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PGPR: Heart of soil and their role in sustainable agriculture

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Micro-organisms are the key components of the soil biodiversity. Both free-living and non free living soil biota beneficial to plant growth, usually referred to as plant growth-promoting rhizobacteria's (PGPRs), are capable of promoting plant growth by colonizing the plant root. These are associated with the rhizosphere, which is an important soil ecological environment and plant health for plant–microbes interactions. Beneficial micro-organisms that help in promoting plant growth, protecting from biotic and abiotic stresses, and significantly increasing soil fertility. Due to increase inputs of pesticides and fertilizers, the role of these micro-organisms is marginalized in sustainable agriculture. For increasing crop yields, the use of PGPRs has been well proven for its eco-friendly sound by promoting plant growth either direct or indirect mechanism. The mechanisms of PGPRs include resistance against plant pathogens, solubilizing nutrients for easy uptake, and maintaining the plant growth regulator hormone. 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. PGPR have the potential contribute to sustainable plant growth promotion.

Rhizobacteria are root-colonizing bacteria that form symbiotic relationships with many plants. The word comes from the Greek *Rhiza*, meaning root. Though parasitic varieties of rhizobacteria exist, the term usually refers to bacteria that form mutualism. Rhizobacteria are often referred to as plant growth-promoting rhizobacteria, or PGPRs. PGPR can promote growth and yield of crop plants by direct and indirect mechanisms. Direct growth promoting mechanisms enhance by PGPR include: nitrogen fixation phytohormone production such as indole-3-acetic acid (IAA), gibberellic acid (GA_3), and cytokinins, *e.g.*, Zeatin, iron sequestration by bacterial siderophores and phosphate solubilization. Indirect plant growth promotion enhance by biocontrol-PGPB in biotic stress conditions includes a variety of mechanisms by which bacteria prevent the deleterious effects of phytopathogens on plant growth, such as rhizospheric competition, induced systemic resistance (ISR), biosynthesis of stress-related phytohormones like jasmonic acid, or ethylene and biosynthesis of antimi- crobial molecules. Only 1 to 2% of bacteria promote plant growth in the rhizosphere.

They not only promote plant growth but also help in sustainable agricultural development and protecting the environment. Certain plant growth promoting rhizobacteria (PGPR) contain a vital enzyme, 1- aminocyclopropane-1-carboxylic acid (ACC) deaminase, which regulates ethylene production by metabolizing ACC into α-ketobutyrate and ammonia. Application of PGPR might play an important role in the further development of remediation methods. Micro-organisms can enhance biomass production and tolerance of the plants to heavy metals and other soil conditions. The bacteria that colonize the roots of plants seed inoculation and enhance plant growth.

Classification of PGPRs:PGPRs are classifed on the basis of their locations, functions, and activities.

On the Basis of Location: According to their location in the rhizosphere, they are divided into two categories. Extracellular PGPRs (ePGPRs) These PGPRs are found in the rhizosphere, in the rhizoplane, or in the spaces between cells of the root cortex, but they are never present inside the cells. Examples are species of Pseudomonas, Bacillus, etc., which are present in the soil as well as in the intercellular space of cortical cells as endophytes.

Intracellular PGPRs (iPGPRs) These generally exist inside the cells specially in specialized nodular structure. Examples are Rhizobia and Frankia, both of which are associated with higher plants and present inside the cells where they fix atmospheric nitrogen.

On the basis of functionality: PGPRs are divided into three groups, *viz.*, plant growth-promoting, biocontrol, and stress homeoregulating bacteria.

Plant growth-promoting bacteria : Some rhizobacteria directly induce plant promotion via nitrogen fixing, phytohormone production like IAA ,cytokinin, siderophore production and phosphate solubilization

Biocontrolling bacteria : They indirectly promote plant growth by releasing phytotoxic substances such as hydrogen cyanide, chitinase, pectinase, cellulase, ethylene, antibiotics, etc., which are responsible for controlling plant pathogens.

Stress homeoregulating bacteria : These bacteria can facilitate plant growth directly or indirectly in biotic and abiotic stresses. Direct facilitation by these bacteria includes releasing stress-related phytohormones, such as abscisic acid, salicylic acid, and jasmonic acid plant growth regulators, like cadaverine.

On the basis of activities, PGPRs dividesinto following categories:

Phytostimulators : Certain bacteria stimulate the plant growth by producing different phytohormones like *Pseudomonas, Azospirillum, Bradyrhizobium,* etc.

