Plant Growth Promoting Rhizobacteria: A Critical Review

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Abstract

Plant growth-promoting rhizobacteria (PGPR) are naturally occurring soil bacteria that aggressively colonize plant roots and benefit plants by providing growth promotion. Inoculation of crop plants with certain strains of PGPR at an early stage of development improves biomass production through direct effects on root and shoots growth. Inoculation of ornamentals, forest trees, vegetables, and agricultural crops with PGPR may result in multiple effects on early-season plant growth, as seen in the enhancement of seedling germination, stand health, plant vigor, plant height, shoot weight, nutrient content of shoot tissues, early bloom, chlorophyll content, and increased nodulation in legumes. PGPR are reported to influence the growth, yield, and nutrient uptake by an array of mechanisms. They help in increasing nitrogen fixation in legumes, help in promoting free-living nitrogen-fixing bacteria, increase supply of other nutrients, such as phosphorus, sulphur, iron and copper, produce plant hormones, enhance other beneficial bacteria or fungi, control fungal and bacterial diseases and help in controlling insect pests. There has been much research interest in PGPR and there is now an increasing number of PGPR being commercialized for various crops. Several reviews have discussed specific aspects of growth promotion by PGPR. In this review, we have discussed various bacteria which act as PGPR, mechanisms and the desirable properties exhibited by them.

Keywords: PGPR; Siderophore; Phosphate solubilisation; Antifungal; Biocontrol; Systemic resistance; Plant growth promotors.

1. Introduction

Plant growth in agricultural soils is influenced by many abiotic and biotic factors. There is a thin layer of soil immediately surrounding plant roots that is an extremely important and active area for root activity and metabolism which is known as rhizosphere. The rhizosphere concept was first introduced by Hiltner to describe the narrow zone of soil surrounding the roots where microbe populations are stimulated by root activities [1]. The original concept has now been extended to include the soil surrounding a root in which physical, chemical and biological properties have been changed by root growth and activity [2]. A large number of microorganisms such as bacteria, fungi, protozoa and algae coexist in the rhizosphere. Bacteria are the most abundant among them. Plants select those bacteria contributing most to their fitness by releasing organic compounds through exudates [3] creating a very selective environment where diversity is low [4, 5]. Since bacteria are the most abundant microorganisms in the rhizosphere, it is highly probable that they influence the plants physiology to a greater extent, especially considering their competitiveness in root colonization [6, 7].

Microorganisms that colonize the rhizosphere can be classified according to their effects on plants and the way they interact with roots, some being pathogens whereas other trigger beneficial effects. Rhizobacteria inhabit plant roots and exert a positive effect ranging from direct influence mechanisms to an indirect effect. So, the bacteria inhabiting the rhizosphere and beneficial to plants are termed PGPR [8]. In the last few years, the number of PGPR that have been identified has seen a great increase, mainly because the role of the rhizosphere as an ecosystem has gained importance in the functioning of the biosphere. Various species of bacteria like *Pseudomonas, Azospirillum, Azotobacter, Klebsiella, Enterobacter, Alcaligenes, Arthrobacter, Burkholderia, Bacillus* and *Serratia* have been reported to enhance the plant growth [9-12]. There are several PGPR inoculants currently commercialized that seem to promote growth through at least one mechanism; suppression of plant disease (termed Bioprotectants), improved nutrient acquisition (Biofertilizers), or phytohormone production (Biostimulants). Inoculant development has been most successful to deliver biological control agents of plant disease i.e. organisms capable of killing other organisms pathogenic or disease causing to crops. Various bacteria which are predominantly studied and increasingly marketed as the biological control agents includes the genera *Bacillus*, *Streptomyces*, *Pseudomonas*, *Burkholderia* and *Agrobacterium*. They suppress plant disease through at least one mechanism; induction of systemic resistance, and production of siderophores or antibiotics. Exposure to the PGPR triggers a defence response by the crop as if attacked by pathogenic organisms. Siderophores produced by some PGPR scavenge heavy metal micronutrients in the rhizosphere (e.g. iron) starving pathogenic organisms of proper nutrition to mount an attack of the crop. Antibiotic producing PGPR releases compounds that prevent the growth of the pathogens. Bioprotectants are currently being studied by the laboratories of Fernando and Daayf in the Department of Plant Science, University of Manitoba. Biofertilizers-nitrogen fixing bacteria are also available for increasing crop nutrient uptake of nitrogen from nitrogen fixing bacteria associated with roots (*Azospirillum*). Nitrogen fixing biofertilizers provide only a modest increase in crop nitrogen uptake (at best an increase of 20 Kg N acre^{-1}). The elemental sulphur present in

the soil must be transformed or oxidised into sulphate by the bacteria before it is available for plants. The inoculation of sulphur-oxidizing bacteria (*Thiobacillus*) onto the seeds of high S-demanding crops has proved to be quite successful in making sulphur more available for the plants. The rock phosphate is an approved source of phosphorus but its availability to plants is limited under most growing conditions. Phosphorus oxidizing bacteria help in making this phosphorus available to the plants. The phytohormones they produce include indole-acetic acid, cytokinins, gibberellins and inhibitors of ethylene production. Rhizoremediers PGPR also help in degrading organic pollutants. *Azospirillum* sp. shows osmoadaptation and can survive under salinity/osmolarity due to the accumulation of compatible solutes. The bacteria like *P. fluorescens* can survive under dry conditions and hyperosmolarity.

The use of PGPR offers an attractive way to replace chemical fertilizer, pesticides, and supplements; most of the isolates result in a significant increase in plant height, root length, and dry matter production of shoot and root of plants. PGPR help in the disease control in plants. Some PGPR especially if they are inoculated on the seed before planting, are able to establish themselves on the crop roots. PGPR as a component in integrated management systems in which reduced rates of agrochemicals and cultural control practices are used as biocontrol agents. Such an integrated system could be used for transplanted vegetables to produce more vigorous transplants that would be tolerant to nematodes and other diseases for at least a few weeks after transplanting to the field [13]. Selected strains of beneficial PGPR trigger a plant mediated induced systemic resistance (ISR) response that is effective against a broad spectrum of plant pathogens. ISR is a plant-mediated mechanism it resembles classic pathogen-induced resistance, in which non-infected parts of previously pathogen-infected plants become more resistant to further infection [14]. In forestry, the potential of inoculating tree roots with PGPR has been recognised. There has been a new focus on investigating the application of PGPR and fungi to commercial forestry operation especially in the areas of enhancing tree growth and survival of tree seedlings though microbially mediated phytohormone production [15].

2. Plant growth promoting rhizobacteria (PGPR)

The recognition of plant growth-promoting rhizobacteria (PGPR), a group of beneficial plant bacteria, as potentially useful for stimulating plant growth and increasing crop yields has evolved over the past several years to where today researchers are able to repeatedly use them successfully in field experiments. Increased growth and yields of potato, sugar beet, radish and sweet potato [16] have been reported. Commercial applications of PGPR are being tested and are frequently successful; however, a better understanding of the microbial interactions that result in plant growth increases will greatly increase the success rate of field applications [17]. PGPR, root-colonizing bacteria are known to influence plant growth by various direct or indirect mechanisms. Several chemical changes in soil are associated with PGPR. Plant growth-promoting bacteria (PGPB) are reported to influence the growth, yield, and nutrient uptake by an array of mechanisms. Some bacterial strains directly regulate plant physiology by mimicking synthesis of plant hormones, whereas others increase mineral and nitrogen availability in the soil as a way to augment growth. The isolates could exhibit more than two or three PGP traits, which may promote plant growth directly or indirectly or synergistically [12, 18]. The plant growth stimulating efficiency of bacterial inoculants is affected by soil nutritional condition. The bacterial inoculation has a much better stimulatory effect on plant growth in nutrient deficient soil than in nutrient rich soil [19]. The simultaneous screening of rhizobacteria for growth promotion under gnotobiotic conditions and *in vitro* production of auxins is a useful approach for selecting effective PGPR [20]. Some PGPR releases a blend of volatile components like 2, 3-butanediol and acetoin that promote growth of *Arabidopsis thaliana* [21]. The diazotroph bacterial inoculation significantly increases the seed cotton yield, plant height and microbial population in soil [22]. Double and triple combination of IBA, bacteria and carbohydrates are more effective in increasing rooting capacity and more quality rooting in case of apple [23]. The bacteria isolated from composts which included farm waste compost (FWC), rice straw compost (RSC), *Gliricidia* vermin compost (GVC), and macrofauna associated with FWC when applied with composts show the synergistic effect on the growth of pearl millet [24]. The use of PGPR with P-enriched compost in an integrated manner improves the growth, yield and nodulation in chickpea [25].

3. Applications of PGPR

3.1 Biological nitrogen fixation

A number of bacterial species belonging to genera *Azospirillum*, *Alcaligenes*, *Arthrobacter*, *Acinetobacter*, *Bacillus*, *Burkholderia*, *Enterobacter*, *Erwinia*, *Flavobacterium*, *Pseudomonas*, *Rhizobium* and *Serratia* are associated with the plant rhizosphere and are able to exert a beneficial effect on plant growth [26, 27]. The important role is played by plants in selecting and enriching the types of bacteria by the constituents of their root exudates. Thus, the bacterial community in the rhizosphere develops depending on the nature and concentrations of organic constituents of exudates, and the corresponding ability of the bacteria to utilize these as sources of energy [28]. There is a continuum of bacterial presence in soil rhizosphere, rhizoplane and internal of the plant tissues [29]. Rhizospheric bacterial communities however have efficient systems for uptake and catabolism of

organic compounds present in root exudates [30]. Several bacteria help to derive maximum benefit from root exudates by their ability to attach to the root surfaces (rhizoplane). Since associative interactions of plants and microorganisms must have come into existence as a result of co evolution, the use of latter group as bio inoculants must be pre-adapted, so that it fits into a long-term sustainable agricultural system. PGPR are commonly used as inoculants for improving the growth and yield of agricultural crops and offers an attractive way to replace chemical fertilizers, pesticides, and supplements [31]. The use of bio-fertilizer and bioenhancer such as N_2 (nitrogen) fixing bacteria and beneficial micro-organism can reduce chemical fertilizer applications and consequently lower production cost. Utilization of PGPR in order to increase the productivity may be a viable alternative to organic fertilizers which also helps in reducing the pollution and preserving the environment in the spirit of an ecological agriculture [32]. Thus rhizospheric bacteria can be a promising source for plant growth promoting agent in agriculture [33] and are commonly used as inoculants for improving the growth and yield of agricultural crops. PGPR or combinations of PGPR and AMF can improve the nutrient use efficiency of fertilizers and allow reduced application rates of chemical fertilizers [34]. The use of PGPR isolates as inoculants biofertilizers is beneficial for rice cultivation as they enhance growth of rice and by inducing other plant growth promoting traits [31]. Applying the combined inoculation of PGPR as biofertilizer affects beneficially the yield and growth of chickpea in field conditions [35]. Biological nitrogen fixation contributes 180 X 10^6 metric tons/year globally, out of which symbiotic associations' produces 80% and the rest comes from free-living or associative systems [36]. The ability to reduce and derive such appreciable amounts of nitrogen from the atmospheric reservoir and enrich the soil is confined to bacteria and Archaea [37]. These include symbiotic nitrogen fixing (N_2-fixing) forms, viz. *Rhizobium,* the obligate symbionts in leguminous plants and *Frankia* in non-leguminous trees, and non-symbiotic (free-living, associative or endophytic) N_2-fixing forms such as cyanobacteria, *Azospirillum*, *Azotobacter*, *Acetobacter diazotrophicus*, *Azoarcus* etc.

3.1.1 Symbiotic nitrogen fixers

Two groups of nitrogen fixing bacteria have been studied extensively, which includes *Rhizobia* and *Frankia*. *Frankia* forms root nodules on more than 280 species of woody plants from 8 different families [38] however, its symbiotic relationship is not as well understood. *Frankia* is known to form effective symbiosis with the species of *Alnus* and *Casuarina* [39-42]. A number of individual species may improve plant nutrition by releasing plant growth regulators, siderophores and hydrogen cyanide or may increase phosphate availability [43]. An increase in rhizosphere populations has been reported after crop rotation with non-legumes [44] with abundance benefiting subsequent crops [45]. A considerable change in taxonomic status has come about during the last years. Sahgal and Johri [46] outlined the status of rhizobial taxonomy and enlisted 36 species distributed among seven genera (*Allorhizobium*, *Azorhizobium*, *Bradyrhizobium*, *Mesorhizobium*, *Methylobacterium*, *Rhizobium* and *Sinorhizobium*) derived, based on the polyphasic taxonomic approach. Under different agro-climatic conditions, legumes of economic importance are grown in India and presence of native rhizobia has therefore been anticipated.

