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Dynamic role of plant growth promoting rhizobacteria (PGPR) in agriculture

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Abstract
Plant Growth promoting rhizobacteria (PGPR) is a heterogeneous group of bacteria (eg- Pseudomonas, Azospirillum, Azotobacter, Klebsiella, Enterobacter, Arthrobacter, Burkholderia, Bacillus etc.) that are associated and colonized with root surface of plant. The rhizosphere of plant, contains different type of bacteria but only 2-5% of bacteria act as a PGPR (Antoun and Prevost, 2005). Bashan 1998; Gupta *et al*. 2000; Lucy *et al*. 2004 revealed that growth promoting ability of some rhizospheric bacteria is highly specific with plant species. In present scenario, PGPR plays an important tool for sustainable agriculture and trend for the future. The increasing demand for crop production with consequential reduction of synthetic fertilizers and pesticide use a big challenge. PGPR is a new alternative practice in Indian agriculture and it is an eco-friendly approach which can help by directly and indirectly mechanism to facilitating the growth and yield of the plant. The direct mechanisms likes nitrogen fixation, phosphate solublization, potassium solublization, siderophore production, phytoharmone production (i.e. IAA, Cytokinin, GA, Ethylene) etc. while indirect mechanisms likes Antibiotic production, Hydrolytic enzyme production, Induced systemic resistance (ISR), Exopolysaccharide production etc. The mechanisms of PGPR include regulating hormonal and nutritional balance, inducing resistance against plant pathogens and solubilizing nutrients for easy uptake by plants.

Keywords: PGPR, Rhizosphere, IAA, Phosphate solubilisation

Introduction
Worldwide, PGPR has gained popularity, importance and acceptance for agricultural benefits. During 1978, PGPR term first time coined by Kloepper and Schroth and to describe soil bacteria that colonize the plant root and act as an additional source of hormones, and growth factors that are helpful to improve plant growth and yield". The use of micro flora with the purpose to improving nutrient availability for plant significantly (Freitas *et al*. 2007) [22]. The different researchers observed that plant inoculated with PGPR, significantly enhanced yield and growth of crop (Kloepper *et al*. 1980; Vessey 2003; Gray and Smith 2005; Figueiredo *et al*. 2008; Zhang *et al*. 1996) [31, 59, 25, 19, 66]. On 1904, Rhizospheric term firstly coined by Hiltner and stated that the zone of soil which surrounded the root surface where microbial population are accelerated by root activities. The plant roots secreted different type of exudates, mucigels, mucilages, secondary metabolites, alkaloids etc. that acts as a source of carbon and energy for microbes. Soil is the habitat of different type of micro flora like PGPR, actinomycetes, fungi, protozoa and algae. The rhizospheric soil contains large number heterogeneous microbes over non rhizospheric soil, this is due to the secreation of root exudates, mucilage, mucigel, alkaloids etc. that function as a source of carbon and energy to the microbes (Burdman *et al*. 2000) [11]. Weller and Thomashow (1994) [62] illustrated that the rhizosphere is a narrow zone which is enriched with nutrients for microbial proliferation and this zone contains 10 to 100 times more bacteria than bulk soil. The rhizospheric bacteria plays a significant role in nutrient cycle, mineral solubilization, organic matter decomposition, secreation of phyto-harmones like indole acetic acid (IAA), IBA(indole butyric acid), cytokinines, gibberilic acid and ethylene.

Types of PGPRs
Extracelluar PGPR (ePGPR): existing in the rhizosphere, on the rhizoplane, or in the spaces between cells of the root cortex. Eg: Agrobacterium, Arthrobacter, Azotobacter, Azospirillum,

Bacillus, Burkholderia, Caulobacter, Chromobacterium, Erwinia, Flavobacterium, Micrococcous, Pseudomonas and Serratia.

Intracellular PGPR (iPGPR): Locate generally inside the specialized nodular structures of root cells. Family of Rhizobiaceae includes Allorhizobium, Bradyrhizobium, Mesorhizobium and Rhizobium, endophytes and Frankia species.

