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REVIEW ARTICLE

# Plant Growth Promoting Rhizobacteria (PGPR): A Budding Complement of Synthetic Fertilizers for Improving Crop Production

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**ABSTRACT**
Group of free-living soil bacteria that colonize the rhizosphere and benefit the growth and development in plants are stated as plant growth promoting rhizobacteria (PGPR). Bacteria of various genera such as *Azospirillium, Azotobactor, Pseudomonas, Bacillus, Enterobactor, Rhizobium etc.* are recognized as PGPR. Usually, PGPR perform their functions in three different ways: 1)producing certain compounds for the plants, 2)assisting the certain nutrients uptake from the soil, and 3)declining or averting the plants from diseases. Plant growth promotion and development may be facilitated both directly and indirectly. Direct plant growth promotion is induced by the production of phytohormones like auxins, gibberellins, cytokinins and ethylene, providing biologically fixed nitrogen, and increasing the phosphorous uptake by inorganic phosphates solubilization. While, indirect plant growth improvement includes the prevention of the harmful effects of phytopathogenic organisms. A lot of studies exhibited that inoculation with PGPR resulted in substantial growth and yield increases in different agronomic and horticultural crops without causing any harmful effects on aerial and soil environment and reduced their need for synthetic fertilizers.

Crop plants needs specific mineral elements for the provision of nutrients essential for their growth and development. So the proper availability of these nutrients is required to obtain the optimum crop yield (Ibrahim et al., 2010). Modern agriculture is facing severe problems of environmental pollution as well as the disgrace of land resources due to the excessive use of synthetic fertilizers in order to increase the yield per unit area (Ibrahim et al., 2011; Abbasdokht and Gholami, 2010, Sarwar et al., 2010). As a result, the concept of eco-friendly agriculture is getting to be a new field of interest to diminish the harmful outcomes of commercialized farming presently being experienced.

The rhizosphere, volume of soil surrounding roots influenced physically, chemically, and biologically by plant root, is a extremely encouraging habitat for the reproduction of micro-organisms, that employs a potential impact on soil fertility and plant health (Tahir et al., 2013; Podile and Kishore 2006; Antoun and Prevost 2005). In the rhizosphere, important and intensive interactions occur among the plant, soil, micro-organisms, and soil microfauna (Antoun and Prevost, 2005) which can considerably influence plant growth and crop yields. In the rhizosphere, bacteria are the most abundant micro-organisms. These microbial communities are beneficial for plant growth, yield, and crop quality, and they have been called "plant growth promoting rhizobacteria (PGPR)" (Kloepper and Schroth 1978) including numerous strains of the genera *Arthrobacter, Azospirillium, Azotobacter, Serratia, Azoarcus, Bacillus, Burkholderia, Enterobacter, Erwinia, Gluconacetobacter, Klebsiella, Pseudomonas, Beijerinckia, Rhizobium, etc.* (Esitken et al., 2006; Murphy et al., 2003).

Glick (1995) reported that PGPR function in three different ways: synthesizing particular compounds for the plants, assisting the certain nutrients uptake from the environment (Cakmakci et al., 2006), and averting the plants from diseases (Guo et al., 2004; Jetiyanon and Kloepper 2002). In other words, these mentioned bacteria can directly cause seed emergence, plant growth, or improvement in crop yields by generating plant growth regulators such as auxins, gibberellins (GAs), and cytokinins. supplying biologically fixed nitrogen, and increasing the phosphorous uptake by solubilization of inorganic phosphates (Podile and Kishore 2006) while indirect mechanisms that involve suppression of bacterial, fungal, viral, and nematode pathogens (Kirankumar et al., 2008). So microbial activity have vital role in agriculture for plant growth on sustain basis by lowering the requirement of synthetic fertilizers and reducing cost of crop production (Iqbal et al., 2008).