3.1.1.1 *Rhizobium*

When rhizobia colonize the roots from non-legume plant in a non specific relationship the strains from this genus may behave as PGPR. Under the All India Coordinated Pulse Improvement Programme, an extensive survey of nodulation status of legumes, viz. chickpea, pigeonpea, moongbean, soybean and groundnut with native rhizobia during 1967–72 [47, 48] and in 1977–80 [49] has belied this assumption since except for groundnut, at more than 50% of the places surveyed most legumes nodulated poorly. Another survey determined the serological types of the native rhizobial population, frequency of effective types and the fate of the introduced antigenic type in competition with the native types in chickpea [47, 50, 51] moongbean [52], groundnut [53, 54] and clover [55] and revealed that only 20–30% of indigenous rhizobia are effective. Field trials conducted in India showed that depending on the legume, soil and agroclimatic conditions nearly 50% of nitrogenous fertilizer could be saved through rhizobial inoculations with considerable increase in yield [56, 57]. Inoculation of *Rhizobium* sp. causes a greater increase in growth and yield and the number of nodules per root system is significantly higher in plants inoculated with *Rhizobium* sp. compared to plants without *Rhizobium* sp. under field condition [58]. In addition to their beneficial N_2-fixing activity with legumes, rhizobia can improve plant P nutrition by mobilizing inorganic and organic P. Many rhizobia isolates from different cross-inoculation groups of rhizobia, isolated from soils in Iran are able to mobilize P from organic and inorganic sources [59]. Conjunctive use of *Rhizobium* with Phosphate Solubilising Bacteria (PSB) revealed synergistic effect on symbiotic parameters and grain yield of mungbean. Phosphate solubilizing bacteria improves the competitive ability and symbiotic effectiveness of inoculated *Rhizobium* sp. in lentil under field conditions [60]. Data recorded from tillage versus no-tillage experiment revealed more nodulation and leghaemoglobin content in no-tillage treatment [61]. The single and dual inoculation *Rhizobium* and phosphorus (P) solubilising bacteria with fertilizer (P_2O_5) significantly increases root and shoot weight, plant height, spike length, grain yield, seed P content, leaf protein and leaf sugar content of the wheat crop in a P deficient natural non-sterilized sandy loam soil and is 30-40% better than only P fertilizer for improving grain yield [62]. The P-solubilising strains and the N_2-fixing bacterial strains have great potential in being formulated and used as biofertilizers [63].

3.1.1.2 *Bradyrhizobium*

Bradyrhizobium species are Gram-negative bacilli (rod shaped) with a single subpolar or polar flagellum. They are a common soil dwelling microorganism that can form symbiotic relationships with leguminous plant species where they fix nitrogen in exchange for carbohydrates from the plant. Like other rhizobia, they have the ability to fix atmospheric nitrogen into forms readily available for other organisms to use. They are slow growing in contrast to *Rhizobium* species, which are considered fast growing rhizobia. In a liquid media broth, it takes *Bradyrhizobium* species 3-5 days to create a moderate turbidity and 6-8 hours to double in population size. They tend to grow best with pentoses as a carbon source [64]. Some studies indicate that co-inoculation of *Bradyrhizobium* and certain PGPRs can positively affect symbiotic nitrogen fixation by enhancing both root nodule number or mass, dry weight of nodules, yield components, grain yield, soil nutrient availability and increasing the nitrogenase activity [65-67] and increases the nodulation and nitrogen fixation in *Glycine max*. at a low root zone temperature [68, 69]. The competition between PGPR and *B. japonicum* for the niches in the rhizoplane, production of auxins, and induction of systemic resistance (ISR) by the production of siderophores or by lipopolysaccharides present in the outer membrane (LPS) are the probable reasons for the enhancement of the biological nitrogen fixation, nodulation and growth of *Lupinus al.bus* l. cv *Multolupa* by plant growth promoting rhizobacteria [70].

3.1.2 Non-symbiotic nitrogen fixers

Non-symbiotic nitrogen fixation has a great agronomic significance. One main limitation that it faces is the availability of carbon and energy source for the energy intensive nitrogen fixation process. However, this limitation can be compensated by moving closer to or inside the plants, viz. in diazotrophs present in rhizosphere, rhizoplane or those growing endophytically. Some important non-symbiotic nitrogen-fixing bacteria include *Azoarcus* sp., *Gluconacetobacter diazotrophicus*, *Herbaspirillium* sp., *Azotobacter* sp. [71, 72], *Achromobacter*, *Acetobacter*, *Al.cal.igenes*, *Arthrobacter*, *Azospirillum*, *Azomonas*, *Bacillus*, *Beijerinckia*, *Clostridium*, *Corynebacterium*, *Derxia*, *Enterobacter*, *Klebsiella*, *Pseudomonas*, *Rhodospirillum, RhodoPseudomonas* and *Xanthobacter* [73].

3.1.2.1 *Azotobacter*

The family Azotobacteriaceae comprises of two genera [74] namely, *Azomonas* (non-cyst forming) with three species (*A. agilis, A. insignis* and *A. macrocytogenes*) and *Azotobacter* (cyst forming) comprising of 6 species [75], namely, *A. chroococcum, A. vinelandii, A. beijerinckii, A. nigricans, A. armeniacus* and *A. Paspali. Azotobacter* is generally regarded as a free-living aerobic nitrogen-fixer. *Azotobacter paspali,* which was first described, by Dobereiner and Pedrosa [76] has been isolated from the rhizosphere of *Paspalum notatum*, a tetraploid subtropical grass, and is highly host specific. Various crops in India have been inoculated with diazotrophs particularly *Azotobacter* and *Azospirillum* [77, 78]. Reports prove that application of *Azotobacter* and *Azospirillum* improves the yield of both annual and perennial grasses [79]. Saikia and Bezbaruah [80] reported increased seed germination of *Cicer arietinum, Phaseolus mungo, Vigna catjung* and *Zea mays*. *Azotobacter* strains could affect seed germination and seedling growth [81] in a plant. It has been shown that wheat yield increased up to 30% with *Azotobacter* inoculation [82, 83].

3.1.2.2 *Azospirillum*

Since 1970's, *Azospirillum* strains have been isolated and used [84]. This group of free-living rhizobacteria encompasses ten species, each one classified according to its particular biochemical and molecular characteristics: *A. lipoferum* and *A. brasilense* [85]; *A. amazonense* [86]; *A. halopraeferens* [87]; *A. irakense* [88]; *A. largimobile* [89]; *A. doebereinerae* [90]; *A. Oryzae* [91]; *A. melinis* [92] and recently *A. canadensis* [93]. Although *Azospirillum* was first isolated from cereals and most of its initial inoculation has been done on the main cereal crops and, there are more non-cereal species successfully inoculated with *Azospirillum* than cereals. *Azospirillum* strains have no preferences for crop plants or weeds or for annual or perennial plants and can be successfully applied to plants that have no previous history of *Azospirillum* in their roots. It appears that *Azospirillum* is not a plant specific bacterium and is a general root colonizer [for details on plant species see 94, 95]. Members of the genus *Azospirillum* fix nitrogen under microaerophilic conditions and are frequently associated with root and rhizosphere of a large number of agriculturally important crops and cereals. Sen [96] made one of the earliest suggestions that the activity of associated nitrogen fixing bacteria such as *Azospirillum* could meet the nitrogen nutrition of cereal crops. After establishing in the rhizosphere, *Azospirilla* usually, but not always, promote the growth of plants [97, 98, 94]. Although they posses N_2-fixing capability (~1–10 kg N/ha), the increase in yield is mainly attributed to improved root development due to the production of growth promoting substances and consequently increased rates of water and mineral uptake [99-101]. Isolation and characterization of bacterial diversity from endorhizosphere of sugarcane (*Saccharum* sp.) and rye grass (*Lolium perenne*) sugested that *Azospirillum* isolates from sugarcane and rye grass exhibited maximum nitrogenase activity among *Azospirillum, Bacillus, E. coli* and *Pseudomonas* [102].

3.1.2.3 *Acetobacter*

Acetobacter has gained importance as an inoculant for sugarcane [103, 104]. This bacterium successfully colonizes sugarcane varieties in India where the chemical N fertilization is completely avoided for at least two successive years and replaced by organic manures [105]. The family Acetobacteriaceae includes genera, *Acetobacter, Gluconobacter*, *Gluconoacetobacter* and *Acidomonas*. Based on 16S rRNA sequence analysis, the name *Acetobacter diazotrophicus* has been changed to *Gluconoacetobacter diazotrophicus* [106]. *G. diazotrophicus* isolated from various sources does not exhibit much variation in the genetic diversity [107, 108]. However, Suman *et al.* [109] found that the diversity of the isolates of *G. diazotrophicus* by RAPD analysis was more conspicuous than that reported on the basis of morphological and biochemical characters. Certain genetically related groups of *G. diazotrophicus* or its ancestors have acquired the capability of colonizing plants by themselves or with the aid of the vectors such as insects or fungi [110]. *G. diazotrophicus* has been found to harbour plasmids of 2–170 kb [111].

3.1.2.4 *Azoarcus*

Azoarcus, which is an aerobic/microaerophilic nitrogen-fixing bacterium, was isolated from surface-sterilized tissues of kaller grass (*Leptochloa fusca* L Kunth) [112] and can infect roots of rice plants as welL Kallar grass used as a pioneer plant in Pakistan on salt-affected low fertility soils as it is a salt-tolerant grass. The genus *Azoarcus* has been identified, with two species, *A. indigens* and *A. communis*, and three additional unnamed groups, which were distinct at species level. Nitrogen fixation by *Azoarcus* is extremely efficient.

3.1.3 *Bacillus*

Bacillus is the most abundant genus in the rhizosphere, and the PGPR activity of some of these strains has been known for many years, resulting in a broad knowledge of the mechanisms involved [113, 114]. There are a number of metabolites that are released by these strains [115], which strongly affect the environment by increasing nutrient availability of the plants [45]. Naturally present in the immediate vicinity of plant roots, *B. subtilis* is able to maintain stable contact with higher plants and promote their growth. In a micropropagated plant system, bacterial inoculation at the beginning of the acclimatisation phase can be observed from the perspective of the establishment of the soil microbiota rhizosphere. *Bacillus licheniformis* when inoculated on tomato and pepper shows considerable colonisation and can be used as a biofertiliser without altering normal management in greenhouses [116]. Jaizme-Vega *et al.* [117] evaluated the effect of a rhizobacteria consortium of *Bacillus* spp. on the first developmental stages of two micropropagated bananas and concluded that this bacterial consortium can be described as a prospective way to increase plant health and survival rates in commercial nurseries. *Bacillus* is also found to have potential to increase the yield, growth and nutrition of raspberry plant under organic growing conditions [118]. *Bacillus megatorium* is very consistent in improving different root parameters (rooting performance, root length and dry matter content of root) in mint [119]. The PSB *Bacillus megaterium* var. *phosphaticum* and Potassium Solubilising Bacteria (KSB) *Bacillus mucilaginosus* when inoculated in nutrient limited soil showed that rock materials (P and K rocks) and both bacterial strains consistently increased mineral availability, uptake and plant growth of pepper and cucumber, suggesting its potential use as fertilizer [120, 121]. The *Bacillus pumilus* 8N-4 can be used as a bio-inoculant for biofertilizer production to increase the crop yield of wheat variety *Orkhon* in Mongolia [122].

3.1.4 *Pseudomonas*

Pseudomonas sp. is ubiquitous bacteria in agricultural soils and and has many traits that make them well suited as PGPR. The most effective strains of *Pseudomonas* have been *Fluorescent Pseudomonas* spp. Considerable research is underway globally to exploit the potential of one group of bacteria that belong to *Fluorescent pseudomonads* (FLPs). FLPs help in the maintenance of soil health and are metabolically and functionally most diverse [123, 124]. The presence of *Pseudomonas fluorescence* inoculant in the combination of microbial fertilizer plays an effective role in stimulating yield and growth traits of chickpea [35]. Isolates of FLPs from roots, shoots, and rhizosphere soil of sugarcane provides significant increases in fresh and dry masses [125]. Field trials of a pseudomonad strain (GRP3) lead to a great increase in yield of legumes [126]. Specific strains of the *Pseudomonas fluorescens-putida* group have recently been used as seed inoculants on crop plants to promote growth and increase yields. These pseudomonads, termed PGPR, rapidly colonize plant roots of potato, sugar beet and radish, and cause statistically significant yield increases up to 144% in field tests [127-132]. The occurrence and activity of soil microorganisms are affected by a variety of environmental factors (e.g. soil type, nutrient abundance, pH, moisture content) as well as plant-related factors (species, age). So, while working on two winter wheat cultivars it was found that the genus *Pseudomonas* show higher counts, thus the population size of bacteria of the genus *Pseudomonas* depends on the development phase of wheat plants [133].