Role of PGPR in agriculture

PGPR performs a various mechanism (i.e. direct and indirect), that plays a crucial role in augmenting the growth of plants. The rhizosphere contains small fraction i.e. 2-5% of total bacteria are present in the vicinity are PGPR (Antoun and Prevost, 2005) [3]. PGPR posses a different mode of action that all depends upon the host type plants (Dey *et al*. 2004) [14]. Some PGPR have high affinity toward the nitrogen fixation like rhizobium sp., Azotobacter and frankia fix the nitrogen in the range of 50-250, 20-30 and 50-150 kg N/ha/year respectively. These nutrients incorporate every year in the soil to enhance the fertility status and also avail the adequate of essential nutrient in the soil solution pool for plant uptake. Some strains of PGPR are used as a bio-remidiation for control the abiotic and biotic stress which is the major constraints in the soil that directly or indirectly reduces the yield of crop. At 2002, Pishchik *et al*. reported that *Klebsiella mobilis* CIAM 88o inoculated barley that thrive well in poor and Cadmium (Cd) polluted field through binding the soluble Cd that present in the soil suspension to form biologically unavailable complex form. Apart from this bacterial strain helps to elongate the root length, increasing 120% yield as well as 2 fold decreased the Cd content in barley. Marulanda *et al*. 2010 [38], observed that *Bacillus megaterium* strain were inoculated with Zea mays (Maize) then it shown the higher root hydraulic conductivity that helpful in water absorption under salt affected soil. Sharma and saikia (2014) [51] revealed that the green gram innocualed with *Pseudomonas aeruginosa* GGRJ21 strain, improved the growth and root proliferation of plant under drought stress condition through different mechanism like sequestration of cell osmolyte, different type of antioxidant enzymes etc.

Phytostimulator

- Phytostimulator is a synthetic substances which produced outside the plant and act as a growth stimulator of the plant and also boosting the crop production. Phyto hormones are organic substances which are produced by microorganisms that alter the concentration of IAA, Gibberelic acid and cytokinines (Lugtenberg *et al* 2002; Somers) [36, 54]. Low concentrations of Phyto hormones are sufficient to influence the physiological, morphological and biochemical process of the plant.

Auxin

- Auxin is one of key molecules that regulating the most crucial metabolic activity of plant by directly and indirectly (Tanimoto 2005) [56]. During 2015, Jha and Saraf observed that all rhizospheric bacteria don't have ability to produce auxin, but large extent of bacteria flora i.e. more than 80% in the rhizosphere produce auxin. Dobbelaere *et al*. (1999) and Khalid *et al*. (2004) demonstrated that biosynthesis of IAA by various PGPR to increase root proliferation and its length. According to Spaepen and Vacheron reported that low amount of auxin is sufficient for primary root proliferation, whereas high IAA level that causes a negative impact on root length, root hair formation and also show the positive impact in lateral root formation. Thus optimum concentration of auxin increases the large surface area of root which is helpful in efficient nutrient uptake.

Gibberelic acid (GA)

- **GA** is a synthetic compound that plays an important role in seed germination, stem elongation, floral induction and fruit setting (Bottini *et al*. 2004) [9]. Since 2011, Spaepen *et al*. [55] revealed that shoot elongation is the primary physiological effect of GA. Khan *et al*. (2014) [29] recorded that Tomato plant inoculated with LK11 strain of gibberellin producing *Sphingomonas sp*. that plays a significant role to increasing in various growth of plant. However, the production of gibberellins by PGPR is uncommon, with only two species i.e. *Bacillus pumilus* and *Bacillus licheniformis*. being documented that produce gibberellins (Jha and Saraf, 2015) [28].

Cytokinines

- Cytokinines is a crucial molecules which function is prominently observed in shoot and root initiation, cell devision, cell enlargement and induce root hair proliferation that increase root surface area significantly (Salamone *et al*. 2005; Werner *et al*. 2003) [50, 63]. Liu *et al*. (2013) [34] noticed that the oriental Thuja seedlings inoculated with cytokinin-producing *Bacillus subtilis* strains were more resistant to stress due to draught. Some of the rhizo-bacteria that have ability to produce cytokinines like *Rhizobium spp, Bacillus subtilis, Rhodospirillium rubrum, Paenibacillus rubrum, Pseudomonas fluorescens and Pantoea agglomerans* (Glick 2012 and Salamone *et al*. 2001) [23, 49].

