Chapter

Plant Growth Promoting Rhizobacterial Consortium: A Sustainable Crop Production Strategy

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Abstract

The prime concern for sustainable production is linked with biotic and abiotic pressures in environment as it impedes yield by producing ROS, which damage cell organelles and other biomolecules. Also the population is increasing at an alarming rate along with the climate change thereby leading to food insecurity. The only alternative to food security is adoption of Plant growth-promoting rhizobacteria (PGPR), as it provides an environmental-friendly and green substitute to chemical substance and traditional agricultural practices to achieve sustainable agriculture by enhancing plant growth and resistance to various pressures. The functions carried out by these microbes in agriculture include nutrient uptake, resistance of host plant to various animate and inanimate pressures. These surround the roots and affect the growth and development through various direct and indirect ways. Furthermore, they have the ability to combat harmful influence of pressures like salinity, drought, heavy metals, floods, and other stresses on plants by inducing the production of antioxidant enzymes such as catalase, peroxidase, and superoxide dismutase. To meet the increasing demand for food, and to evade environmental degradation, the utilization of PGPR consortium is a sustainable and ecofriendly technique to ameliorate the effectiveness of resource utilization and enhancing production under extreme climatic conditions and under increasing population.

Keywords: plant growth promoting rhizobacteria, sustainable, ecofriendly, microbial consortium, pathogens, growth promotion

1. Introduction

PGPR can be defined as the critical component of root zone bearing microorganisms that promote the development of host plants when they grow in association with host plants. Owing to great adjustment in diverse ecosystems, rapid growth, biochemical flexibility to break down numerous natural and synthetic substances, these have became prosperous root zone inhibiting bacteria sustaining in the soil environment [1]. These are regarded as considerable constituent in the regulation of agricultural practices with inherent genetic potential [2]. To qualify for PGPR the microbial strains should at minimum satisfy two out of three standards viz., aggressive colonization, promotion of plant growth and biological control [3, 4]. The basic types of interactions that occur between rhizospheric bacteria and host plants are neutral, positive and negative [5]. The interaction can be commensalism, in which bacteria establishes edible relationship with the host plant, thus no noticeable impact on the growth and development of host plants is exhibited [6]. In negative relationship, the growth and metabolism of host plants is impeded due to release of noxious substances like HCN, ethylene by Rhizobacteria, however some PGPRs have positive influence on the host plants through various direct and indirect processes like solubilization of nutrients, nitrogen fixation, formation of growth managers, encouraging development of mycorrhizae, elimination of pathogens or phytotoxic substances [7]. Furthermore, based on the extent of relationship between the roots of plants and microorganisms, these PGPRs are categorized into two types viz. extracellular plant growth promoting rhizobacteria (ePGPR) and intracellular plant growth promoting rhizobacteria (iPGPR) [8]. The extracellular plant growth promoting rhizobacteria can be found in the rhizosphere, on the rhizoplane or in the intercellular spaces in cortex. The typical examples of ePGPRs include Agrobacterium, Arthrobacter, Azotobacter, Azospirillum, Bacillus, Burkholderia, Caulobacter, Chromobacterium, Erwinia, Flavobacterium, Micrococcous, Pseudomonas and Serratia [9], while as intracellular plant growth promoting rhizobacteria (iPGPRs) occur in the nodules of roots. The typical iPGPRs are endophytes (Allorhizobium, Azorhizobium, Bradyrhizobium, Mesorhizobium and Rhizobium) and Frankia species, both having ability to fix nitrogen in symbiotic association with higher plants [10]. Endophytes colonize the roots of plants and promote growth ***(Wang and Martinez-Romero 2000). Plant growth-promoting rhizobacteria (PGPR) have the potential to increase development of plants through numerous processes viz. solubilization of phosphorus, synthesis of iron chelating compounds(Siderophores), biological fixation of nitrogen, rhizosphere engineering, generation of 1-Aminocyclopropane-1-carboxylate deaminase (ACC) and phytohormones, quorum sensing (QS) signal intervention and hampering of biofilm development, posses antifungal properties, produce volatile organic compounds (VOCs), induce systemic resistance, encourage useful interaction between plants and microbes, impede noxious substance production with pathogens etc. [11].