3.2 PGPR in HCN production

One group of microorganisms which acts as biocontrol agents of weeds include the Deleterious Rhizobacteria (DRB) that can colonize plant root surfaces and able to suppress plant growth [134]. Many DRB are plant specific [135]. Cyanide is a dreaded chemical produced by them as it has toxic properties. Although cyanide acts as a general metabolic inhibitor, it is synthesized, excreted and metabolized by hundreds of organisms, including bacteria, algae, fungi, plants, and insects, as a mean to avoid predation or competition. The host plants are generally not negatively affected by inoculation with cyanide-producing bacterial strains and host-specific rhizobacteria can act as biological weed-control agents [136]. A secondary metabolite produced commonly by rhizosphere pseudomonads is Hydrogen Cyanide (HCN), a gas known to negatively affect root metabolism and root growth [137] and is a potential and environmentally compatible mechanism for biological control of weeds [138]. The HCN production is found to be a common trait of *Pseudomonas* (88.89%) and *Bacillus* (50%) in the rhizospheric soil and plant root nodules [139, 115] and is a serious environmental pollutant and a biocontrol metabolite in *Pseudomonas* species. It was previously not known if glycine was a carbon precursor for HCN in *Pseudomonas aeruginosa*. Castric [140] presented evidence that glycine is an HCN precursor for *P. aeruginosa*, but that this process differs significantly from cyanogenesis in other bacteria because: (i) other amino acids besides glycine stimulate HCN production; and (ii) both carbons of glycine are used as sources of cyanide carbon. The level of HCN produced in root-free soil by *P. putida* and *A. delafieldii* generally increased with higher amounts of supplemental glycine, with *P. putida* typically generating more HCN (8–38 μM) at a given glycine level [141]. The sorghum seedlings [*Sorghum bicolor* (L) Moench] of different genotypes differ in associations with soil microorganisms and differentially affect the number of FLPs in cropping systems [142]. Some of the recent studies have indicated that and some of the *Pseudomonas* spp. metabolites such as HCN may enhance plant establishment. Wani *et al.* [143] tested the rhizosphere isolates for HCN producing ability *in vitro* to find that most of the isolates produced HCN and helped in the plant growth. The isolates from the rhizospheric soil of chickpea also exhibits more than two or three PGPR traits including HCN production, which promotes plant growth directly or indirectly or synergistically [12]. The rhizosphere competent *Mesorhizobiumloti* MP6 produces hydrocyanic acid (HCN) under normal growth conditions and enhances the growth of Indian mustard (*Brassica campestris)* [144]. Bacterial isolates belonging to genera *Bacillus* and *Pseudomonas* isolated from rhizospheric soils of mustard produces HCN and application of herbicides (quizalafop-p-ethyl & clodinafop) do not have any significant change in HCN production by these isolates [145]. The entomopathogenic bacterium *Pseudomonas entomophila* produces HCN which is a secondary metabolite and is implicated in biocontrol properties and pathogenicity exerted by other bacteria [146]. The *Pseudomonas fragi* CS11RH1 (MTCC 8984), a psychrotolerant bacterium produces hydrogen cyanide (HCN) and the seed bacterization with the isolate significantly increases the percent germination, rate of germination, plant biomass and nutrient uptake of wheat seedlings [147].

3.3 Plant growth producers

Plant hormones are chemical messengers that affect a plant's ability to respond to its environment. Hormones are organic compounds that are effective at very low concentration; they are usually synthesized in one part of the plant and are transported to another location. They interact with specific target tissues to cause physiological responses, such as growth or fruit ripening. Each response is often the result of two or more hormones acting together. Because hormones stimulate or inhibit plant growth, many botanists also refer to them as plant growth regulators. Botanists recognize five major groups of hormones: auxins, gibberellins, ethylene, cytokinins, and abscisic acid.

IAA (indole-3-acetic acid) is the member of the group of phytohormones and is generally considered the most important native Auxin [31]. It functions as an important signal molecule in the regulation of plant development including organogenesis, tropic responses, cellular responses such as cell expansion, division, and differentiation, and gene regulation [148]. Diverse bacterial species possess the ability to produce the auxin phytohormone IAA. Different biosynthesis pathways have been identified and redundancy for IAA biosynthesis is widespread among plant-associated bacteria. Interactions between IAA-producing bacteria and plants lead to diverse outcomes on the plant side, varying from pathogenesis to phytostimulation. Reviewing the role of bacterial IAA in different microorganism–plant interactions highlights the fact that bacteria use this phytohormone to interact with plants as part of their colonization strategy, including phytostimulation and circumvention of basal plant defense mechanisms. Moreover, several recent reports indicate that IAA can also be a signaling molecule in bacteria and therefore, can have a direct effect on bacterial physiology [149]. There are numerous soil microflora involved in the synthesis of auxins in pure culture and soil [150]. The potential for auxin biosynthesis by rhizobacteria can be used as a tool for the screening of effective PGPR strains [151]. Accumulating evidence indicates that PGPR influence plant growth and development by the production of phytohormones such as auxins, gibberellins, and cytokinins. The effects of auxins on plant seedlings are concentration dependent, i.e. low concentration may stimulate growth while high concentrations may be inhibitory [152]. Different plant seedlings respond differently to variable auxin concentrations [153] and type of microorganisms [154]. The strains which produce the highest amount of auxins i.e. indole acetic acid (IAA) and indole acetamide (IAM) in non-sterilized soil, causes maximum increase in growth and yield of the wheat crop [151]. Even the strains, which produce low amounts of IAA, release it continuously, thus improving plant growth [155]. The isolates producing a large amount of IAA support the plant like *L al.bescens* H. et Arn. in adverse ecological conditions [156]. The survival of bacteria in the rhizosphere as well as the root and shoot weight

of wheat plants are positively affected by the addition of IAA [157]. Originally isolated from the roots of the epiphytic orchid *Dendrobium moschatum*, the strains of *Rhizobium*, *Microbacterium*, *Sphingomonas*, and *Mycobacterium* genera are among the most active IAA producers [155]. Biostimulant species of *Pseudomonas* and *Bacillus* can produce yet not well characterized phytohormones or growth regulators that cause crops to have greater amounts of fine roots which have the effect of increasing the absorptive surface of plant roots for uptake of water and nutrients. Rhizobia are the first group of bacteria, which are attributed to the ability of PGPR to release IAA that can help to promote the growth and pathogenesis in plants [158]. The IAA production is studied in *Rhizobium* strains associated only with a few legume hosts [159-161]. Nevertheless, Sridevi and Mallaiah [162] showed that all the strains of *Rhizobium* isolated from root nodules of *Sesbania sesban* (L) Merr. produces IAA. The *Rhizobium* sp. isolated from the root nodules of common pulse plant *Vigna mungo* (L) Hepper is found to provide high levels of IAA to young and healthy root nodules [158]. All the *Rhizobium* spp. isolated from *Crotalaria* sp. are found positive for IAA production, but the isolates differ significantly in auxin production depending upon the cultural conditions. The experiment indicates that Rhizobia can be used as bioenhancer and biofertilizer for wheat production as it can uptake more nutrients (N, P and K) by producing IAA and subsequently increases the plant root system [163]. Among all the isolates maximum amount of IAA is produced by isolate from *C. retusa* [164]. Independent of the origin (rhizosphere vs. phyllosphere), bacterial strains produced IAA, which accounts for the overall synergistic effect on growth of peas and wheat. The highest concentration of IAA is produced by bacterial strain *P. fluorescens* and *Kocuria varians* [165, 154]. While working on chickpea it is found that all the isolates of *Bacillus, Pseudomonas* and *Azotobacter* produced IAA, whereas only 85.7% of *Rhizobium* was able to produce IAA [12]. *Pseudomonas fluorescens* B16 is a plant growth-promoting rhizobacterium and produces Pyrroloquinoline Quinone which is a plant growth promotion factor [166]. However, the ability of *Azotobacter* to produce plant growth promoting substances such as phytohormone and IAA is attributed more to yield improvement rather than to diazotrophic activity. *Pseudomonas* bacteria, especially *P. fluorescens* and *P. putida* are the most important kinds of PGPR which produce auxin and promote the yield. Khakipour *et al.* [167] evaluated the auxin productivity potential in studied *Pseudomonas* strains through chromatography, using HPLC devise; comparing the methods used and appointing IAA synthesize method by the studied strains in the applied cultivars. In fact, a variety of auxins like indole-3-acetic acid (IAA), indole-3-pyruvic acid, indole-3-butyric acid and indole lactic acid [168, 169]; cytokinins [170, 171] and gibberellins [172] are detected, with auxin production being quantitatively most important [173]. *Azospirillum brasilense* strain SM has the potential to be a competent rhizospheric bacterium as it triggers the IAA accumulation under nutrient stresses, likely environmental fluctuations and long-term batch cultures and beneficially influences the growth of sorghum. Further, it also has the ability to promote the growth of a number of other plants like Mung bean, Maize, and Wheat [174]. Some of the P-solubilizing bacteria and fungi act as plant growth promoters due to their ability to produce IAA but there is a different IAA production potential among PSB and PSF isolates [175]. *Bacillus megaterium* from tea rhizosphere is able to produce IAA and thus it helps in the plant growth promotion [176]. The cytokinin receptors play a complimentary role in plant growth promotion by *B. megaterium* [177].

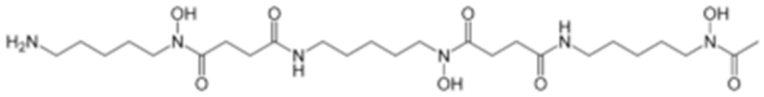
Some microorganisms produce auxins in the presence of a suitable precursor such as L-tryptophan. The tryptophan increases the production of IAA in *Bacillus amyloliquefaciens* FZB42 [178]. Tien *et al.* [179] showed that *Azospirillum* is able to produce auxins when exposed to tryptophan. Plants inoculated with the rhizobia together with Ag^{+} ion and L-tryptophan (Trp), give the highest root dry weight, and significantly increase the uptake of N, P and K compared to non-inoculated control plants [163]. Karnwal [180] tested *Fluorescent Pseudomonas* isolates for their ability to produce indole acetic acid in pure culture in the absence and presence of L-tryptophan and found that for both strains, indole production increased with increases in tryptophan concentration.

Isolates producing IAA have stimulatory effect on the plant growth. When the crop is inoculated with the isolates capable of IAA production significantly increases the plant growth by the N, P, K, Ca and Mg uptake of sweetpotato cultivar [181]. There is a significant increase in rooting and root dry matter of cuttings of eucalypts when grown on IAA producing rhizobacteria-inoculated substrate. Some rhizobacterial isolates stimulates the rhizogenesis and plant growth, maximizing yield of rooted cuttings in clonal nurseries [182]. When cucumber, tomato and pepper are inoculated with different strains of PGPR which produce IAA, there is a significant increase in the growth of the vegetables [183]. IAA of microbial origin plays a major role in promotion of orchid germination, at least when the bacterial strains are in tight association with the seeds. *Azospirillum brasilense* strain Az39 and *Brayrhizobium japonicum* strain E109 both are able to excrete IAA into the culture medium, at a concentration sufficient to produce morphological and physiological changes in young seed tissues of Corn (*Zea mays* L) and Soybean (*Glycine max* L) and are responsible for their early growth promotion [184]. The use of PGPR isolates is beneficial for rice cultivation as they enhance the growth of rice by inducing IAA production [31]. A plant growth promoting consortium comprising two species, *Burkholderia* sp. MSSP and *Sinorhizobium meliloti* PP3 with abilities to produce IAA when tested on *Cajanus cajan* show exceptional increase in seedling growth [185].