Rhizoremediators : Many of the bacteria are used in degradation of herbicides, pesticides, and other hazardous organic compounds and/or pollutants in the soil which could be helpful in plant growth by increasing soil fertility.

Biopesticides : Many of the bacteria produce antibiotics and other toxic compounds which are helpful in the reduction of pathogens, e.g., *Pseudomonas* and *Bacillus* spp.

Bioprotectants : Large numbers of bacteria are helpful in the disease suppression which directly and indirectly enhance plant growth.

Biofertilizers : Many of the PGPRs enhance soil fertility and productivity by involving in nutrient cycling. Different types of biofertilizers are being used such as:

Nitrogen- fixing biofertilizers like *Rhizobium, Bradyrhizobium, Nitrosomonas, Azospirillum, Azotobacter,* etc.

Phosphorus-solubilizing and phosphorus-mobilizing biofertilizers like *Bacillus, Pseudomonas, Mycorrhiza,* etc.

Plant growth-promoting biofertilizers like *Pseudomonas, Bacillus,* etc.

Mechanisms of action PGPR : The PGPR strains generally promote plant growth and development either direct or indirect. The main mechanisms PGPRs use to contribute to the increase of nutrients in the soil are nitrogen fixation and phosphate solubilization, along with solubilization of other minerals. After photosynthesis, nitrogen fixation is the most important biological process in nature, enabling the circulation of nitrogen in the biosphere.

Symbiotic bacteria from the group Rhizobium and Frankia, and non-symbiotic bacteria such as *Azospirlillum* sp., *Azotobacter* sp. and *Acetobacter* sp. have the ability to assimilate N_2 from the atmosphere and convert it into NH_3 as part of nitrogen fixation. The transformation of nitrogen takes place through ammonification, nitrification, nitrogen fixation and denitrification. The conversion of insoluble forms of phosphorus into forms that are more available to the plant in the rhizosphere is achieved by means of bacteria called phosphate-solubilizers.Some of the PGPRs, including *Pseudomonas* sp., *Bacillus* sp., *Burkholderia* sp., *Rhizobium* sp. and *Flavobacterium* sp., have the ability to solubilize some insoluble phosphate compounds. The usage of these bacteria as a part of bioinoculants may enhance the assimilation of phosphate and offers numerous advantages to the direct stimulation of plant growth.It has been recently reported that inoculation with Zn-solubilizing bacteria can help to enhance Zn nutrition by plants, therefore improving the growth of plant. PGPRs are also able to make phytohormones which stimulate plant growth, thus the