2. Why PGPR consortium

Microbial consortium is defined as the collection of microorganisms working together in a synergistic manner and is considerably more competent in comparison to single strain of organisms with varying potential. The various reasons that necessitate the utilization of PGPR consortium include meeting the demands of increasing population and increasing production under harsh climatic conditions. Since the global population is increasing at an alarming rate, it is estimated that by 2050, the global population will reach to 9 billion, so to meet the demands of growing population the production rate need to increase by 50% [12]. The food demand for increasing population necessitated the over utilization of synthetic fertilizers [13] since the advent of green revolution as well as over exploitation of arable land [14], thereby resulted in escalation of emission of greenhouse gas (GHG) [15] and change in climate [16]. Over last few decades the uncontrolled utilization of synthetic chemicals has resulted in decline in crop productivity globally due to deterioration in physicochemical and biological health of soil [17–19]. In addition to decline in crop production, climate alteration stem by GHG emissions, resulted in hike in price of agricultural products, which is intended to escalate the chance of food insecurity for 77 million people by 2050 [20]. Few plant species have the tendency to grow competently under adverse environmental conditions due to evolution of plasticity to combat alterations, but most plants cannot resist the adverse environmental conditions leading to diminish in productivity. It has been reported that maize and wheat has undergone a percentage loss in productivity by 3.8 and 5.5% due to climate alteration [21, 22]. To meet the increasing demand for food, and to evade the environmental degradation, while securing the productivity and biological health of soil, the only solution is to promote sustainable agriculture with progressive decline in the utilization of synthetic chemicals and outstanding use of bio-based products, as well as harnessing the biological and genetic potential of crops and associated microbes [23–25]. Thus the utilization of PGPR consortium is the sustainable and ecofriendly technique to ameliorate the effectiveness of resource utilization and enhancing the production under extreme climatic conditions [26]and under increasing population. Furthermore in addition to boost in crop production, these microbes have the capability to withstand various biotic and abiotic pressures [27, 28]. The microbe based products are safe, ecofriendly as well as means of growth stimulation and disease control. The harnessing of effective plant growth promoting rhizobacteria (PGPR) as biofertilizers and biological control agents is considered as a viable option for reducing the utilization of synthetic agrochemicals in crop production [4, 29–31].

3. PGPR for sustainable crop production

The utilization of PGPR in agriculture is progressing gradually, as it furnishes alternative to synthetic fertilizers, pesticides and other agrochemicals. The rhizosphere inhibiting microbes release significant amount of growth promoting substances that obliquely affect morphology of plants. The PGPRs have paramount importance in agriculture as it helps in welfare of crops by fixing atmospheric nitrogen, phosphate solubilization, decrease in concentration of heavy metals, releasing growth promoting hormones, degradation of crop refuse and soil organic matter, and checking plant pathogens [32, 33]. These PGPRs perform action through directly as well as indirectly as shown in **Figure 1**.

4. Growth promotion of plants by PGPRs through direct actions

PGPRs have the ability to promote growth of plants by assisting in the acquisition of essential nutrients viz., N, P and other micronutrients. Example, PGPRs assist in the transformation of atmospheric nitrogen into plant available forms, through a process called biological nitrogen fixation in presence of nitrogenase enzyme [34, 35]. These organisms either live in symbiotic association or non symbiotic association with the host plants [36]. Microbes like Rhizobium, Bradyrhizobium, Sinorhizobium, and Mesorhizobium live in symbiotic association with the roots of leguminous plants, on the other hand Frankia forms association with the non-leguminous plants [37]. Futher more