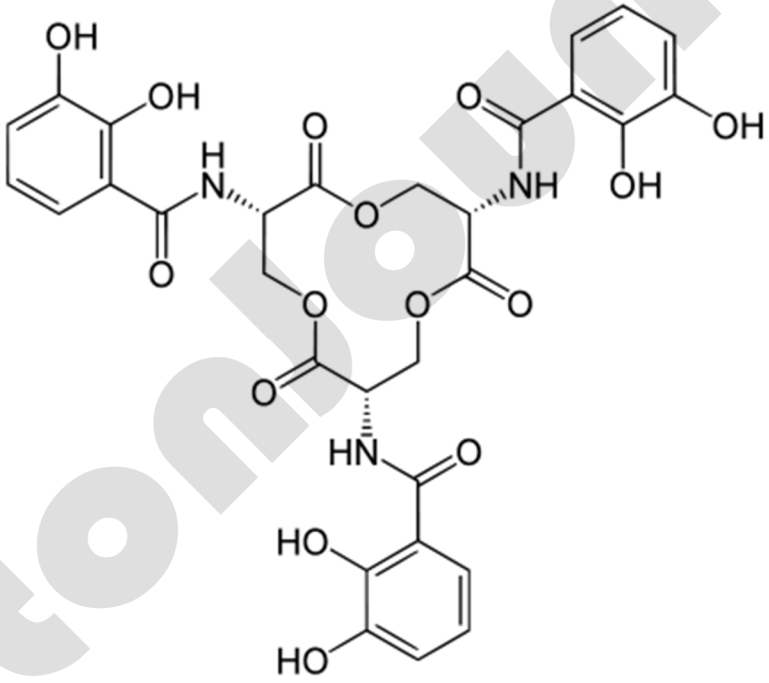
3.4 Siderophore production

Iron is an essential growth element for all living organisms. The scarcity of bioavailable iron in soil habitats and on plant surfaces foments a furious competition [186]. Under iron-limiting conditions PGPB produce low-molecular-weight compounds called siderophores to competitively acquire ferric ion [187]. Siderophores (Greek: "iron carrier") are small, high-affinity iron chelating compounds secreted by microorganisms such as bacteria, fungi and grasses [188-190]. Microbes release siderophores to scavenge iron from these mineral phases by formation of soluble Fe^{3+} complexes that can be taken up by active transport mechanisms. Many siderophores are non-ribosomal peptides [191], although several are biosynthesised independently [192]. Siderophores are also important for some pathogenic bacteria for their acquisition of iron [191]. Siderophores are amongst the strongest binders to Fe^{3+} known, with enterobactin being one of the strongest of these [193]. Distribution of siderophore-producing isolates according to amplified ribosomal DNA restriction analysis (ARDRA) groups, reveals that most of the isolates belong to Gram- negative bacteria corresponding to the *Pseudomonas* and *Enterobacter* genera, and *Bacillus* and *Rhodococcus* genera are the Gram-positive bacteria found to produce siderophores [194].

Examples of siderophores produced by various bacteria and fungi:



Desferrioxamine B, a hydroxamate siderophore.



Enterobactin, a catecholate siderophore.

A myriad of environmental factors modulate siderophores synthesis, including pH, the level of iron and the form of iron ions, the presence of other trace elements, and an adequate supply of carbon, nitrogen, and phosphorus [195]. The bacterial growth as well as siderophore production is stimulated by $(NH_4)_2SO_4$ and amino acids however, the optimum siderophore yield is obtained with urea [196]. The rhizobacteria able to produce siderophores *in vitro* increases early soybean growth in non-sterile soil [197]. Production of siderophores by plant growth promoting rhizobacteria is detected via the chrome azurol S assay, a general test for siderophores, which is independent of siderophore structure. The siderophores are produced by various bacteria and fungi. Siderophores are usually classified by the ligands used to chelate the ferric iron. The major groups of siderophores include the catecholates (phenolates), hydroxamates and carboxylates (e.g. derivatives of citric acid). The high-resolution analysis of catechol-type siderophores using polyamide thin layer chromatography has been performed by Xie *et al.* [198]. TLC methods are found very effective for separating simple catechol compounds such as 2, 3-dihydroxybenzoic acid (2, 3-DHBA) and catechol after carrying out the sidero-analysis of *Pseudomonas putida* it is revealed that this siderophore molecule contains hydroxamate as well as catecholate iron chelating groups and confirmed that this siderophores belongs to pyoverdine

type [199]. *Rhizobium* strains isolated from the root nodules of the *Sesbania sesban* (L) Merr. show the ability to produce hydroxamate-type of siderophores [200]. Rhizobial isolates belonging to genera *Rhizobium* sp. and *Mesorhizobium* sp. produces only catecholate type of siderophores [201]. Jurkevitch *et al.* [202] studied the differential availabilities of the hydroxamate siderophores ferrioxamine B (FOB) and ferrichrome (FC) and the pseudobactin siderophores as sources of Fe for soil and rhizosphere bacteria and found that the ability of bacteria to utilize a large variety of siderophores confers an ecological advantage. Some of the examples of Hydroxamate siderophores are: the siderophore ferrichrome is produced by *Ustilago sphaerogena*, Desferrioxamine B (Deferoxamine) is produced by *Streptomyces pilosus* and *Streptomyces coelicolor*, Desferrioxamine E is produced by *Streptomyces coelicolor*, Fusarinine C is produced by *Fusarium roseum* and Ornibactin is produced by *Burkholderia cepacia*. *Acinetobacter calcoaceticus* obtained from wheat rhizosphere in black cotton soils of North Maharashtra region produces catechol type of siderophores during exponential phase which is influenced by iron content of medium [203]. There are some examples of Catecholate siderophores like the siderophores Enterobactin is produced by *Escherichia coli*, bacillibactin is produced by *Bacillus subtilis* and *Bacillus anthracis* and vibriobactin is produced by *Vibrio cholerae*. The examples of siderophores with mixed ligands are the siderophores azotobactin is produced by *Azotobacter vinelandii*, pyoverdine is produced by *Pseudomonas aeruginosa* and yersiniabactin is produced by *Yersinia pestis*. Some poaceae (grasses) including wheat and barley produce a class of sideorphores called phytosiderophores or mugineic acids. The majority of the strains of endophytic actinomycetes produce antibiotic siderophores [204]. Although various bacterial siderophores differ in their abilities to sequester iron, in general, they deprive pathogenic fungi of this essential element since the fungal siderophores have lower affinity [205]. Some PGPB strains go one-step further and draw iron from heterologous siderophores produced by cohabiting microorganisms [205-209, 187]. *Pseudomonas* sp. have the capacity to utilize siderophores produced by diverse species of bacteria and fungi, and *Pseudomonas putida* can utilize the heterologous siderophores produced by rhizosphere microorganisms to enhance the level of iron available to it in the natural habitat [205]. The two strains *Fluorescent Pseudomonas* and *Pseudomonas fluorescens* NCIM 5096 along with *P. putida* NCIM 2847 produce maximum yield of hydroxamate type of siderophore in the modified succinic acid medium (SM).

Soil bacteria isolates incluing *Azotobacter vinelandii* MAC 259 and *Bacillus cereus* UW 85 produces siderophores and they can be used as efficient PGPR to increase the yield of the crop [210]. *Bacillus megaterium* from tea rhizosphere is able produce siderophore and thus it helps in the plant growth promotion and reduction of disease intensity [176]. *E. coli* isolated and characterized from endorhizosphere of sugarcane (*Saccharum* sp.) and rye grass (*Lolium perenne*) is found to produce maximum siderophores and thus is found to help in the growth of the plants [211]. Specific strains of the *Pseudomonas fluorescens-putida* group have recently been used as seed inoculants on crop plants to promote growth and increase yields of various crops. These results prompted Kloepper *et al.* [212] to investigate the mechanism by which plant growth was enhanced. A previous study indicated that PGPR increase plant growth by antagonism to potentially deleterious rhizoplane fungi and bacteria, but the nature of this antagonism was not determined [213]. They presented evidence that PGPR exert their plant growth-promoting activity by depriving native microflora of iron. PGPR produces extracellular siderophores (microbial iron transport agents) [189] which efficiently complex environmental iron, making it less available to certain native microflora [212]. The siderophores production by *Bacillus* and *Pseudomonas* when assessed both in the presence and in absence of technical grade of herbicides (quizalafop-p-ethyl & clodinafop) show that the metabolic activities of plant growth promoting rhizobacteria (PGPR) decline following herbicides application [214].

3.5 Phosphate Solubilizing Bacteria (PSB)

The improvement of soil fertility is one of the most common strategies to increase agricultural production. The biological nitrogen fixation is very important in enhancing the the soil fertility. In addition to biological nitrogen fixation, Phosphate solubilization is equally important. Phosphorus (P) is major essential macronutrients for biological growth and development. Microorganisms offer a biological rescue system capable of solubilising the insoluble inorganic P of soil and make it available to the plants. The ability of some microorganisms to convert insoluble phosphorus (P) to an accessible form, like orthophosphate, is an important trait in a PGPB for increasing plant yields [215, 216]. The rhizospheric phosphate utilizing bacteria could be a promising source for plant growth promoting agent in agriculture [33]. The use of phosphate solubilising bacteria as inoculants increases the P uptake by plants [216, 217]. Among the heterogeneous and naturally abundant microbes inhabiting the rhizosphere, the Phosphate Solubilising Microorganisms (PSM) including bacteria have provided an alternative biotechnological solution in sustainable agriculture to meet the P demands of plants. These organisms in addition to providing P to plants also facilitate plant growth by other mechanisms. Current developments in our understanding of the functional diversity, rhizosphere colonizing ability, mode of actions and judicious application are likely to facilitate their use as reliable components in the management of sustainable agricultural systems [218]. PSM include largely bacteria and fungi. The most efficient PSM belong to genera *Bacillus, Rhizobium* and *Pseudomonas* amongst bacteria, and *Aspergillus* and *Penicillium* amongst fungi. Within rhizobia, two species nodulating chickpea, *Mesorhizobium ciceri* and *Mesorhizobium mediterraneum*, are known as good phosphate solubilizers [219]. However, it is known that every aspect of the process of nodule formation is limited by the availability of P.

Legumes like alfalfa and clover show a high positive response to P supplementation [220], but most of the supplemented P become unavailable when its reacts with soil components. Many soil microorganisms are able to solubilise this unavailable P through their metabolic activities exudating organic acids, which directly dissolve the rock phosphate, or chelating calcium ions that release P to the solution. About 95% of Gram-positive soil bacilli belong to the genus *Bacillus* [221]. Members of *Bacillus* species are able to form endospores and hence survive under adverse conditions; some species are diazotrophs such as *Bacillus subtilis* [222], whereas others have different PGPR capacities [116, 223, 113, 45]. While working with two *Bacillus* strains, Orhan *et al.* [118] found that *Bacillus* M_3 alone or in combination with *Bacillus* OSU-142 have the potential to increase the yield, growth and nutrition of raspberry plant under organic growing conditions. Bacterial strains *Azotobacter vinelandii* and *Bacillus cereus* when tested *in vitro* are found to solubilise Phosphate and thus help in the growth of plant [210]. *Bacillus megaterium* from tea rhizosphere is able to solubilize phosphate and thus it helps in the plant growth promotion [176]. The group of *Rhizobium leguminosarum* bv. *viciae* mobilized in liquid TCP Sperber medium significantly releases more P than other rhizobia tested. The efficient mineral phosphate solubilising phenotype in Gram-negative bacteria has resulted from extracellular oxidation of glucose to gluconic acid *via* the quinoprotein glucose dehydrogenase [224].

In a screening of 4800 bacterial isolates from the root-free soil, rhizosphere and rhizoplane of *P. Juliflora* growing in alkaline soils, the incidence of PSB was highest in the rhizoplane, followed by rhizosphere and root-free soil [225]. Isolates from the rhizosphere of Soyabean are found to solubilise P *in vitro* along with other plant growth promoting traits and increases the soyabean growth [197]. Bacterial isolates *Pseudomonas* sp. and *Azospirillum* sp. from the rhizosphere soil and root cuttings of *Piper nigrum* L exhibits high phosphate solubilising ability *in vitro* [226]. The organism *Pseudomonas putida* exhibits a battery of PGPR traits including enhanced production of plant growth hormone indoleacetic acid. AM fungi are known to enhance plant uptake of phosphorus (P) and other mineral nutrients [227]. *E. coli* isolated and characterized from endorhizosphere of sugarcane (*Saccharum* sp.) and rye grass (*Lolium perenne*) is found to solubilise phosphate and thus is found to help in the growth of the plants [211]. The majority of the strains of endophytic actinomycetes can solubilize [204].

Identification and characterization of soil PSB for the effective plant growth-promotion broadens the spectrum of phosphate solubilizers available for field application. The application of PSM and PGPR together can reduce P application by 50% without any significant reduction of grain yield in corn *Zea mays* [228]. The PSB inoculation with mineral phosphorus raises the efficiency of P fertilizer and decreases the required P rate to plants. It also enhances vegetative growth and fruit quality, in addition to reduce the pollution of environment [229]. The use of PGPR isolates as inoculants is beneficial for rice cultivation as they enhance the growth of rice and phosphorus solubilisation [31].