**Mode of action of PGPR**

**Direct mechanism**

**Biological nitrogen fixation**

Nitrogen (N) is one of the principal plant nutrients for improved plant growth and yield (Ayub et al., 2010). However, the global nitrogen cycle pollutes groundwater and increases the risk of chemical spills and its low availability due to the high losses by emission or leaching is a limiting factor in agricultural ecosystems, hence bacteria with ability to make atmospheric N available for plants play a critical role reducing the need for chemical fertilizers and decreasing their adverse environmental effects.

Biological nitrogen fixation fixes about 60% of the earth's available nitrogen and represents an economically beneficial and environmentally sound alternative to chemical fertilizers (Ladha and Kundu, 1997). Hence legume and their rhizobia are often introduced to agricultural ecosystems to improve soil fertility and crop growth.On the other hand, non-symbiotic biological N fixation, is carried out by free living diazotrophics, which can stimulate growth in non-legume plants There are studies showing that N-fixing bacteria, free-living as well as Rhizobium strains, can stimulate the growth of non-legumes such as radish, rice,sugar beet, sugar cane, rice, maize, and wheat (Sahin et al., 2004; Mirza et al., 2006) in this way contributing to reduced dependence on N-based fertilizers (Bhattacharjeeet al., 2008). Non-symbiotic N-fixing PGPR belonging to genera including *Azoarcus, Azospirillum, Burkholderia, Gluconacetobacter* and *Pseudomonas* (Bashan and de-Bashan, 2010; Mirzaet al., 2006) have been isolated from different soils and gaining attention in the recent years, because of their association with important crops and potential to enhance the plant growth. For example, experiments with *Bacillus* species and *A. brasilense* sp. have a potential on plant growth activity increases in cereals in organic and low-N input agriculture (Cakmakci et al., 2001). Seed inoculation of chickpea with Rhizobium, N-fixing *Bacillus subtilis* significantly increased N percentage compared with the control treatment and may substitute costly N fertilizers in chickpea production even in cold highland areas (Elkoca et al., 2008). Furthermore, inoculation commonly and significantly reduced the required doses of nitrogen fertilization in numerous greenhouse and field experiments in a lot of plant species (Bashan and Levanony 1990).

**Solubilization of phosphates**

Phosphorus is considered as the fundamental macronutrient after N which have significant role for improved plant growth and yield (Podile and Kishore 2006; Ali et al., 2012). Even in phosphorous rich soil, most of the P is unavailable for the plants, as large amount of soil P is found in its insoluble form due to fixation as aluminum and iron phosphates in acid soils and calcium phosphates in alkaline soils (Gyaneshwar et al., 2002). Phosphate solubilizing PGPR are common in the rhizosphere and can be used to overcome this problem (Vessey 2003). PSB secretes organic acids (*e.g.* gluconate, citrate, lactate and succiónate) and phosphatases that convert the insoluble phosphates into soluble monobasic and dibasic ions and may also solubilize inorganic phosphate and make soil phosphorus available to the plants, which otherwise remain fixed (Whitelaw 2000; Gyaneshwar et al., 2002). In other words, phosphate solubilizing microorganisms translate insoluble phosphates into soluble forms through the process of acidification, chelation, and exchange reactions (Rodriguez et al., 2004). Various studies revealed the recent trends, progress and development with respect to mineral phosphate solublization by various plant growths promoting rhizobacteria. Fatima et al. (2009) isolated seven rhizobacterial strains from the wheat croprhizosphereat four different locations of Pakistan. Characterization of these rhizobacterial isolates displayed that four isolates *Azospirillum* (WPR-42, WP-3), *Pseudomonas* (WPR-61) and *Azotobacter* (WPR-51) expressed ability to change insoluble P fractions into soluble available form. Few other examples of beneficial association with phosphate solubilizing PGPR and plants include *B. megaterium* (M-3) and chickpea (Elkoca et al., 2008), *Enterobacter agglomerans* and tomato (Kim et al., 1998), *P. chlororaphis, P. putida,* and soybean (Cattelan et al., 1999), Avena sativa and PGPR strains isolated from the rhizosphere of forage (WenXing et al., 2008), *Serratiam arcescens, Pseudomonas* sp. and maize (Hameeda et al., 2008)and 50% reduction in the phosphorus fertilizers application could be achieved by the combined use of phosphorus solubilizing micro-organisms and plant growth promoting rhizobacteria without decreasing the yield (Yazdani et al., 2009).

