Plant Growth Promoting Rhizobacteria for enhanced Crop Production

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Plant Growth Promoting Rhizobacteria (PGPR) were first defined by Kloepper and Schroth to describe soil bacteria that colonize the roots of plants following inoculation onto seed and that enhance plant growth. The following are implicit in the colonization process: ability to survive inoculation onto seed, to multiply in the spermosphere (region surrounding the seed) in response to seed exudates, to attach to the root surface, and to colonize the developing root system. The ineffectiveness of PGPR inthe field has often been attributed to their inability to colonize plant roots. A variety of bacterial traits and specific genes contribute to this process, but only a few have been identified. These include motility, chemotaxis to seed And root exudates, production of pili or fimbriae, production of specific cell surface components, ability to use specific components of root exudates, protein secretion, and quorum sensing. The generation of mutants altered in expression of these traits is aiding our understanding of the precise role each one plays in the colonization process. Progress in the identification of new, previously uncharacterized genes is being made using nonbiased screening strategies that rely on gene fusion technologies.

Mechanisms of Action:

PGPRs enhance plant growth by direct and indirect means, but the specific mechanisms involved have not all been well characterized. Direct mechanisms of plant growth promotion by PGPRs can be demonstrated in the absence of plant pathogens or other rhizosphere microorganisms, while indirect mechanisms involve the ability of PGPRs to reduce the harmful effects of plant pathogens on crop yield. PGPRs have been reported to directly enhance plant growth by a variety of mechanisms: fixation of atmospheric nitrogen transferred to the plant production of siderophore that chelate iron and make it available to the plant root, solubilization of minerals such as phosphorus, and synthesis of phytohormones. Direct enhancement of mineral uptake due to increases in specific ion fluxes at the root surface in the presence of PGPRs has also been reported. PGPR strains may use one or more of these mechanisms in the rhizosphere. Molecular approaches using microbial and plant mutants altered in their ability to synthesize or respond to specific phytohormones have increased understanding of the role of phytohormone synthesis as a direct mechanism of plant growth enhancement by PGPRs. PGPR that synthesize auxins and cytokinins or that interfere with plant ethylene synthesis have been identified.

PGPR as Bio fertilizers:

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. N2-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. N2-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 un inoculated soils.

Nitrogen Fixation: Nitrogen fixation is one of the most beneficial processes performed by rhizobacteria. Nitrogen is a vital nutrient to plants and gaseous nitrogen (N_2) is not available to them due to the high energy required to break the triple bonds between the two atoms. Rhizobacteria, through nitrogen fixation, are able to convert gaseous nitrogen (N_2) to ammonia (NH_3) making it an available nutrient to the host plant which can support and enhance plant growth. The host plant provides the bacteria with amino acids so they do not need to assimilate ammonia. The amino acids are then shuttled back to the plant with newly fixed nitrogen. Nitrogenase is an enzyme involved in nitrogen fixation and requires anaerobic conditions.

Membranes within root nodules are able to provide these conditions. The rhizobacteria require oxygen to metabolize, so oxygen is provided by a hemoglobin protein called leghemoglobin which is produced within the nodules. Legumes are well-known nitrogen-fixing crops and have been used for centuries in crop rotation to maintain the health of the soil.

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

S.N	PGPR	Crop parameters
1	*Rhizobiumleguminosarum*	Direct growth promotion of canola and lettuce
2	*Pseudomonas putida*	Early developments of canola seedlings, growth stimulation of tomato plant
3	*P. flurescens*	Growth of pearl millet, increase in 4growth, leaf nutrient contents and yield of banana (*Musa*)
4	*Azotobacter*and *Azospirillum*spp.	Growth and productivity of canola

Phosphate solubilising Bacteria (PSB) :

These are beneficial bacteria capable of solubilizing inorganic phosphorus from insoluble compounds. P-solubilization ability of rhizosphere microorganisms is considered to be one of the most important traits associated with plant phosphate nutrition.

It is generally accepted that the mechanism of mineral phosphate solubilization by PSB strains is associated with the release of low molecular weight organic acids, through which their hydroxyl and carboxylgroups chelate the cations bound to phosphate, thereby converting it into soluble forms. PSB have been introduced to the Agricultural community as phosphate Biofertilizer. Phosphorus (P) is one of the major essential macronutrients for plants and is applied to soil in the form of phosphate fertilizers. However, a large portion of soluble inorganic phosphate which is applied to the soil as chemical fertilizer is immobilized rapidly and becomes unavailable to plants. Currently, the main purpose in managing soil phosphorus is to optimize crop production and minimize P loss from soils. PSB have attracted the attention of agriculturists as soil inoculums to improve the plant growth and yield. When PSB is used with rock phosphate, it can save about 50% of the crop requirement of phosphatic fertilizer. The use of PSB as inoculants increases P uptake by plants. Simple inoculation of seeds with PSB gives crop yield responses equivalent to 30 kg P_2O_5 /ha or 50 percent of the need for phosphatic fertilizers. Alternatively, PSB can be applied through fertigation or in hydroponic operations. Many different strains of these bacteria have been identified as PSB, including *Pantoeaagglomerans* (P5), *Microbacterium laevaniformans* (P7) and *Pseudomonas putida* (P13) strains are highly efficient insoluble phosphate solubilizers. Recently, researchers at Colorado State University demonstrated that a consortia of four bacteria (sold commercially as Mammoth P), synergistically solubilize phosphorus at a much faster rate than any single strain alone.

Rhizobium and phosphorus (P) solubilizing bacteria are important to plant nutrition. Thesemicrobes 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 Ca3 (PO4)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.

Phytohormone Production:

Plant hormones affect gene expression and transcriptionlevels, cellular division, and growth. They are naturally produced within plants, though very similar chemicals are produced by fungi and bacteria that can also affect plant growth. A large number of related chemical compounds are synthesized by humans. They are used to regulate the growth of cultivated plants, weeds, and in vitro-grown plants and plant cells; these manmade compounds are called plant growth regulators or PGRs for short.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 (GA3), zeatin, ethylene and abscisic acid (ABA).

Table 2.Examples of different phytohormone-producing PGPR.

S.N	**Phytohormones**	**PGPR**
1	Indole-3-acetic acid (IAA)	*Acetobacterdiazotrophicus*and*Herbaspirillumseropedicae*
2	Indole-3-acetic acid (IAA)	Indole-3-acetic acid (IAA)
3	Gibberellic acid (GA3)	*Azospirillumlipoferum*
4	Abscisic acid (ABA)	*Azospirillum brasilense*

Recent studies confirmed 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 uses of all formulations of synthetic plant growth regulators, such as indole-3-butyric acid (IBA), are prohibited in organic agriculture throughout the world.