3.6 Biocontrol agents

PGPR are indigenous to soil and the plant rhizosphere and play a major role in the biocontrol of plant pathogens. They can suppress a broad spectrum of bacterial, fungal and nematode diseases. PGPR can also provide protection against viral diseases. The use of PGPR has become a common practice in many regions of the world. Although significant control of plant pathogens has been demonstrated by PGPR in laboratory and greenhouse studies, results in the field have been inconsistent. Recent progress in our understanding of their diversity, colonizing ability, and mechanism of action, formulation and application should facilitate their development as reliable biocontrol agents against plant pathogens. Some of these rhizobacteria may also be used in integrated pest management programmes. Greater application of PGPR is possible in agriculture for biocontrol of plant pathogens and biofertilization [230]. The bacterial strains isolated from *Lolium perenne* rhizosphere are capable of acting as plant growth promoting bacteria and as biocontrol agents as they show various plant growth promoting activities [231]. A major group of rhizobacteria with potential for biological control is the *Pseudomonades* [232]. *Pseudomonas* sp. is ubiquitous bacteria in agricultural soils. Tremendous progress has been made in characterizing the process of root colonization by *pseudomonads*, the biotic and abiotic factors affecting colonization, bacterial traits and genes contributing to rhizosphere competence, and the mechanisms of pathogen suppression [233]. *Pseudomonads* possess many traits that make them well suited as biocontrol and growth-promoting agents [234]. These include the ability to (i) grow rapidly *in vitro* and to be mass produced; (ii) rapidly utilize seed and root exudates; (iii) colonize and multiply in the rhizosphere and spermosphere environments and in the interior of the plant; (iv) produce a wide spectrum of bioactive metabolites (i.e., antibiotics, siderophores, volatiles, and growth-promoting substances); (v) compete aggressively with other microorganisms; and (vi) adapt to environmental stresses. In addition, pseudomonads are responsible for the natural suppressiveness of some soils to soil borne pathogens [235]. The major weakness of pseudomonads as biocontrol agents is their inability to produce resting spores (as do many *Bacillus* spp.), which complicates formulation of the bacteria for commercial use. *Fluorescent Pseudomonas* spp. has been studied for decades for their plant growth-promoting effects through effective suppression of soil borne plant diseases. Among various biocontrol agents, *Fluorescent pseudomonads*, equipped with multiple mechanisms for biocontrol of phytopathogens and plant growth promotion, are being used widely [236-239] as they produce a wide variety of antibiotics, chitinolytic enzymes, growth promoting hormones, siderophores, HCN and catalase, and can solubilize phosphorous [236, 240-242]. *Pseudomonas fluorescens* MSP-393,

a plant growth-promoting rhizobacterium is an efficient biocontrol agent in rice grown in saline soils of coastal ecosystems [243]. Cold-tolerant fluorescent *Pseudomonas* isolated from Garhwal Himalayas act as potential plant growth promoting and biocontrol agents in pea [244].

Cyanide production is one of the possible ways by which rhizonbacteria may suppress plant growth in soil. Rudrappa *et al.* [245] elucidated the role of cyanide production in pseudomonad virulence affecting plant root growth and other rhizospheric processes. Growth inhibition of lettuce and barnyard grass by volatile metabolites of the cyanogenic rhizobacteria confirmed that HCN is the major inhibitory compound produced [246]. Leafy spurge is a serious invasive weed of grasslands of the northern Great Plains of the U.S. and Prairie Provinces of Canada. Leafy spurge is very difficult to control with herbicides, insect biological control agents, and other cultural practices. A synergism between plant-associated microorganisms and root-damaging insects is the most effective condition for inducing disease and subsequent mortality of leafy spurge [247]. The plant-parasitic nematodes are among the most destructive plant pests, causing substantial economic losses to agronomic crops worldwide. HCN is potentially an important compound with activity against RKN as well as *C. elegans*, and *C. elegans* can act as a useful model system for studying plant-parasitic nematode control using *Pseudomonas* [248]. Multitrophic interactions mediate the ability of fungal pathogens to cause plant disease and the ability of bacterial antagonists to suppress disease. A pathogen metabolite functions as a negative signal for bacterial antibiotic (HCN) biosynthesis, which can determine the relative importance of biological control mechanisms available to antagonists and which may also influence fungus-bacterium ecological interactions [249]. Positive correlations are found between HCN production *in vitro* and plant protection in the cucumber/*Pythium ultimum* and tomato/*Fusarium oxysporum* f. sp. *radicis-lycopersici* pathosystems [250].

Bacillus subtilis is also used as a biocontrol agent. This prevalent inhabitant of soil is widely recognized as a powerful biocontrol agent. In addition, due to its broad host range, its ability to form endospores and produce different biologically active compounds with a broad spectrum of activity, *B. subtilis* as well as other *Bacilli* are potentially useful as biocontrol agents [251]. *Bacillus megaterium* from tea rhizosphere is able to solubilize phosphate, produce IAA, siderophore and antifungal metabolite and thus it helps in the plant growth promotion and reduction of disease intensity [176]. Two strains [*Bacillus thuringiensis (kurstaki)* and *Bacillus sphaericus*] have the ability to solubilise inorganic phosphates and help in the control of the lepidopteron pests [252].

Arbuscular Mycorrhizal (AM) fungi are ubiquitous in nature and constitute an integral component of terrestrial ecosystems, forming symbiotic associations with plant root systems of over 80% of all terrestrial plant species, including many agronomically important species. AM fungi are particularly important in organic and/or sustainable farming systems that rely on biological processes rather than agrochemicals to control plant pathogens. Of particular importance is the bioprotection conferred to plants against many soil born pathogens such as species of *Aphanomyces*, *Cylindrocladium*, *Fusarium*, *Macrophomina*, *Phytophthora*, *Pythium*, *Rhizoctonia*, *Sclerotinium*, *Verticillium* and *Thielaviopsis* and various nematodes by AM fungal colonisation of the plant root [253]. AM fungi are known to enhance plant uptake of other mineral nutrients [227] and this enhanced plant development leads to disease escape or to heigher tolerance against soil-born pathogens [254].

Azospirillum spp. is not considered a classic biocontrol agent of soil-borne plant pathogens. However, *A. Brasilense* have moderate capabilities of biocontrolling crown gall-producing *Agrobacterium* [255]; bacterial leaf blight of mulberry [256]; and bacterial leaf and/or vascular tomato diseases [257, 258]. In addition, the proliferation of other non-pathogenic rhizosphere bacteria can be restricted by *A. brasilense* [259]. These *Azospirillum* antibacterial activities could be related to its already known ability to produce bacteriocins [260] and siderophores [261, 262]. In addition, *A. brasilense* was recently reported to synthesize phenylacetic acid (PAA), an auxin-like molecule with antimicrobial activity [263]. Recently, actinobacteria residing in plants called endophytic actinomycetes, have been reported as new sources for bioactive compounds [264-266] and had beneficial effects to the host plant by protecting plant from pathogens [267].

3.7 Antifungal activity

PGPR improve plant growth by preventing the proliferation of phytopathogens and thereby support plant growth. Some PGPR synthesize antifungal antibiotics, e.g. *P. fluorescens* produces 2,4-diacetyl phloroglucinol which inhibits growth of phytopathogenic fungi [268]. Certain PGPR degrade fusaric acid produced by *Fusarium* sp. causative agent of wilt and thus prevents the pathogenesis [269]. Some PGPR can also produce enzymes that can lyse fungal cells. For example, *Pseudomonas stutzeri* produces extracellular chitinase and laminarinase which lyses the mycelia of *Fusarium solani* [270]. In recent years, *fluorescent Pseudomonas* has been suggested as potential biological control agent due to its ability to colonize rhizosphere and protect plants against a wide range of important agronomic fungal diseases such as black root-rot of tobacco [271], root-rot of pea [272], root-rot of wheat [273], damping-off of sugar beet [274-276] and as the prospects of genetically manipulating the producer organisms to improve the efficacy of these biocontrol agents [277]. A concern is shown on the use of FLPs in crop

plants as the antifungal substances released by the bacterium, particularly 2, 4-diacetylphloroglucinol (DAPG) could affect the arbuscular mycorrhizal fungi [278]. Gaur *et al.* [279] confirmed that DAPG producing pseudomonads recovered from wheat rhizosphere did not adversely affect AM colonization. However, given the toxicity of DAPG, such an inhibition may probably be dependent on the amounts released by the bacterium. *Fluorescent pseudomonads* exhibit strong antifungal activity against *P. oryzae* and *R. solani* mainly through the production of antifungal metabolites [280]. One of the isolate of a *fluorescent Pseudomonas* spp. EM85 is found to be strongly antagonistic to *Rhizoctonia solani*, a causal agent of damping-off of cotton [281]. The *P. oryzihabitans* and *X. nematophila* strains produce secondary metabolites and suppress *Pythium* and *Rhizoctonia* species which also causes damping-off of cotton [282]. *Fluorescent pseudomonads* also exhibits strong antifungal activity against *Rhizoctonia bataticola* and *Fusarium oxysporum* found in rice and sugarcane rhizosphere, mainly through the production of antifungal metabolites [276]. *Xanthomonas oryzae* pv. *oryzae* and *Rhizoctonia solani* – the bacterial leaf blight (BB) and sheath blight (ShB) pathogens of rice (*Oryza sativa*) are suppressed by indigenous *Pseudomonas* strains isolated from rhizosphere of rice cultivated in the coastal agri-ecosystem under both natural and saline soil conditions [283]. Isolates of *Pseudomonas fluorescens* from rice rhizosphere are also shown to exhibit strong antifungal activity against *P. oryzae* and *R. solani* mainly through the production of antifungal metabolites [284]. 50–60% of *fluorescent pseudomonads* recovered from the rhizosphere and endorhizosphere of wheat grown in Indo-Gangetic plains are antagonistic towards *Helminthosporium sativum* [279]. Zadeh *et al.* [285] worked to show the antagonistic potential of non-pathogenic rhizosphere isolates of *fluorescent Pseudomonas* in the biocontrol of *Pseudomonas Savastanoi* which is the causative agent of Olive knot disease. *P. corrugata*, a form that grows at 4°C under laboratory conditions [286], produces antifungals such as diacetylphloroglucinol and/or phenazine compounds. *Pseudomonas fluorescens* CHA0 suppresses black root rot of tobacco, a disease caused by the fungus *Thielaviopsis basicola* [271] and contributes in the biocontrol of *Meloidogyne javanica*, the root-knot nematode, *in situ* [287]. In addition, certain soils from Morens, Switzerland, are naturally suppressive to *Thielaviopsis basicola*-mediated black root rot of tobacco, and *fluorescent pseudomonads* populations producing the biocontrol compounds [288]. *Pseudomonas* shows biocontrol potential against Phytopathogenic fungi *in vivo* and *in vitro* conditions from chickpea rhizosphere [289]. *P. putida* has potential for the biocontrol of root-rot disease complex of chickpea by showing antifungal activity against *Macrophomina phaseolina*. It has also been shown that anaerobic regulator ANR-mediated cyanogenesis contributes to the suppression of black root rot [290]. *Pseudomonas* strains acts as the effective candidates in suppressing *P. capsici* in all seasons of plant growth as *Fluorescent pseudomonad* antagonizes all the reproductive phases of the *Phytophthora capsici*, the causal organism of foot rot disease [291]. Some metabolites produced by *Pseudomons aeruginosa* Sha8 produces toxic volatile compound which reduces the growth of both *F. oxysporium* and *Helmithosporium* sp. while, *A. niger* is not affected [292]. *B. luciferensis* strain KJ2C12 reduces *Phytophthora blight* of pepper by protecting infection courts through enhanced effective root colonization with protease production and an increase of soil microbial activity [293]. Lima bean (*Phaseolus lunatus* L) plants release hydrogen cyanide (HCN) in response to damage caused by natural enemies, thereby directly defending plant tissue [294]. The bacteria *Pseudomonas fluorescens* CHA0 shows biocontrol against the ciliated protozoa *Tetrahymena pyriformis* which feeds on it [295].

The nutritional superiority of more vigorous AM plants has been proposed to be a mehanism in reduction of root diseases [227]. Wild rhizobial cultural filterates and/or AM plants are found to have a significant antagonistic effect against soil born pathogenic fungi and therefore enhances the plant resistance to diseases [296]. Siderophore mediated antagonism by *Acinetobacter calcoaceticus* is observed against common phytopathogens viz., *Aspergillus flavus*, *A. niger, Colletotrichum capsicum* and *Fusarium oxysporum* [203].

Soil application of bacterial PSMs manages the wilt of tomato caused by *Fusarium oxysporum* f. sp. *lycopersici* [297]. Inoculation of pepper with the phosphate solubilising bacteria significantly reduces the Phytophthora blight or crown blight of peppers and increases the yield compared to untreated controls [298]. *Azotobacter* isolates, *Pseudomonas* and *Bacillus* showed broad-spectrum antifungal activity on Muller-Hinton medium against *Aspergillus*, one or more species of *Fusarium* and *Rhizoctonia bataticola* [139].