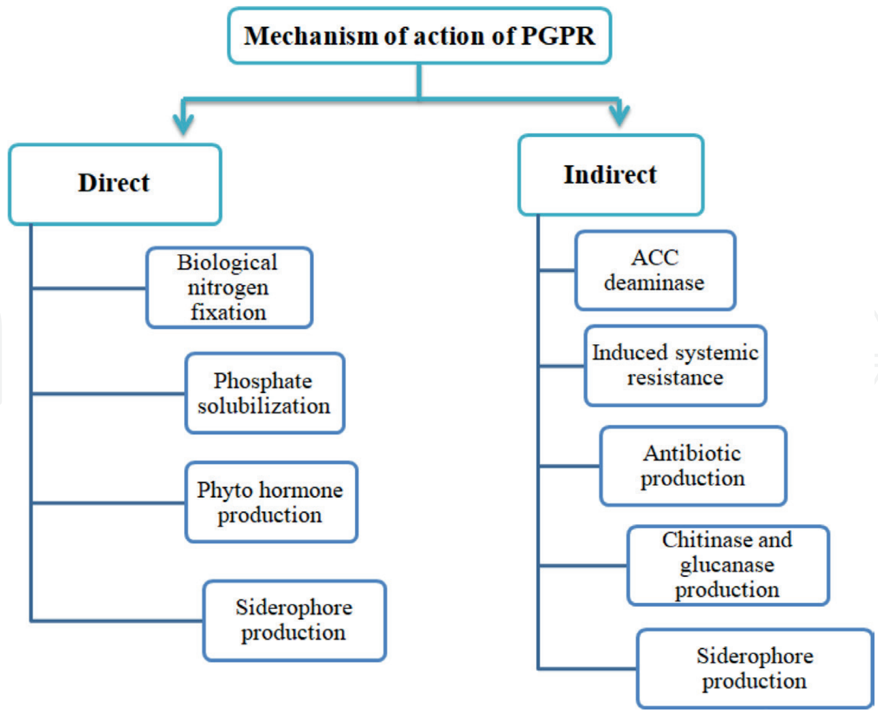

Figure 1.
Flow chart showing mechanism of action of PGPRs.

microbes like cyanobacteria, Azospirillum, Azotobacter, Burkholderia, Enterobacter, Gluconacetobacter, and Pseudomonas are non symbiotic in nature [11, 38, 39]. Hence inoculating these organisms with seeds, or seedlings or soil promotes the growth of plants, improves quality of soil and concentration of nitrogen [40]. Phosphate solubilizing microorganisms inhibiting root zone of plants have the tendency to mineralize, insoluble phosphate from soil into plant available forms (monobasic or dibasic ions) by producing different low molecular weight acids like gluconic acid and citric acid as 90% of phosphorus in soil is in insoluble forms [4, 41]. The phosphate solubilizing microbes are Arthrobacter, Bacillus, Beijerinckia, Burkholderia, Enterobacter, Microbacterium, Pseudomonas, Erwinia, Rhizobium, Mesorhizobium, Flavobacterium, Rhodococcus, and Serratia are phosphate solubilizers [42]. Another element is Iron which is critical for growth of plants, but it is commonly found in insoluble forms and thus not easily available to plants [43]. The PGPR strains viz. Pseudomonas, Bacillus, Rhizobium, Azotobactor, Enterobacter, and Serratia have the tendency to produce low molecular weight compounds called Siderophores which chelate iron under deficient conditions making it available to plants [44]. In addition to making iron available to plants, these Siderophores reduce the stress caused by heavy metals to plants [45–47]. Some Siderophores have the ability to control attack of pathogens to plants like inhibition of plants pathogens Fusarium, Pythium, and Aspergillus species by Siderophores from pseudomonads [48, 49]. It has been reported that potato wild disease by Fusarium oxysporum have been controlled by Siderophore (Pyoverdine) released by pseudomonads [50]. Another important function of PGPRs is the generation of various phytohormones, which regulate the growth, and activate defense [40]. The examples of bacteria producing phytohormones include Rhizobium, Bradyrhizobium, Mesorhizobium, Bacillus, Pantoea, Arthrobacter Pseudomonas, Enterobacter, and Burkholderia [51].

5. Growth promotion of plants by PGPRs through indirect actions

Growth promotion by indirect ways involve evading the attack of pathogens to the plants by generating various enzymes which cause break down of pathogens, anti microbial substances and induce systemic resistance [52]. A number