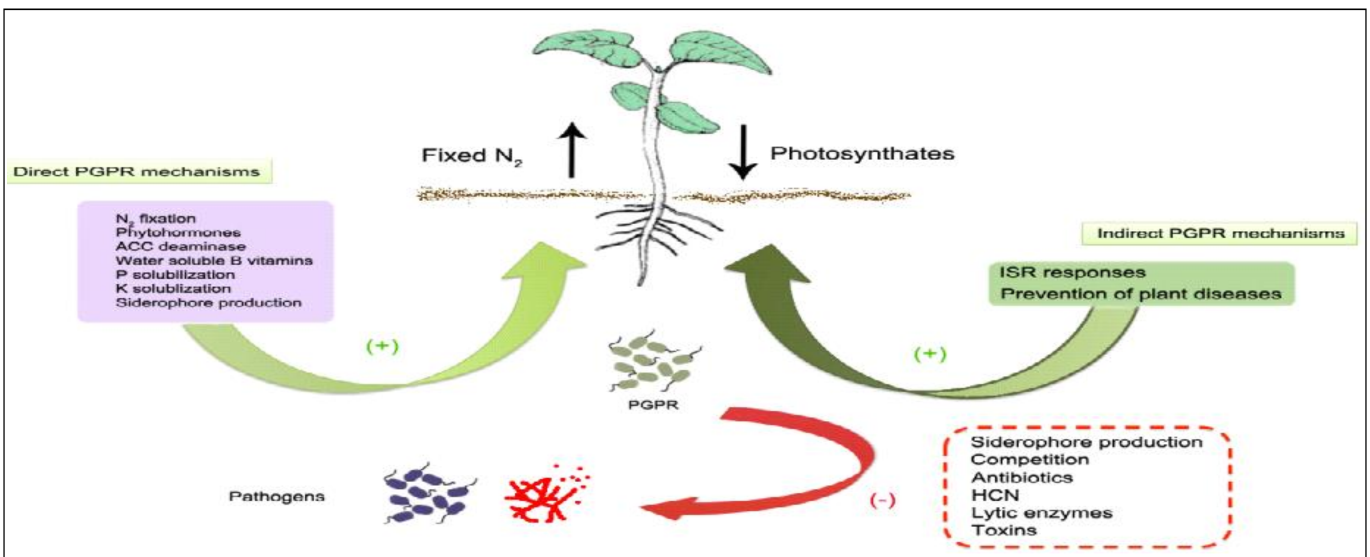

Fig. 1 : Mechanisms of plant growth-promoting rhizobacteria

mechanism of their activity is known as biostimulation. Some of the most important phytohormones are auxins, cytokinins, gibberellins and abscisic acid. Auxins are plant hormones with a cardinal role to modulate the development of a plant. As much as 80% of the PGPRs can synthesize the indole acetic acid (IAA), which has an important role in the stimulation of cellular division and differentiation. IAA induces the occurrence of lateral roots among dicotyledons and adventive roots among monocotyledons, improves secondary thickening of the walls and an increase in xylem cells, which results in better minerals and water. Azospirillum sp., fluorescent Pseudomonas sp., and several other PGPRs secrete IAA. Gibberellins take part in cellular elongation and division, as well as the internodium elongation. Ninety per cent of rhizosphere microorganisms have the ability to produce and release cytokinins, while approximately 30 compounds from the group of cytokinins that promote growth have a microbial origin. Existing data indicates that Rhizobium sp. produces cytokinins. Abscisic acid regulates the physiological processes in plant. In part, it is synthesized in the chloroplasts, while its entire biosynthesis primarily takes place in the leaves, initiated by the stressful environmental conditions such as a lack of water and low temperatures. It helps the germination of the seed, the closing of stomata and tolerance to environmental stress.

Indirect PGPR mechanisms of action : Various pathogenic bacteria, fungi and nematodes may infect the plant and thus reduce crop yield to a great extent. PGPRs significantly influence the induction of plant resistance to pathogens by synthesizing various antibiotics, siderophores, lytic enzymes. One of the main mechanisms for the control of pathogens is the ability to synthesize one or more antibiotics. Many PGPRs with the ability to synthesize antibiotics also produce cyanide, which in most cases has a synergistic effect when combined with antibiotics. Furthermore, with the aim to prevail over the restricted supply of iron in the soil, some PGPRs are able to produce siderophores. Siderophores are low molecular mass organic compounds with strong chelating affinity towards ions of iron (Fe^{+3}). In presence of oxygen, most of the iron particles are only partly soluble and thus are not completely available to the living organisms. Bacterial siderophores have a positive effect on the growth of plants, functioning as a source of iron that is readily usable to the plant. Certain studies have indicated that Pseudomonas, which produces siderophores, influences antifungal activity towards different pathogenic fungi, while Bacillus cereus has a potential in biocontrol of rice fungi. In addition, PGPRs have a positive effect on the characteristics of the soil itself and their consortiums are successfully used in the processes of bioremediation. This is how nutrient poor and polluted soil becomes arable land available to agricultural production, since a transformation occurs in the hydrocarbons and other pollutants into less detrimental forms. Microorganisms that effectively break down hydrocarbons and oil-based pollutants include *Nocardia* sp., *Pseudomonas* sp., *Acinetobacter* sp., *Flavobacterium* sp., *Micrococcus* sp., *Arthrobacter* sp., *Corynebacterium* sp., *Mycobacterium* sp., *Bacillus* sp., etc. AM fungi are also studied in the phytoremediation processes, indicating their role in improving soil conditions and enhancing plant tolerance to heavy metals. Some studies have shown that commonly known PGPR (*Bacillus* sp., *Pseudomonas* sp., *Agrobacterium* sp., etc.) not only improve the plant growth, but also reduce uptake of heavy metals by plants. For example, Microbacterium sp. successfully prevented chromium toxic effect on pea by simply reducing its bioavailability in soil. On the other hand, *Pseudomonas putida* is capable of simultaneously degrading naphthalene in soil, protecting the seed and the plant from possible lethal effect.

Conclusion : The present review indicates the PGPR's can be a best alternative of chemical fertilizer for sustainable and ecofriendly agriculture. They will not only provide nutrients to the plants (direct plant growth promotion) and protect plants against the phytopathogens (indirect plant growth promotion) but also increase the soil fertility. Thus, awareness must prevail among the farmers about negative impact of chemical fertilizers and positive aspects of PGPR's as biofertilizer.

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