Biofertilizer

- Globally, biofertilizers are most frequently used in organic farming and sustainable agriculture to suppliment the use of synthrtic chemical fertilizers. According to Vessey (2003) [59] Biofertilizer is a product that containing latent cells or living strains of efficient microbes which can be applied on seed, plant surface and soil that colonizes in the root vicinity of rhizosphere and enhanced the root growth by increasing primary nutrient availability. Rhizobacteria associated with rhizosphere of different non leguminous species like rice, maize, wheat and sugarcane are inoculated, that can fix nitrogen, and solubilization of phosphorous (Dobereiner 1997) [15]. Biofertilizer has been an alternative approach to mineral fertilizers to improve the yield and growth of plant in sustainable agriculture (Canbolat *et al*. 2006) [12]. Common biofertilizers are enlisted that frequently used in major crops (Table 1).

Table 1: List of some common plant growth promoting rhizobacteria used in field crop.

Crops	PGPR	PGPR Mechanisms	References
Rice	Azoarcus	Nitrogen fixation	Reinhold-Hurek B and Hurek T (1998) [46].
Rice	Rhizobium	Nitrogen fixation	Yanni Y *et al*. (2001) [64].
Wheat	Azorhizobium	Nitrogen fixation	Sabry SRS *et al*. (1997) [47].
Wheat, moong bean	Pseudomonas	ACC deaminase synthesis	Ahmad M *et al*. (2013); Shaharoona B *et al*. (2008) [13, 52].
Wheat, barley, oats, rice, tea, tobacco, coffee, sunflower, maize, beetroot and coconuts	Azotobacter	Nitrogen fixation	Wani SA *et al*. (2013) [61].
Wheat	Pseudomonas	Antibiotic production	Mazzola M *et al*. (1995) [40].
Sugarcane	Azospirillum	Nitrogen fixation	30; Tejera N *et al*. (2005); Sahoo RK *et al*. (2014); Berg RH *et al*. (1980) [57, 48, 7].
Sugarcane	Beijerinckia	Nitrogen fixation	30, Dobereiner J (1961) [16].
Potato	Bacillus	Auxin synthesis	Ahmed A and Hasnain S (2010) [2].
Maize, peanuts	Bacillus	Induction of plant stress resistance	Egamberdiyeva D (2007); El-Akhal MR *et al*. (2013) [17, 18].
Maize	Bacillus	Siderophore production	Beneduzi A *et al*. (2012) [15].
Alfalfa	Bacillus	Antibiotic production	Silo-Suh LA *et al*. (1994) [53].
Cotton, maize	Pseudomonas	Induction of plant stress resistance	Egamberdiyeva D (2007) [17].
Pigeon pea	Pseudomonas	Chitinase and Beta-glucanases production	Kumar H *et al*. (2010) [32].
Potato, maize	Pseudomonas	Siderophore production	Beneduzi A *et al*. (2012) [15].
Legumes	Rhizobia	Nitrogen fixation	Young JPW and Haukka KE (1996) [65].
Legumes	Rhizobia	Hydrogen cyanide production	Thamer S *et al*. (2011) [58].
Peanut	Rhizobia	Induction of plant stress resistance	El-Akhal MR *et al*. (2013) [18].
Tomato	Rhizobium	Indole acetic acid synthesis and siderophore production	Garcia-Fraile P *et al*. (2012); Flores-Felix JD *et al*. (2013) [22, 20].
Tomato, mung beans	Rhizobium	ACC deaminase synthesis	Ahmad M *et al*. (2013); Garcia-Fraile P *et al*. (2012) [13, 22].

Siderophore

- Soil ecosystem contains iron mainly in the oxidized ferric form in abundant but there is no importance for plant because plants are unable to up take iron in ferric form. To mitigate this problem, some of the PGPR perform peculiar characteristics to secretes a Siderophore which is a low molecular weight compound that act as a chelator and shows high affininity towards the iron (Miethke and Marahiel 2007; Machuca *et al*. 2007) [41, 37]. The siderophore contains specific sites for iron binding to form siderophore complex on bacterial cell membrane, where ferric reduced to ferrous form and has released by siderophore under iron limitated condition for plant uptake (Boukhalfa and Crumbliss 2002) [10]. Flores-Felix *et al*. (2015) [21] noticed that *Phyllobacterium* strain a siderophore-producing rhizobacteria that promotes the growth and quality of strawberry. The iron sequestration through siderophore mechanism illustrated in fig.1.