PGPR/Consortium	Effects
Rosa et al. [81] reported that effect of phosphate solubilizing consortia comprising of A. brasilense and *B. subtilis* under field conditions	Escalation in yield, dry matter, phosphorus accumulation, and 75% reduction in fertilization
Santos et al. [82] reported generation of IAA and enzymes (endoglucanases and xylanases) by *B. pumilus* under pot conditions	Increase in dry matter and number and diameter of tillers
Chandra et al. [83] reported solubilization of phosphorus and generation of siderophores, IAA, ammonia, and HCN under field conditions by *B. subtilis* (BSSC11) and *Bacillus megaterium* (BMSE7)	Enhancement in root and shoot length and total dry matter
Li et al. [84] reported nitrogen fixing capacity, phytohormones synthesis, and biocontrol by *P. koreensis* and *P. entomophila* under growth chamber	Enhancement of plant growth and development
Patel et al. [85] reported antagonism to phytopathogens, IAA production, P solubilization, and biological nitrogen fixation under green house conditions	Amplification in plant height, stem diameter, and number of leaves
Muthukumarasamy et al. [86] reported P solubilization by *Burkholderia gladioli* TNCSF 021 under pot conditions	Escalation in chlorophyll and N content of leaves and total biomass
Liu et al. [87] reported biological control by *Bacillus altitudinis* and *Bacillus velezensis* under green house conditions	Enhancement in dry weight, surface area, and total root length
Xia et al. [88] reported production of siderophores, IAA, amylase, pectinase, cellulase, chitinase, protease, and ACC deaminase and phosphate solubilization by Bacillus xiamenensis PM14 under green house conditions	Escalation in height, length, fresh weight, and root diameter and length
Ahmad et al. [89] reported production of IAA, siderophores and hydrogen cyanide; phosphate solubilization; and antifungal activity by Azotobacter sp. (AZS3), *P. fluorescens* (Ps5), and Bacillus sp. (Bc1) under pot conditions	Enhancement of dry weight of roots and shoots and shoot height
Viswanathan and Samiyappan [90] reported antifungal activity and induced systemic resistance of *P. fluorescens* under field conditions	Enhancement in germination and production
Lopes et al. [91] reported Nitrogenase activity of *A. brasilense* under field conditions	Increase in length, diameter, and Brix value
Hassan et al. [92] reported production of IAA, phosphate solubilization, and antifungal activity by *B. subtilis* NH-160 under green house conditions	Inhibition of red rot infection
Moutia et al. [93] reported capability of Azospirillum spp. against water stress under pot conditions	Increase in root dry matter

Table 1.
PGPR or their consortia for growth promotion of sugar cane under field as well as controlled conditions.

PGPR/Consortium	Effects
Breedt et al. [94] reported biological nitrogen fixation and IAA production by *Lysinibacillus sphaericus* (T19) under field conditions	Escalation in productivity
Cassan et al. [95] reported Phytohormone production by *A. brasilense* Az39, *Bradyrhizobium japonicum* E109 (individual experiments and consortia) in Growth chamber	seed germination promotion and early seedling development (use of isolated or combined species)
Kuan et al. [96] reported biological nitrogen fixation by *B. pumilus* S1r1 under Greenhouse conditions	Increase in corncob productivity (up to 30.9%)
Di Salvo et al. [97] reported IAA production and phosphate solubilization *A. brasilense* and *P. fluorescens* under Field conditions	Grain yield increment
Rocha et al. [98] reported nutrient addition by *P. fluorescens* F113 under greenhouse conditions	Addition of nutrients like N, K, Ca, Mg, and Mn with approximate percentage of 40, 49, 60, 100, and 141%, respectively, in the shoots
Danish et al. [99] reported under green house conditions ACC deaminase production by Enterobactercloacae	Escalation in grain production by 60%, photosynthetic rate by 73%, stomatal conductance by 43%, chlorophyll A by 69%, total chlorophyll by 76% and carotenoids by 42%
Pereira et al. [100] reported Phosphate solubilization potential by *B. subtilis* and *A. brasilense* under field conditions	Higher grain yield
Youseif [101] reported that Chryseobacterium sp. NGB-29 and Flavobacterium sp. O NGB-31 have BNF and production of large amounts of IAA under greenhouse conditions	Increment in all growth parameters
Moreira et al. [102] reported bioavailability of Zn in the soil under greenhouse conditions by *Ralstonia eutropha* 1C2 and *Chryseobacterium humi* ECP37 Zn bioavailability in the soil	Increased biomass and Zn accumulation and availability in plants
Rosas et al. [103] reported generation of phytohormones, antibiotics, and siderophores by *Pseudomonas aurantiaca* SR1 under field conditions	Increased productivity, length, and shoot and root dry weight
Lobo et al. [104] reported Phosphate solubilization and phytohormone production by *B. subtilis* 320 under field	Increase in productivity and P in the shoots
Zhao et al. [105] reported biocontrol properties and phosphate solubilization capacity of *Burkholderia cepacia* under greenhouse	Increase in leaf area, length, and shoot and root dry weight
Viruel et al. [106] reported Phosphate solubilization by *Pseudomonas tolaasii* IEXb under field conditions	Increase in seedling emergence, shoot length, grain yield, 1000-grain weight, total dry biomass, and P content in plants
Alori et al. [107] reported Phosphate solubilization and biocontrol ability of *Pseudomonas kilonensis* F113 and Pseudomonas protegens CHA0 under field conditions	Increase in leaf yield, height, and length
Verma et al. [108] reported Phosphate solubilization by *Enterobacter cloacae* PGLO9 under greenhouse conditions	Longer root length, shoot length, and increased shoot and root biomass