**Production of phytohormones**

The phytohormonesproduction by PGPR is now being deliberatedas one of the most important mechanisms through which severalrhizobacteria promote plant growth (Spaepen et al., 2007). Phytohormones are indicator molecules that act as chemical messengers and show a vital role as growth and development managers in the plants. The capabilityof producing phytohormoneis widely disseminated among bacteria related with soil and plants. Studies have verified that the PGPR can stimulate plant growth through the production of auxins (indole acetic acid) (Spaepen et al., 2008), gibberellines (Bottiniet al., 2004) and cytokinins (Timmusk et al., 1999), or by regulating the high levels of endogenous ethylene in the plant (Glick et al., 1998).

The auxin (IAA) play role in division, expansion and differentiation of plant cells and tissues and inspires root elongation. The IAA synthesizing capacity has been detected in many symbiotic and free living bacterial species present in rhizosphere(Costacurtaet al., 1995; Tsavkelova et al., 2006).Gibberellinesare a class of phytohormonesbeing usually associated with amending plant morphology by the extension of plant tissue, principally stem tissue. Bottini et al. (2004) recorded IAA and GA production by P-solubilizing *Enterobacter*, *Xanthomonas* and *Pseudomonas* isolated from rhizosphere of sorghum plants. Ethylene is also considers essential for the plants growth and development, but its effects on plant growth has been different depending on its concentration in root tissues. It may be harmful at high concentrations, as it encourages defoliation and cellular processes leading to inhibition of stem and root growth as well as premature senescence that ultimately lead to poor performance of crop (Li et al., 2005). Under different types of environmental stress, likedraught, cold, flooding, heavy metals presence,pathogens infections, plants respond by synthesizing 1-aminocyclopropane-1-carboxylate (ACC) that is the originator for ethylene (Chen et al., 2002; Glick, 2007). Some of the ACC is secreted into the rhizosphere and is reabsorbed by the roots, where it is converted into ethylene. This accumulation of ethylene leads to a downward spiral effect, as poor root growth hints to a reduced ability to obtain water and nutrients, which, in turn, leads to further stress. Thus, PGPR through the ability to degrade ACC in the rhizosphere can assist to disrupt this downward cycle and reconstruct a healthy root system, needed to cope with environmental stress. Among PGPR species capable improving growth and development in several crops by producing these beneficial phytohormones, belonging to *Azospirillum* (Dobbelaere et al., 1999) *Azotobacter* (Ahmad et al., 2008), *Bacillus* (Swain et al., 2007), *Burkholderia, Enterobacter, Pseudomonas and Rhizobium* genera, have been isolated from different rhizosphere soils (Shoebitz et al., 2009).