3.8 PGPR action under stressed conditions

Agricultural crops are exposed to many stresses that are induced by both biotic and abiotic factors. These stresses decrease yields of crops and represent barriers to the introduction of crop plants into areas that are not suitable for crop cultivation. The occurrence and activity of soil microorganisms are affected by a variety of environmental factors as well as plant-related factors (species, age). Abiotic stress factors include high and low temperature, salinity, drought, flooding, ultraviolet light, air pollution (ozone) and heavy metals. The yield losses associated with abiotic stresses can reach 50% to 82%, depending on the crop. In many semi-arid and arid regions of the world, crop yield is limited due to increasing salinity of irrigation water as well as soil salinity. Under high salinity, plants exhibit a reduced leaf growth rate due to decreased water uptake, which restricts photosynthetic capacity. Plant involves a number of metabolic and physiological changes in response to salt stress and water deficiency (drought) [299]. The inoculation of salt-stressed plants with PGPR strains alleviates the salinity stress in plants. Soil

salinity is one of the most severe factors limiting nodulation, yield and physiological response in soybean. An increase in salinity in the soil causes a physiological response or disorder in lettuce plants [300]. The long-term goal of improving plant–microbe interactions for salinity affected fields and crop productivity can be met with an understanding of the mechanism of osmoadaptation in *Azospirillum* sp. The synthesis and activity of nitrogenases in *A. brasilense* is inhibited by salinity stress [301]. Tripathi *et al.* [302] reported that in *Azospirillum* sp. there is an accumulation of compatible solutes such as glutamate, proline, glycine betaine and trehalose in response to salinity/osmolarity; proline plays a major role in osmoadaptation through increase in osmotic stress that shifts the dominant osmolyte from glutamate to proline in *A. brasilense*. Azospirillum-inoculated sorghum plants had more water content, higher water potential, and lower canopy temperature in their foliage. Hence, they were less drought-stressed than noninoculated plants. Saleena *et al.* [303] have studied the diversity of indigenous *Azospirillum* sp. associated with rice cultivated along the coastline of Tamil Nadu.

The PGPR containing ACC deaminase are present in various soils and offer promise as a bacterial inoculum for improvement of plant growth, particularly under unfavourable environmental conditions such as flooding, heavy metals, phytopathogens, drought and high salt. Ethylene is an important phytohormone, but over-produced ethylene under stressful conditions can result in the inhibition of plant growth or death, especially for seedlings. PGPR containing ACC deaminase can hydrolyze ACC, the immediate precursor of ethylene, to F-ketobutarate and ammonia, and in this way promote plant growth. Inoculation of crops with ACC deaminase-containing PGPR may assist plant growth by alleviating deleterious effects of salt stress ethylene [304].

The establishment and performance of PSM is however affected severely under stressed conditions such as high salt, pH and temperature prevalent in degraded ecosystems represented by alkaline soils with tendency to fix phosphorus [305]. Production of microbial metabolites results in a decrease in soil pH, which probably plays an important role in the solubilization [306] thus, there is a close relationship found between the phosphate solubilising activity and low pH levels in the growth medium which suggests that phosphate solubilization is the result of organic acids released from bacterial metabolism [307, 59, 252]. An inverse relationship between pH and P solubilization is found while working on *Arthrobacter ureafaciens*, *Phyllobacterium myrsinacearum*, *Rhodococcus erythropolis* and *Delftia* sp. They are being reported for the first time as PSB after confirming their capacity to solubilise considerable amount of tricalcium phosphate in the medium by secreting organic acids and thus decreasing the pH of the soil [216]. The inoculation of some microorganisms that solubilises the insoluble phosphates, into a microcosm containing soil from a barren lakeside area enhances the plant growth significantly and this plant growth promoting capability can be used for the rapid revegetation of barren or disturbed land [308]. Savannas are natural ecosystems that predominate in the tropics. These systems usually have acid soils with low fertility in which nutrients, especially phosphorus, are scarce.

The metal resistant PGPB can serve as an effective metal sequestering and growth-promoting bioinoculant for plants in metal-stressed soil [309]. The deleterious effects of heavy metals taken up from the environment on plants can be lessening with the use of PGP bacteria or mycorrhizal fungi [310-312]. The soil microbes, plant growth promoting rhizobacteria (PGPR), P-solubilizing bacteria, mycorrhizal-helping bacteria (MHB) and arbuscular mycorrhizal fungi (AMF) in the rhizosphere of plants growing on trace metal contaminated soils plays an important role in phytoremediation [313]. Phytoremediation provides a cheap, energy efficient detoxification method that manipulates intrinsic plant characteristics to concentrate the metal contamination in shoot biomass and reduce the bioavailability of the heavy metals. Soil microbes mitigate toxic effects of heavy metals on the plants through secretion of acids, proteins, phytoantibiotics, and other chemicals [312]. Jing *et al.* [314] reviewed recent advances in effect and significance of Rhizobacteria in phytoremediation of heavey metal contaminated soils. Cd in soil induces plant-stress ethylene biosynthesis [315] and probably contributes to the accumulation of ACC in roots, the PGPR protect the plants against the inhibitory effects of cadmium [316]. ACC deaminase lowers the ethylene production under cadmium stress condition when measured *in vitro* ethylene evolution by wheat seedlings treated with ACC deaminase positive isolates [317]. A plant growth-promoting bacterium, *Kluyvera ascorbata* SUCD165 contains high level of heavy metals is resistant to the toxic effects of Ni^{2+}, Pb^{2+}, Zn^{2+}, and CrO_4-. This bacterium decreases nickel toxicity in the seedlings [318]. Wu *et al.* [319] carried a greenhouse study with *Brassica juncea* to critically evaluate effects of bacterial inoculation on the uptake of heavy metals from Pb–Zn mine tailings by plants. The presence of these beneficial bacteria stimulated plant growth and protected the plant from metal toxicity; it had little influence on the metal concentrations in plant tissues, but produced a much larger aboveground biomass and altered metal bioavailability in the soil. As a consequence, higher efficiency of phytoextraction was obtained compared with control treatments. The organism *Pseudomonas putida* is also tolerant to number of heavy metals at higher levels. These characteristics make *P. putida* an excellent candidate for field application in contaminated soil [320]. *P. fluorescens* can survive under dry conditions and hyperosmolarity [321]. The hydroxamate siderophores contained in culture filtrates of *S. acidiscabies* E13 promotes Cowpea growth under nickel contamination by binding iron and nickel, thus playing a dual role of sourcing iron for plant use and protecting against nickel toxicity [322].

PGPR can have positive effects on vigour and productivity, especially under stress conditions. Seed inoculations with PGPR in asparagus (*Asparagus officinalis* L) results in a positive response and enhances plant growth under drought [323]. The phosphate-solubilising microorganisms can interact positively in promoting plant growth as well as P uptake of maize plants, leading to plant tolerance improving under water deficit stress conditions [324]. On the basis of mutational studies of *Azospirillum,* Kadouri *et al.* [325] proved the role of PHB synthesis and accumulation in enduring various stresses, viz. UV irradiation, heat, osmotic pressure, osmotic shock and desiccation. *Azospirillum*-inoculated wheat (*T. aestivum*) seedlings subjected to osmotic stress developed significant higher coleoptiles, with higher fresh weight and better water status than non-inoculated seedlings [326, 327]. A multi-process phytoremediation system (MPPS) utilizes plant/PGPR (plant growth promoting rhizobacteria) interactions to mitigate stress ethylene effects, thereby greatly increasing plant biomass, particularly in the rhizosphere and it also causes the decontamination of persistent petroleum and organic contaminants in soil [328].

4. Mechanism shown by PGPR

Induced Systemic Resistance (ISR) of plants against pathogens is a widespread phenomenon that has been intensively investigated with respect to the underlying signalling pathways as well as to its potential use in plant protection. Elicited by a local infection, plants respond with a salicylic-dependent signalling cascade that leads to the systemic expression of a broad spectrum and long-lasting disease resistance that is efficient against fungi, bacteria and viruses. Salicylic acid (SA) has an important role in the signalling pathway leading to ISR. After infection, endogenous levels of SA increase locally and systemically, and SA levels increase in the phloem before ISR occurs. SA is synthesized in response to infection both locally and systemically; *de novo* production of SA in non-infected plant parts might therefore contribute to systemic expression of ISR [329]. Compared to pathogens inducing SAR, non-pathogenic rhizobacteria inducing ISR trigger a different signal-transduction pathway not dependent on the accumulation of the SA and activation of Pathogensis-related (PR)-genes but dependent on precipitation of ethylene and jasmonic acid [330]. Evaluation of growth promotion and induced systemic disease resistance (ISR) in cucumber mediated by plant growth-promoting rhizobacteria (PGPR), with and without methyl bromide soil fumigation proves that in cucumber production systems, withdrawal of methyl bromide does not negatively impact PGPR mediated ISR, and also that PGPR have potential as an alternative to methyl bromide fumigation [331]. The plant growth-promoting *Pseudomonas* strains, which induced resistance systematically in watermelon to gummy stem rot, are investigated on their induced systemic resistance (ISR) - related characteristics by Lee *et al.* [332]. Their work supports the concept that PGPR can protect plants against the pathogens by inducing defense mechanisms by iron-binding siderophore, HCN and other associates. The plant growth promoting rhizobacteria induced systemic protection against Tomato late blight [333]. Under *in vitro* conditions *P. fluorescens* (ENPF1) and *P. chlororaphis* isolate (BCA) promotes plant growth and induce systemic resistance against stem blight pathogen *Corynespora cassiicola* in *P. amarus* [334]. The involvement of ISR is typically studied in systems in which the *Pseudomonas* bacteria and the pathogen are inoculated and remain spatially separated on the plant, e.g., the bacteria on the root and the pathogen on the leaf, or by use of split root systems. Since no direct interactions are possible between the two populations, suppression of disease development has to be plant-mediated [335]. The combination of two bacilli strains with chitosan results in significant growth promotion that is correlated with induced resistance in tomato (*Lycopersicon esculentum)*, bell pepper (*Capsicum annuum*), cucumber (*Cucumis sativus*) and tobacco (*Nicotiana tabacum*) [13]. *P. fluorescens* can survive under dry conditions and hyperosmolarity, the gene AlgU is a crucial determinant of this adaptation [321]. Some PGPR strains release a blend of volatile organic compounds (VOCs) that promote growth in *Arabidopsis* seedlings and induce resistance against *Erwinia carotovora* subsp. *carotovora* [336]. Plant growth promotion induced by the antagonistic fungus, *Pythium oligandrum*, is the result of a complex interaction which includes an indirect effect through control of pathogens in the rhizosphere and/or a direct one mediated by plant-induced resistance [337].

Enzymatic pathways involving hydrolytic, oxidative, reductive, and substitution/transfer reactions are implicated in detoxification of cyanide by bacteria and fungi. The enzyme rhodanese from cyanogenic bacterium *Pseudomonas aeruginosa* involved in transfer reactions causes cyanide detoxification [338]. The enzymes like chitinase, β-1, 3 Glucanase and Cellulase are involved in antagonistic action of *Pseudomonas* against fungal pathogens [289]. The enzyme formamide hydro-lyase is involved in HCN detoxification in sorghum infected by *Gloeocercospora sorghi* [339]. The HCN synthase which produces HCN is encoded by three biosynthetic genes (*hcnA*, *hcnB*, and *hcnC*), but little is known about the diversity of these genes in *fluorescent Pseudomonas* spp and in other bacteria [250]. The PCR amplification of hydrogen cyanide biosynthetic locus hcnAB in *Pseudomonas* spp. has been done. The PCR-based assay targeting hcnAB which are essential genes for hydrogen cyanide (HCN) biosynthesis, allows sensitive detection of HCN+ pseudomonads between logs 2.9 and 3.5 cells per PCR reaction tube [340]. RhdA, a thiosulfate: cyanide sulphur transferase (rhodanese) is a cytoplasmic enzyme acting as the principal rhodanese in *P. aeruginosa*. It is regarded as an effector of *P. aeruginosa* intrinsic resistance to cyanide, insofar as it provides the bacterium with a defense mechanism against endogenous cyanide toxicity, in addition to cyanide-resistant respiration [338]. Infact in *P. fluorescens*, the anaerobic regulator ANR and the global activator GacA are both required for the maximal expression of the HCN biosynthetic genes *hcnABC*. So, we can conclude that cyanogenesis is sequentially activated by ANR at the level of transcription

and by components of the GacA network at the level of translation. In the biocontrol strain CHA0 of *Pseudomonas fluorescens*, the response regulator GacA is essential for the synthesis of extracellular protease (AprA) and secondary metabolites including hydrogen cyanide [341, 342]. In the plant-beneficial rhizosphere bacterium *Pseudomonas fluorescens* CHA0, the GacS/GacA system is essential for the production of antibiotic compounds and hence for biological control of root-pathogenic fungi. The differential expression of three small RNAs facilitated the fine tuning of GacS/A-controlled cell population density-dependent regulation in *P. fluorescens* [343].

The aromatic amino acid-dependent expression of Indole-3-Pyruvate decarboxylase which is a key enzyme in the production of indole-3-acetic acid (IAA) in rhizobacterium *Enterobacter cloacae* UW5 is regulated by TyrR protein [344]. Siderophore biosynthesis is generally tightly regulated by iron-sensitive Fur proteins, the global regulators GacS and GacA, the sigma factors RpoS, PvdS, and FpvI, quorum-sensing autoinducers such as *N*-acyl homoserine lactone, and site-specific recombinases [345, 346]. However, some data demonstrate that none of these global regulators is involved in siderophore production. Neither GacS nor RpoS significantly affects the level of siderophores synthesized by *Enterobacter cloacae* CAL2 and UW4 [347]. RpoS is not involved in the regulation of siderophore production by *Pseudomonas putida* strain WCS358 [348]. In addition, GrrA/GrrS, but not GacS/GacA, are involved in siderophore synthesis regulation in *Serratia plymuthica* strain IC1270, suggesting that gene evolution occurred in the siderophore-producing bacteria [349].

