensuring food security and employment. Sustainable agriculture is vitally important in today's world because it offers the potential to meet our future agricultural needs, something that conventional agriculture will not be able to do. Recently there has been a great interest in eco-friendly and sustainable agriculture. PGPR are known to improve plant growth in many ways when compared to synthetic fertilizers, insecticides and pesticides. They enhance crop growth and can help in sustainability of safe environment and crop productivity. The rhizospheric soil[1] contains diverse types of PGPR communities, which exhibit beneficial effects on crop productivity. Several research investigations are conducted on the understanding of the diversity, dynamics and importance of soil PGPR communities and their beneficial and cooperative roles in agricultural productivity. Some common examples of PGPR genera exhibiting plant growth promoting activity are: *Pseudomonas, Azospirillum, Azotobacter, Bacillus, Burkholdaria, Enterobacter, Rhizobium, Erwinia, Mycobacterium, Mesorhizobium, Flavobacterium*, etc. This article presents perspectives on the role of PGPR in agriculture sustainability.

[1] The soil surrounding plant root area where intense biological and chemical activities are influenced by root exudates, and microorganisms feeding on the compounds.

Keywords
Agriculture, biofertilizers, PGPR, sustainable agriculture.

Many studies and reviews have reported plant growth promotion, increased yield, solubilization of P (phosphorus) or K (potassium), uptake of N (nitrogen), etc. through inoculation with PGPR.

PGPR as Biofertilizers

Free-living PGPR have shown promise as biofertilizers. Many studies and reviews have reported plant growth promotion, increased yield, solubilization of P (phosphorus) or K (potassium), uptake of N (nitrogen) and some other elements through inoculation with PGPR. In addition, studies have shown that inoculation with PGPR enhances root growth, leading to a root system with large surface area and increased number of root hairs.

A huge amount of artificial fertilizes are used to replenish soil N and P, resulting in high costs and increased environmental pollution. Most of P in insoluble compounds is unavailable to plants. N_2-fixing and P-solubilizing bacteria may be important for plant nutrition by increasing N and P uptake by the crop plants, and playing a crucial role in biofertilization. N_2-fixation and P-solubilization, production of antibiotics, and other plant growth promoting substances are the principal contribution of the PGPR in the agro-ecosystems. More recent research findings indicate that the treatment of agricultural soils with PGPR inoculation significantly increases agronomic yields as compared to uninoculated soils.

Mechanisms of Plant Growth Promotion by PGPR

Several mechanisms have been suggested by which PGPR can promote plant growth; some important ones are as follows (*Table* 1):

Box 1.

Plant growth promoting rhizobacteria (PGPR): PGPR (rhizo-biofertilizers) are a group of bacteria that actively colonize plant roots and enhance plant growth and yield.

Biofertilizer: Composition of living micro-organisms which, when applied to surface of plant, seed, or soil, colonize the plant rhizosphere or inside the plant body (as endophyte) and promotes plant growth through enhancing the supply or availability of fundamental nutrients to crop plants.

Sustainable agriculture: Sustainable agriculture involves the successful management of agricultural resources to satisfy human needs while maintaining or enhancing environmental quality without exploiting the natural resources of future generations.

PGPR	Crop parameters
Rhizobium leguminosarum	Direct growth promotion of canola and lettuce
Pseudomonas putida	Early developments of canola seedlings, growth stimulation of tomato plant
Azospirillum brasilense and *A. irakense*	Growth of wheat and maize plants
P. flurescens	Growth of pearl millet, increase in growth, leaf nutrient contents and yield of banana (*Musa*)
Azotobacter and *Azospirillum* spp.	Growth and productivity of canola
P. alcaligenes, Bacillus polymyxa, and *Mycobacterium phlei*	Enhances uptake of N, P and K by maize crop
Pseudomonas, Azotobacter and *Azospirillum* spp.	Stimulates growth and yield of chick pea (*Cicer arietinum*)
R. leguminismarum and *Pseudomonas* spp.	Improves the yield and phosphorus uptake in wheat
P. putida, P. flurescens, A. brasilense and *A. lipoferum*	Improves seed germination, seedling growth and yield of maize
P. putida, P. fluorescens, P. fluorescens, P. putida, A. lipoferum, A. brasilense	Improves seed germination, growth parameters of maize seedling in greenhouse and also grain yield of field grown maize

Table 1. PGPR and their effect on growth parameters/ yields of crop/fruit plants.