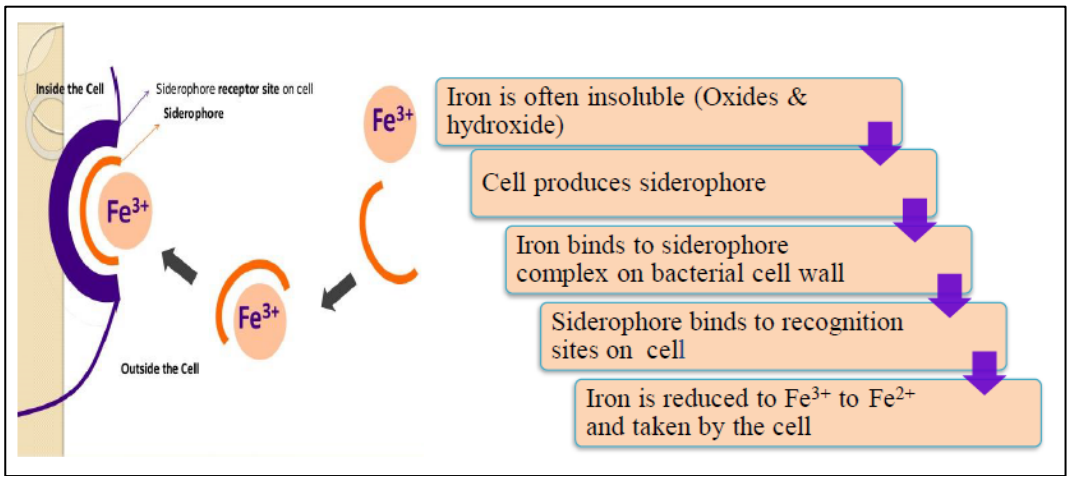
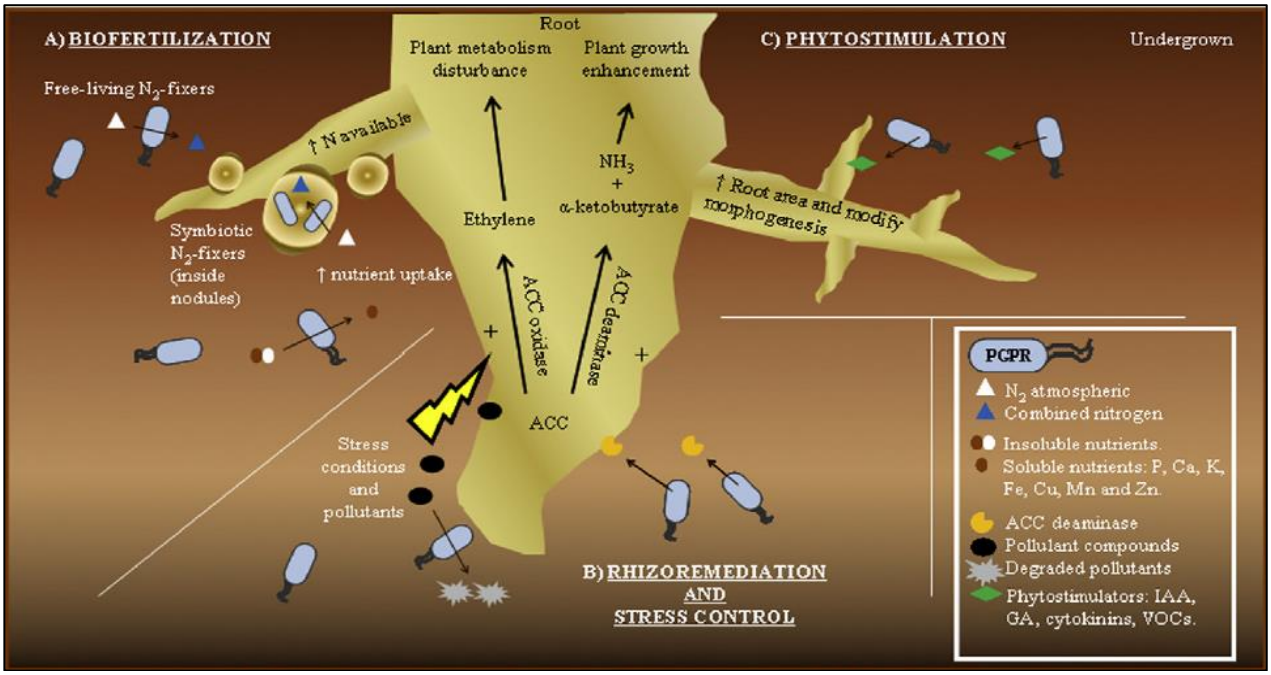