Kumar *et al.* [276] carried out the genotyping of the antifungal compounds while working on rice and sugarcane. A large group of bacteria originating from the roots of pea, lentil, and chickpea grown in Saskatchewan shows several plant growth-promoting traits, suppresses legume fungal pathogens and promotes plant growth. Several of these isolates have the potential for development as biofertilizers or biopesticides for western Canadian legume crops [350].

5. Conclusion

Plant growth promoting rhizobacteria (PGPR) are a heterogeneous group of bacteria that can be found in the rhizosphere, at root surfaces and in association with roots, which can improve the extent or quality of plant growth directly and/or indirectly. In last few decades a large array of bacteria including species of *Pseudomonas, Azospirillum, Azotobacter, Klebsiella, Enterobacter, Alcaligenes, Arthrobacter, Burkholderia, Bacillus, Rhizobium* and *Serratia* have reported to enhance plant growth. The direct promotion by PGPR entails either providing the plant with plant growth promoting substances that are synthesized by the bacterium or facilitating the uptake of certain plant nutrients from the environment. The indirect promotion of plant growth occurs when PGPR prevent deleterious effects of one or more phytopathogenic microorganisms. The exact mechanisms by which PGPR promote plant growth are not fully understood, but are thought to include (i) the ability to produce or change the concentration of plant growth regulators like indoleacetic acid, gibberellic acid, cytokinins and ethylene [351, 352], (ii) asymbiotic N_2 fixation [353], (iii) antagonism against phytopathogenic microorganisms by production of siderophores [354], antibiotics [275] and cyanide [355] (iv) solubilization of mineral phosphates and other nutrients [356, 357]. Some PGPR may promote plant growth indirectly by affecting symbiotic N_2 fixation, nodulation or nodule occupancy [358]. However, role of cyanide production is contradictory as it may be associated with deleterious as well as beneficial rhizobacteria [359, 360]. In addition to these traits, plant growth promoting bacterial strains must be rhizospheric competent, able to survive and colonize in the rhizospheric soil [197]. Unfortunately, the interaction between associative PGPR and plants can be unstable. The good results obtained *in vitro* cannot always be dependably reproduced under field conditions [361, 362]. The variability in the performance of PGPR may be due to various environmental factors that may affect their growth and exert their effects on plant. The environmental factors include climate, weather conditions, soil characteristics or the composition or activity of the indigenous microbial flora of the soiL To achieve the maximum growth promoting interaction between PGPR and nursery seedlings it is important to discover how the rhizobacteria exerting their effects on plant and whether the effects are altered by various environmental factors, including the presence of other microorganisms [363]. Therefore, it is necessary to develop efficient strains in field conditions. One possible approach is to explore soil microbial diversity for PGPR having combination of PGP activities and well adapted to particular soil environment.

As our understanding of the complex environment of the rhizosphere, of the mechanisms of action of PGPR, and of the practical aspects of inoculant formulation and delivery increases, we can expect to see new PGPR products becoming available. The success of these products will depend on our ability to manage the rhizosphere to enhance survival and competitiveness of these beneficial microorganisms [364]. Rhizosphere management will require consideration of soil and crop cultural practices as well as inoculant formulation and delivery [364, 365]. Genetic enhancement of PGPR strains to enhance colonization and effectiveness may involve addition of one or more traits associated with plant growth promotion [366, 352, 367]. Genetic manipulation of host crops for root-associated traits to enhance establishment and proliferation of beneficial microorganisms [368, 369] is being pursued. The use of multi-strain inocula of PGPR with known functions is of interest as these formulations may increase consistency in the field [370, 371]. They offer the potential to address multiple modes of action, multiple pathogens, and temporal or spatial variability. PGPR offer an environmentally sustainable approach to increase crop production

and health. The application of molecular tools is enhancing our ability to understand and manage the rhizosphere and will lead to new products with improved effectiveness [372].

References

1. Hiltner L, 1904. Uber neuere erfahrungen und probleme auf dem gebiet der boden bakteriologie und unter besonderer berucksichtigung det grundungung und branche. Arb. Deut. Landw. Ges. 98: 59-78.
2. McCully M, 2005. The rhizosphere: the key functional unit in plant/soil/microbial interactions in the field. Implications for the understanding of allelopathic effects. *In* Proceedings of the 4th World Congress on Allelopathy: 21-26 August 2005; Charles Sturt University, Wagga Wagga, NSW, Australia. International Allelopathy Society. Edited by Harper J, An M, Wu H, Kent J.
3. Lynch JM, 1990. The Rhizosphere. John Wiley & Sons Ltd, Chichester, Edited by Lynch JM, 458.
4. García JL, Probanza A, Ramos B, Mañero FJG, 2001. Ecology, genetic diversity and screening strategies of plant growth promoting rhizobacteria. Journal of Plant Nutrition and Soil Sciences, 164: 1–7.
5. Marilley L, Aragno M, 1999. Phytogenetic diversity of bacterial communities differing in degree of proximity of *Lolium perenne* and *Trifolium repens* roots. Applied Soil Ecology, 13: 127–136.
6. Antoun H, Kloepper JW, 2001. Plant growth promoting rhizobacteria (PGPR). In *Encyclopedia of Genetics*. Academic Press, New York. Edited by Brenner S, Miller JH, 1477–1480.
7. Barriuso J, Solano BR, Lucas JA, Lobo AP, Villaraco AG, Mañero FJG, 2008. Ecology, Genetic Diversity and Screening Strategies of Plant Growth Promoting Rhizobacteria (PGPR). WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, Edited by Ahmad I, Pichtel J, Hayat S, 1-17.
8. Kloepper JW, Leong J, Teintze M, Schroth MN, 1980. Enhanced plant growth by siderophores produced by plant growth-promoting rhizobacteria. Nature, 286: 885–886.
9. Kloepper JW, Lifshitz R, Zablotowicz RM, 1989. Free-living bacterial inocula for enhancing crop productivity. Trends in Biotechnology, 7 (Suppl 2): 39–43.
10. Okon Y, Labandera-Gonzalez CA, 1994. Agronomic applications of *Azospirillum*. In *Improving Plant Productivity with Rhizosphere Bacteria*. Commonwealth Scientific and Industrial Research Organization, Adelaide, Australia, Edited by Ryder MH, Stephens PM, Bowen GD, 274–278.
11. Glick BR, 1995. The enhancement of plant growth by free living bacteria. Canadian Journal of Microbiology, 41 (Suppl 2): 109–114.
12. Joseph B, Patra RR, Lawrence R, 2007. Characterization of plant growth promoting Rhizobacteria associated with chickpea (*Cicer arietinum* L). International Journal of Plant Production, 1 (Suppl 2): 141-152.
13. Kloepper JW, Reddy SM, Rodreguez-Kabana R, Kenney DS, Kokalis- Burelle N, Ochoa NM, 2004. Application for Rhizobacteria in Transplant Production and Yield Enhancement. Acta Horticulturae, 631: 217-229.
14. Pieterse CMJ, Pelt JA, Verhagen BWM, Jurriaan T, Wees SCM, Léon-Kloosterziel KM, Loon LC, 2003. Induced systemic resistance by plant growth-promoting rhizobacteria. Symbiosis, 35 (Suppl 1-3): 39-54.
15. Tizzard AC, Vergnon M, Clinton PW, 2006. The unseen depths of soils- how plant growth promoting microbes may advance commercial forestry practices. New Zealand Journal of Forestry, 51 (Suppl 3): 9-12.
16. Farzana Y, Saad ROS, Kamaruzaman S, 2009. Growth and storage root development of Sweet potato inoculated with rhizobacteria under glasshouse conditions. Australian Journal of Basic and Applied Sciences, 3 (Suppl 2): 1461-1466.
17. Burr TJ, Caesar AM, Schrolh N, 1984. Beneficial plant bacteria. Critical Reviews in Plant Sciences, 2 (Suppl 1): 1–20.
18. Yasmin F, Othman R, Saad MS, Sijam K, 2007. Screening for beneficial properties of Rhizobacteria isolated from sweet potato rhizosphere. Journal of Biotechnology, 6 (Suppl 1): 49-52
19. Egamberdiyeva D, 2007. The effect of plant growth promoting bacteria on growth and nutrient uptake of maize in two different soils. Applied Soil Ecology, 36 (Suppl 2-3): 184–189.
20. Asghar HN, Zahir ZA, Arshad M, 2004. Screening rhizobacteria for improving the growth, yield, and oil content of canola (*Brassica napus* L). Australian Journal of Agricultural Research, 55 (Suppl 2): 187-194.
21. Ryu C, Farag MA, Hu C, Reddy MS, Wei H, Paré PW, Kloepper JW, 2003. Bacterial volatiles promote growth in *Arabidopsis.* Proceedings of the National Academy of Sciences (PNAS), 100 (Suppl 8): 4927-4932.
22. Anjum MA, Sajjad MR, Akhtar N, Qureshi MA, Iqbal A, Jami AR, Mahmud-ul-Hasan, 2007. Response of cotton to plant growth promoting Rhizobacteria (PGPR) inoculation under different levels of nitrogen. Journal of Agricultural Research, 45 (Suppl 2): 135-143.
23. Karakurt H, Aslantas R, Ozkan G, Guleryuz M, 2009. Effects of indol–3-butyric acid (IBA), plant growth promoting rhizobacteria (PGPR) and carbohydrates on rooting of hardwood cutting of MM106 Apple rootstock. African Journal of Agricultural Research, 4 (Suppl 2): 060-064.
24. Hameeda B, Rupela O, Reddy G, Satyavani K, 2006. Application of plant growth-promoting bacteria associated with composts and macrofauna for growth promotion of Pearl millet (*Pennisetum glaucum* L). Biology and Fertility of Soils, 43 (Suppl 2): 221-227.