**Indirect mechanism**

**Suppression of plant diseases by PGPR**

Recently, PGPRs are increasingly and extensively used as inoculants in biological control of bacterial, viral and fungal plant diseases (Altindag et al. 2006; Aliye et al., 2008; Akgul and Mirik, 2008; Xue et al., 2009). In greenhouse study tomato seeds treated with PGPR strains *Bacillus subtilis* and *Bacillus amyloliquefaciens* were noted for maximum disease protection for bacterial canker (Girish and Umesha, 2005). Altindag et al. (2006) suggested that *Burkholdriagladii*OSU 7 has the potential to be used as biopesticide for effective management of brown rot disease on apricot. While *Pseudomonas corrugata, Bacillus megaterium*, and *Flavobacterium* sp. showed consistently good control efficacy against *Phytophthora capsici* and *Phytophthora blight* of pepper (Sang et al., 2008; Akgul and Mirik, 2008). In the same way Kirankumar et al., (2008) found *Pseudomonas* B-25 exceedingly efficient in promoting growth, yield, and nutrient uptake of tomato in the presence of tobacco mosaic virus (TMV) pathogen, and the incidence of pathogenesis was markedly less after PGPR treatment. Banana bunchy top disease (BBTD) the most serious virus disease of banana plantations worldwide is caused by Banana bunchy top virus (BBTV). Under field conditions, *Pseudomonas fluorescens* Pf 1 and CHA0 found significantly operative in dropping BBTV recording 33.33% infection with 60% reduction over control (Harish et al., 2008). The application of PGPR to graminaceous crops also resulted in upgraded yields as *Azotobacter* and *Azospirillum* strains have been shown to hinder*Rhizoctoniasolani* in the wheat rhizophere (Fatima et al., 2009) and *Pseudomonas* spp. have revealed similar activity in rice and maize against a range of fungal pathogens (Hameeda et al., 2008). This response could be due to the association of antimicrobial compounds or competitive exclusion of the pathogen, as well as by inducing systemic resistance in plants.

**Effect of PGPR on growth, development and yield of crops**

Significant increases in growth development and yield of several agronomic and horticultural crops in response to inoculation with plant growth promoting rhizobacteria have been reported. Esitken et al. (2003, 2006) and Orhan et al. (2006) described that *Pseudomonas* BA-8, *Bacillus* OSU-142 and M3 increased the shoot length, crop yield and improved fruit quality of apricot, sweet cherry, and raspberry. Their inoculations also significantly increased different investigated parameters in chickpea such as plant height, root, shoot and nodule dry weight, chlorophyll content, N%, seed yield, total biomass yield, and protein contents in seed compared with the control treatment, equal to or higher than N, P, and NP treatments (Elkoca et al., 2008). The average weight of tomato fruit per plant treated with *Rhodopseudomonas* sp was (82.7 g) higher than those of others including the uninoculated control (Lee et al., 2008a).

In another research, Cakmakci et al. (2006) proposed that in the greenhouse, microbial inoculations with PGPR increased root weight by 2.8–46.7% in sugar beet depending on the species. Root, leaf, and sugar yield were improved by the bacterial inoculation by 12.3–16.1%, 15.5–20.8%, and 9.8–14.7%, respectively. Inoculation with the *Rhizobium leguminosarum* and *Azotobacter* sp. S8, augmented, root dries weight, root length and growth in cotton (Hafeez et al., 2004). While significant positive effects on growth, nodule number, and yield of soybean were obtained after inoculation with *Bradyrhizobium* spp (Egamberdiyeva et al. 2004). Similarly increased sugarcane tillering, stalk population, stalk weight and yieldwith inoculation of PSB *Bacilusmegaterium* and an increase in head diameter, 1,000 seed weight, kernel ratio and oil content which led to the seed and oil yield increase of 15 and 24.7% with PSB, *Bacilus* M-13 as compared to control in sunflower was observed (Sundara et al., 2002; Ekin 2010*). Azotobacter coroocoocum, Azospirilum brasilens, Pseudomonas, putida*, and *Bacilus lentus* inoculation improved yield and growth components of corn and wheat as compared to no application (Yazdani et al., 2009; Cakmakci et al., 2006).

**Conclusions**

Different PGPR have been examined under controlled and field conditions, and generally plant growth promotion such as yield increases in different crops, production of phytohormones, biological nitrogen fixation, solubilization of insoluble phosphates, suppression of diseases, have been clearly demonstrated. So Plant growth promoting rhizobacteria have vital role in agriculture because they are very important in the movement and availability of minerals essential for plant growth also decreasing the disease incidents for improving crop yields on sustain basis and ultimately lower the requirement of synthetic fertilizers and cost of crop production.

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