Phytohormone Production

The enhancement in various agronomic yields due to PGPR has been reported because of the production of growth stimulating phytohormones (*Table* 2) such as indole-3-acetic acid (IAA), gibberellic acid (GA_3), zeatin, ethylene and abscisic acid (ABA).

Phytohormones	PGPR
Indole-3-acetic acid (IAA)	*Acetobacter diazotrophicus* and *Herbaspirillum seropedicae*
Zeatin and ethylene	*Azospirillum* sp.
Gibberellic acid (GA_3)	*Azospirillum lipoferum*
Abscisic acid (ABA)	*Azospirillum brasilense*

Table 2. Examples of different phytohormone-producing PGPR.

The enhancement in agronomic yields by PGPR is due to production of growth stimulating phytohormones and the consequent release of the bound form of phosphate, and extracellular metabolites.

Recent studies confirm that the treatment of seeds or cuttings with non-pathogenic bacteria, such as *Agrobacterium, Bacillus, Streptomyces, Pseudomonas, Alcaligenes,* etc. induce root formation in some plants because of natural plant growth promoting substances produced by the bacteria. Although the mechanisms are not completely understood, root induction by PGPR is the accepted result of phytohormones such as auxins, growth inhibiting ethylene and mineralization. Environment-friendly applications in agriculture have gained more importance, in particular in horticulture and nursery production. The use of PGPR for nursery material multiplication may be important for obtaining organic nursery material because the use of all formulations of synthetic plant growth regulators, such as indole-3-butyric acid (IBA), are prohibited in organic agriculture throughout the world.

Phosphate Solubilization

Rhizobium and phosphorus (P) solubilizing bacteria are important to plant nutrition. These microbes also play a significant role as PGPR in the biofertilization of crops. These bacteria secrete different types of organic acids (e.g., carboxylic acid) thus lowering the pH in the rhizosphere and consequently release the bound forms of phosphate like $Ca_3 (PO_4)_2$ in the calcareous soils. Utilization of these microorganisms as environment-friendly biofertilizer helps to reduce the use of expensive phosphatic fertilizers. Phosphorus biofertilizers could help increase the availability of accumulated phosphate (by solubilization), increase the efficiency of biological nitrogen fixation and render availability of Fe, Zn, etc., through production of plant growth promoting substances.

Siderophore Production

PGPR are reported to secrete some extracellular metabolites called siderophores. For the first time Kloepper et al. (1980) reported the significance of siderophores produced by certain genera of PGPR in plant growth promotion. Siderophores are commonly referred to as microbial Fe-chelating low molecular weight compounds. The presence of siderophore-producing PGPR in rhizosphere increases the rate of Fe^{3+} supply to plants and therefore enhance the plant growth and productivity of crop. Further, this compound after chelating Fe^{3+} makes the soil Fe^{3+} deficient for other soil microbes and consequently inhibits the activity of competitive microbes.

PGPR produce substances that also protect them against various diseases

PGPR as Biocontrol Agents

PGPR produce substances that also protect them against various diseases. PGPR may protect plants against pathogens by direct antagonistic interactions between the biocontrol agent and the pathogen, as well as by induction of host resistance. In recent years, the role of siderophore-producing PGPR in biocontrol of soil-borne plant pathogens has created great interest. Microbiologists have developed techniques for introduction of siderophore-producing PGPR in soil system through seed, soil or root system. PGPR that indirectly enhance plant growth via suppression of phytopathogens do so by a variety of mechanisms. These include:

- The ability to produce siderophores (as discussed above) that chelate iron, making it unavailable to pathogens.
- The capacity to synthesize anti-fungal metabolites such as antibiotics, fungal cell wall-lysing enzymes, or hydrogen cyanide, which suppress the growth of fungal pathogens.
- The ability to successfully compete with pathogens for nutrients or specific niches on the root; and the ability to induce systemic resistance.