Table 2.
PGPR or their consortia for growth promotion of maize under field as well as controlled conditions.

of compounds generated by PGPR, which are non-volatile in nature like pyrrolnitrin, pyoluteorin, phenazines, phloroglucinols, and cyclic lipopeptides (CPLs) have potential to impede growth of pathogens [53]. It has been reported that damage to various vital crop plants has been controlled by PGPRs of genera Bacillus, Pseudomonas, and Streptomyces [54–56]. Pseudomonas, Burkholderia, Brevibacterium, and Streptomyces, have the ability to impede the growth of disease causing fungi and nematodes by releasing polycyclic nitrogenous substances like Phenazines [57–60]. The fungal and bacterial disease causing agents like Gaeumannomyces graminis, Pythium sp., Polyporus sp., Rhizoctonia solani, Actinomyces viscosus, Bacillus subtilis, and Erwinia amylovora has been known to be impeded by phenazine-1-carboxylic acid released by various species of Fluorescent pseudomonads [61]. Few metabolic substances like pyrrolnitrin with extraordinary action against fungal pathogens like Rhizoctonia solani, Fusarium graminearum, and Phytophthora capsici have been reported to be released by both fluorescent and non-fluorescent strains of Pseudomonas [62–64]. In addition to this Pseudomonas and Bacillus sp. boost the safeguard mechanism of host plants, promote root development and antimicrobial capacity by the release of numerous cyclic lipopeptides [65, 66]. Bacterial namely Pseudomonas, Bacillus, Burkholderia, Agrobacterium, Paenibacillus polymyxa, and Xanthomonas also produce numerous volatile substances swapping from aliphatic (dimethyl disulfide), aromatic (indole), ketones, alkanes, or alkenes (1-undecene), and terpenes (e.g., geosmin) [67–69], which activate signaling pathways of auxin, gibberellins, cytokinins, salicylic acid, and brassinosteroids [70–73]. Thus PGPRs have the ability to improve growth and development, fruit and seed development, germination of seeds as well as act as virulence-modulating factors, thereby reducing biotic and abiotic pressures [71, 74, 75]. Few PGPR strains viz., Pseudomonas, Bacillus, Serratia, Azospirillum, and Trichoderma have the potential to boost the defense system of plants without changing the genetic makeup called induced systemic resistance to fight against disease causing agents, in addition to this ethylene and jasmonic acid also activate signaling pathway to induce systemic resistance in plants [76, 77]. Abiotic pressures also affect growth and development of plants, the PGPR enhance resistance against abiotic pressures either directly or indirectly. It has been reported that Pseudomonas, Bacillus, Pantoea, Burkholderia, and Rhizobium increase resistance against abiotic pressures like drought, salinity, heat stress, and chilling injury [78–80]. A number of reports have revealed growth and development promotion of Sugar cane and maize by application of PGPR and their consortia as given in **Tables 1** and **2** respectively.

6. Conclusion

The PGPR research is of considerable interest worldwide, owing to increasing demand of organic food with increase in human population under changing climatic conditions. Adoption of PGPR is sustainable substitute to chemical fertilizers and pesticides. Among all possible biological means of sustainable agriculture, PGPR based formulations have triggered massive attention as they provide number of useful favors to plants. These ameliorate soil fertility, crop productivity, resistance to pathogens. A diverse group of microorganisms like Pseudomonas, Azospirillum, Azotobacter, Klebsiella, Enterobacter, Alcaligenes, Arthrobacter, Burkholderia, Bacillus, and Serratia escalate growth and development of plants. Different Pseudomonas sp. cause prominent increment in germination, seedling growth and yield in different agricultural crops, including wheat. Development of beneficial PGPR formulation requires microbes possessing properties high ability to compete in the root zone, tremendous competitive saprophytic potential, capability to promote growth and development, easily produced at large scale, vide range of activities, should not pose any threat to environment and compatibility with other partnering organisms.

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