Fig 1: Diagrammatically represents the siderophore mechanism

Biocontrol

Biocontrol is the most prominent indirect mechanism that performed by PGPR to producing different type of antibiotics for the control of phyto-pathogen proliferation (Mazurier *et al*. 2009; Hermosa *et al*. 2012) [39, 27]. Berg 2009 [6] obserbed that only 1-35% bacterial isolates of PGPR that had shown the antagonistic property that inhibit the growth of pathogenic microbes *in vitro*. The scientist reported, two effective biocontrol agents of PGPR are Pseudomonas and bacillus (Gong *et al*. 2006 and Leonardo *et al*. 2006) [24, 33] because they survive under wide range of environment and also facilitating the effective biofertilizer formulation (Perez-Garcia *et al*. 2011) [43]. Bhattacharyya and Jha (2012) [8] reported that most of the rhizobacteria produce several

antifungal metabolites like HCN, pyoluteorin, tensin, 2,-4-diacetylphloroglucinol, phenazines, viscosinamide and pyrrolnitrin. Some of the other pathogen suppressive techniques being shown by PGPR like induce systemic resistance (ISR), siderophore, enzymatic secreation and so on. ISR is the phenomenon in which systemic response is stimulated without direct interaction of resistance inducing PGPR with the plant pathogen (Glick 2012) [23]. This is triggered by non pathogenic microbes and starts in the root, extending to the shoot (Ramos Solano*et al*. 2008) [45]. Siderophore is one of efficient mechanism to restrict the growth of plant pathogens, because it is a small molecular protein that has high affinity towards the iron that is present in rhizospheric region. Thus iron becomes unavailable for bacterial and fungal pathogen to prevent its proliferation in the rhizospere region (Olanrewaju *et al*., 2017) [42]. Several enzymes like chitinase, lipase, proteinase and β-1,3-glucanase are produced by various PGPR that help in hydrolyzes the chitin, cellulose, hemicelluloses and protein of the pathogen. High density of PGPR in the vicinity of rhizosphere that is beneficial for growth of plant and enhance the converting of primary nutrients (N, P and K) through biological process and also govern to control the plant pathogen proliferation (Vessey 2003 and Waddington 1998) [60]. The different functions of PGPR are summariesed in figure 2.



***Source*:** Parez-Montano F *et al*. (2014)

Fig 2: Role of PGPR that act as a (A) Biofertilizer, (B) Phytostimulator and (C) Rhizoremediation and stress control that illustrated in the diagram

Conclusion

Day by day the world population is increasing in tremendous rate and they will be reached up to 9 billion in upcoming year (2050) and the demand of food will become inadequate to full fill the upcoming population. The farmers have incorporated more inorganic or synthetic fertilizers for achieving maximum crop production, due to excess use of synthetic fertilizers that increase cost of production and reduce net benefit as well as it has also degraded the soil physiochemical and biological property. In modern day agriculture practices, PGPR application becoming vital because it has not only increases plant growth and yield but also can curtail the use of synthetic agro-chemical. The use of PGPR (i.e. bio-fertilizers) is an eco-friendly; among PGPR some bacteria like KSB, PSB etc that plays a crucial role in the solubilization of insoluble potassium and phosphorous bearing mineral into available K & P by the production of various organic acids on it. PGPR plays various vital role in agriculture i.e. biofertilizers, phytostimulator, bioremediation, biocontrol, antiobiotic property against pathogen etc. Apart from these PGPR have posses some disadvantage and scientist try to mitigate the problem by carried out the research work in field condition. For gaining the potential exploration of PGPR, large scale and long term research field trial are requisite to evaluate the feasibility of PGPR as well as also investigate the economic feasibility for farmers.

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