Among the various PGPRs identified, *Pseudomonas fluorescens* is one of the most extensively studied rhizobacteria, because of its antagonistic action against several plant pathogens. Banana bunchy top virus (BBTV) is one of the deadly virus which severely affects the yield of banana (*Musa* spp.) crop in Western Ghats, Tamil Nadu, India. It has been demonstrated that application of *P. fluorescens* strain significantly reduced the BBTV incidence in hill banana under greenhouse and field conditions. Different

PGPR	Disease resistance
Bacillus pumilus, Kluyvera cryocrescens, B. amyloliquefaciens and *B. subtilus*	Cucumber Mosaic Cucumovirus (CMV) of tomato (*Lycopersicon esculentum*)
B. amyloliquefaciens, *B. subtilis* and *B. pumilus*	Tomato mottle virus
B. pumilus	Bacterial wilt disease in cucumber (*Cucumis sativus*), Blue mold disease of tobacco (*Nicotiana*)
Pseudomonas fluorescens	Sheath blight disease and leaf folder insect in rice (*Oryza sativa*), Reduce the Banana Bunchy Top Virus (BBTV) incidence, Saline resistance in groundnut (*Arachis hypogea*)
B . subtilis and B. pumilus	Downy mildew in pearl millet (*Pennisetum glaucum*)
B. subtilis	CMV in cucumber
B. cereus	Foliar diseases of tomato
Bacillus spp.	Blight of bell pepper (*Capsicum annuum*), Blight of squash
Burkholderia	Maize (*Zea mays*) rot
B. subtilis	Soil borne pathogen of cucumber and pepper (*Piper)*
Bacillus sp. and *Azospirillum*	Rice blast
Fluorescent *Pseudomonas* spp.	Rice sheath rot (*Sarocladium oryzae*)

Table 3. PGPR as biocontrol agents against various plant diseases.

PGPR species as biocontrol agents against various plant diseases are given in *Table* 3.

PGPR as Biological Fungicides

PGPR and bacterial endophytes play a vital role in the management of various fungal diseases.

PGPR and bacterial endophytes play a vital role in the management of various fungal diseases (*Box* 2). But one of the major hurdles experienced with biocontrol agents is lack of appropriate delivery system.

Box 2

Bacillus subtilis, *Pseudomonas chlororaphis*, endophytic *P. fluorescens* inhibit the growth of stem blight pathogen *Corynespora casiicola*. The seed treatment and soil application of *P. fluorescens* reduce root rot of black gram caused by *Macrophomina phaseolina*. Seed and foliar application of *P. fluorescens* reduce sheath blight of rice. *B. subtilis* in peat supplemented with chitin or chitin-containing materials show better control of *Aspergillus niger* and *Fusarium udum* in groundnut and pigeon pea, respectively. Strains of *Burkholderia cepacia* have been shown to have biocontrol of *Fusarium* spp.

Conclusion

Worldwide, considerable progress has been achieved in the area of PGPR biofertilizer technology. It has been also demonstrated and proved that PGPR can be very effective and are potential microbes for enriching the soil fertility and enhancing the agriculture yield. PGPR are excellent model systems which can provide the biotechnologist with novel genetic constituents and bioactive chemicals having diverse uses in agriculture and environmental sustainability. Current and future progress in our understanding of PGPR diversity, colonization ability, mechanisms of action, formulation, and application could facilitate their development as reliable components in the management of sustainable agricultural systems.

It has been also demonstrated and proved that PGPR can be very effective and are potential microbes for enriching the soil and enhancing the agriculture yield.

Suggested Reading

[1] **B R Glick, C L Patten, G Holguin and D M Penrose, *Biochemical and genetic mechanisms used by plant growth promoting bacteria*, Imperial College Press, London. 1999.**

[2] **A R Podile and K Kishore, Plant growth-promoting rhizobacteria. *In: Plant associated bacteria*. Springer Netherlands, pp. 195–230, 2007.**

Address for Correspondence
Jay Shankar Singh
Department of Environment Microbiology
School for Environmental Sciences, BB Ambedkar (Central) University,
Raibarely Road, Lucknow 226025
Uttar Pradesh, India.
Email: jayshankar_1@yahoo.co.in