25. Shahzad SM, Khalid A, Arshad M, Khalid M, Mehboob I, 2008. Integrated use of plant growth promoting bacteria and P-enriched compost for improving growth, yield and nodulating of Chickpea. Pakistan Journal of Botany, 40 (Suppl 4): 1735-1441.
26. Tilak KVBR, Ranganayaki N, Pal KK, De R, Saxena AK, Nautiyal CS, Mittal S, Tripathi AK, Johri BN, 2005. Diversity of plant growth and soil health supporting bacteria. Current Science, 89 (Suppl 1): 136-150.
27. Egamberdiyeva D, 2005. Plant-growth-promoting rhizobacteria isolated from a Calcisol in a semi-arid region of Uzbekistan: biochemical characterization and effectiveness. Journal of Plant Nutrition and Soil Science, 168 (Suppl 1): 94–99.
28. Curl EA, Truelove B, 1986. The Rhizosphere. Springer Verlag, Berlin-Heidelberg, 288.
29. Hallmann J, Quandt-Hallmann A, Mahaffee WF, Kloepper JW, 1997. Bacterial endophytes in agricultural crops. Canadian Journal of Microbiology, 43 (Suppl 10): 895–914.
30. Barraquio WL, Segubre EM, Gonzalez MS, Verma SC, James EK, Ladha JK, Tripathi AK, 2000. Diazotrophic enterobacteria: What is their role in the rhizosphere? In *The Quest for Nitrogen Fixation in Rice*. IRRI, Manila. Edited by Ladha JK, Reddy PM, 93-118.
31. Ashrafuzzaman M, Hossen FA, Ismail MR, Hoque MA, Islam MZ, Shahidullah SM, Meon S, 2009. Efficiency of plant growth-promoting Rhizobacteria (PGPR) for the enhancement of rice growth. African Journal of Biotechnology, 8 (Suppl 7): 1247-1252.
32. Ştefan M, Mihasan M, Dunca S, 2008. Plant growth promoting Rhizobacteria can inhibit the *in vitro* germination of *Glycine Max* L seeds. Scientific Annals of University "Alexandru Ioan Cuza" Iasi, Section Genetics and Molecular Biology, T. IX, 3: 105-110 .
33. Chaiharn M, Chunhaleuchanon S, Kozo A, Lumyong S, 2008. Screening of Rhizobacteria for their plant growth promoting activities. KMITL Science and Technology Journal, 8 (Suppl 1): 18-23.
34. Adesemoye A, Torbert H, Kloepper J, 2009. Plant growth-promoting Rhizobacteria allow reduced application rates of chemical fertilizers. Microbial Ecology, 58 (Suppl 4): 921-929.
35. Rokhzadi A, Asgharzadeh A, Darvish F, Nour-Mohammadi G, Majidi E, 2008. Influence of plant growth promoting Rhizobacteria on dry matter accumulation of Chickpea (*Cicer arietinum L*) under field conditions. Journal of Agriculture and Environmental Sciences, 3 (Suppl 2): 253-257.
36. Graham P. H. 1988. Principles and Application of Soil Microbiology, 322–345.
37. Young JPW, 1992. Phylogenetic classification of nitrogen-fixing organisms. *In* Biological Nitrogen Fixation, Chapman and Hall New York. Edited by Stacey G, Burris RH, Evans HJ, 43–86.
38. Schwintzer R, Tjepkema JD, 1990. The Biology of *Frankia* and Actinorrhizal Plants. Academic Press Inc. San Diego, USA, 99.
39. Wheeler CT, Miller JM, 1990. Current and potential uses of actinorrhizal plants in Europe. *In* The Biology of *Frankia* and Actinorrhizal Plants. Academic Press, San Diego, USA. Edited by Schwintzer CR, Tjepkema JD, 365–389.
40. Huss-Danell K, 1990. The physiology of actinorrhizal roots. In The Biology of Frankia and Actinorrhizal Plants. Academic Press San Diego, USA. Edited by Schwintzer CR, Tjepkema JD, 128–156.
41. Werner D, 1992. Symbiosis of Plants and Microbes, Chapman and Hall, New York, 387–400.
42. Dommergues YR, Marco-Bosco, 1998. The contribution of N_2- fixing trees to soil productivity and rehabilitation in tropical, subtropical and Mediterranean regions. *In* Microbial Interactions in Agriculture and Forestry Oxford & IBH, New Delhi. Edited by Subba Rao NS, Dommergues YR, 65–96.
43. Antoun H, Beauchamp CJ, Goussard N, Chabot R, Lalande R, 1998. Potential of *Rhizobium* and *Bradyrhizobium* species as plant growth promoting rhizobacteria on non-legumes: Effect on radishes (*Raphanus sativus* L). Plant and Soil, 204 (Suppl 1): 57–67.
44. Yanni YG, Rizk RY, Corich V, Squartini A, Ninke K, Philip-Hollingworth S, Orgambide G, de Bruijn F, Stolzfus J, Buckley D, Schmidt TM, Mateos PF, Ladha J K, Dazzo FB, 1997. Natural endophytic association between *Rhizobium leguminosarum* bv. *trifolii* and rice roots and assessment of its potential to promote rice growth. Plant and Soil, 194 (Suppl 1-2): 99–114.
45. Barriuso J, Solano BR, 2008. Ecology, Genetic Diversity and Screening Strategies of Plant Growth Promoting Rhizobacteria (PGPR). Journal of Plant nutrition: 1-17.
46. Sahgal M, Johri BN, 2003. The changing face of rhizobial systematics. Current Science, 84 (Suppl 1): 43–48.
47. Sundara Rao WVB, Sen AN, Gaur YD, 1969. Survey and isolation of root nodule bacteria in Indian soils, Final Report, 1969, Report PL-480 Scheme, Division of Microbiology, IARI, New Delhi, India.
48. Subba Rao NS, Sen AN, Gaur YD, 1972. Final Report, PL-480 Scheme, Division of Microbiology, IARI, New Delhi, India.
49. Rewari RB, 1972. All India Coordinated Pulse Improvement Project, Report, IARI, New Delhi, India.
50. Dadarwal KR, Prabha S, Tauro P, 1978. Varietal differences with regard to *Rhizobium* compatibility and efficiency of nitrogen fixation in chickpea. Proceedings of the National Symposium on Nitrogen Assimilation and Crop Productivity. Indian Agricultural. Research Institute, New Delhi. India, 235–239.
51. Khurana AL, Sharma H, Manchanda N, Tauro P, 1978. Competitiveness of inoculated chickpea rhizobia with native rhizobia. Indian Journal of Microbiology, 18: 58–59.

52. Dadarwal KR, Prabha S, Tauro P, 1979. Efficiency and antigenic characteristics of green gram (*Vigna radiata* var. *aureus*) rhizobia. Indian Journal of Experimental Biology, 17 (Suppl7): 668–670.
53. Dadarwal KR, Singh CS, Subba Rao NS, 1974. Nodulation and serological studies of rhizobia from six species of *Arachis*. Plant and Soil, 40 (Suppl 3): 535–544.
54. Singh CS, Dadarwal KR, Subba Rao NS, 1977. A comparison of physiological properties and efficiency of *Arachis* rhizobia. Zkt. Bakt. Abt. II., 131: 72–78.
55. Sidhu BS, Brar SS, Pareek RP, 1977. Serogrouping of *R. trifolii* strains. Indian Journal of Microbiology, 17: 129–130.
56. Rewari RB, Tilak KVBR, 1988. Microbiology of pulses. *In* Pulse Crops, Oxford & IBH, New Delhi. Edited by Baldev B, Ramanujam S, Jain HK, 373–411.
57. Tilak KVBR, 1993. Bacterial Fertilizers, Indian Council of Agricultural Research, New Delhi, India, 4–33.
58. Akhtar MS, Siddiqui ZA, 2009. Use of plant growth-promoting rhizobacteria for the biocontrol of root-rot disease complex of chickpea. Australian Plant Pathology, 38 (Suppl 1): 44–50.
59. Alikhani HA, Saleh-Rastin N, Antoun H, 2006. Phosphate solubilization activity of *rhizobia* native to Iranian soils. Plant and soil, 287 (Suppl 1-2): 35-41.
60. Kumar R, Chandra R, 2008. Influence of PGPR and PSB on *Rhizobium leguminosarum* Bv. *viciae* strain competition and symbiotic performance in Lentil. World Journal of Agricultural Sciences, 4 (Suppl 3): 297-301.
61. Sharma P, Sekhon HS, Khanna V, Singh G, 2007. Biological Nitrogen Fixation in Mungbean: Facts and Findings. ISHS Acta Horticulturae 752: 597-601.
62. Afzal A, Bano A, 2008. *Rhizobium* and Phosphate Solubilizing Bacteria Improve the Yield and Phosphorus Uptake in Wheat (*Triticum aestivum*). International Journal of Agricultural Biology, 10 (Suppl 1): 85-88.
63. Cakmakc R, Donmez MF, Erdogan U, 2007a. The effect of plant growth promoting rhizobacteria on barley seedling growth, nutrient uptake, some soil properties, and bacterial counts. Turkish Journal of Agriculture and Forestry, 31(Suppl 3): 189-199.
64. Somasegaran P, 1994. Handbook for rhizobia: methods in legume-rhizobium technology. New York: Springer-Verlag. 1–6, 167.
65. Polenko DR, Scher FM, Kloepper JW, Singleton CA, Laliberte M, Zaleska I, 1987. Effects of root colonizing bacteria on nodulation of soybean roots by *Bradyrhizobium japonicam*. Canadian Journal of Microbiology, 33: 498-503.
66. Yahalom E, Okon Y, Dovrat A, 1987. *Azospirillum* effects on susceptibility to *Rhizobium* nodulation and on nitrogen fixation of several forage legumes. Canadian Journal of Microbiology, 33 (Suppl 6): 510-514.
67. Son TTN, Diep CN, Giang TTM, 2006. Effect of *Bradyrhizobia* and Phosphate solubilizing bacteria application on soybean in rotational system in the Mekong delta. Omonrice, 14: 48-57.
68. Zhang F, Dashti N, Hynes RK, Smith DL, 1996. Plant growth promoting rhizobacteria and soybean (*Glycine Max*. (L) Merr) nodulation and nitrogen fixation at suboptimal root zone temperatures. Annals of Botany, 77 (Suppl 5): 453-459.
69. Dashti N, Zhang F, Hynes R, Smith DL, 1998. Plant growth promoting rhizobacteria accelerate nodulation and increase nitrogen fixation activity by field grown soyabean (*Glycine Max* (L) Merr) under short season conditions. Plant and Soil, 200 (Suppl 2): 205-213.
70. García JAL, Probanza A, Ramos B, Flores JJC, Mañero FJG, 2004a. Effects of Plant Growth Promoting Rhizobacteria (PGPRs) on the biological nitrogen fixation, nodulation, and growth of *Lupinus albus* L cv. *Multolupa*. Engineering in Life Sciences, 4 (Suppl 1): 71–77.
71. Vessey JK, 2003. Plant growth promoting rhizobacteria as biofertilizers. Plant and Soil, 255 (Suppl 2): 571–586.
72. Barriuso J, Solano BR, 2008. Ecology, Genetic Diversity and Screening Strategies of Plant Growth Promoting Rhizobacteria (PGPR). Journal of Plant nutrition: 1-17.
73. Saxena AK, Tilak KVBR, 1998. Free-living nitrogen fixers: Its role in crop production. *In* Microbes for Health, Wealth and Sustainable Environment, Malhotra Publ Co, New Delhi. Edited by Verma AK, 25–64.
74. Tchan YT, 1984a. Family II. Azotobacteriaceae. *In* Bergey's Manual of Systematic Bacteriology. Williams and Wilkins, Baltimore, Edited by Krieg NR, Holt JG, 1: 219.
75. Tchan YT, New PT, 1984b. Genus I. *Azotobacter beijerinck*. *In* Bergey's Manual of Systematic Bacteriology, Williams and Wilkins, Baltimore, 220.
76. Dobereiner J, Day JM, 1975. Nitrogen fixation in rhizosphere of grasses. In Nitrogen Fixation by Free-Living Microorganisms. Cambridge: Cambridge University Press, Edited by Stewart WDP, 39–56.
77. Tilak KVBR, Saxena AK, 2001. *Azospirillum* – Its impact on crop production. *In* Recent Advances in Biofertilizer Technology. Society for Promotion & Utilization of Resources and Technology, New Delhi. Edited by Yadav AK, Motsara MR, Ray Chauduri S, 176–189.
78. Saxena AK, Tilak KVBR, 1999. Potentials and prospects of *Rhizobium* biofertilizer. *In* Current Trends in Life Sciences, Agromicrobes, Today & Tomorrow Printers & Publishers, New Delhi, Edited by Jha MN, 51–78.
79. Biswas BC, Tewatia RC, Prasad N, Das S. Biofertilizers in Indian Agriculture, Fertilizer Association of India, New Delhi, India, 1–43.

80. Saikia N, Brezbaruah B, 1995. Iron-dependent plant pathogen inhibition through *Azotobacter* RRLJ 203 isolated from iron-rich acid soils. Indian Journal of Experimental Biology, 33: 571–575.
81. Shaukat K, Affrasayab S, Hasnain S, 2006. Growth responses of *Helianthus annus* to plant growth promoting rhizobacteria used as a biofertilizer. Journal of Agricultural Research, 1 (Suppl 6): 573-581.
82. Gholami A, Shahsavani S, Nezarat S, 2009. The effect of Plant Growth Promoting Rhizobacteria (PGPR) on germination, seedling growth and yield of maize. International Journal of Biological Life Sciences, 1 (Suppl 1): 35-40.
83. Kloepper JW, Beauchamp CJ, 1992. A review of issues related to measuring of plant roots by bacteria. Canadian Journal of Microbiology, 38: 1219–1232.
84. Steenhoudt O, Vanderleyden J, 2000. *Azospirillum*, a free-living nitrogen-fixing bacterium closely associated with grasses: genetic, biochemical and ecological aspects. FEMS Microbiology Reviews, 24 (Suppl 4): 487–506.
85. Tarrand JJ, Krieg NR, Döbereiner J, 1978. A taxonomic study of the *Spirillum lipoferum* group with description of a new genus, *Azospirillum* gen. nov. and two species, *Azospirillum lipoferum* (Beijerinck) comb. nov. And *Azospirillum brasilense* nov. Canadian Journal of Microbiology, 24 (Suppl 8): 967-980.
86. Magalhães FM, Baldani JI, Souto SM, Kuykendall Jr Döbereiner JA, 1983. New acid-tolerant *Azospirillum* species. Anais da Academia Brasileira de Ciências. 55 (Suppl 4): 417-430.
87. Reinhold B, Hurek T, Fendrik I, Pot B, Gillis M, Kersters K, Thielemans S, de Ley J, 1987. *Azospirillum halopraeferens* sp. nov., a nitrogen-fixing organism associated with roots of kallar grass (*Leptochloa fusca* (L) Kunth). International Journal of Systematic Bacteriology, 37: 43-51.
88. Khammas KM, Ageron E, Grimont PA, Kaiser P, 1989. *Azospirillum irakense* sp. nov., a nitrogen-fixing bacterium associated with rice roots and rhizosphere soiL Research in Microbiology, 140 (Suppl 9): 679-693.
89. Dekhil SB, Cahill M, Stackebrandt E, Li S, 1997. Transfer of *Conglomeromonas largomobilis* subsp. *largomobilis* to the genus *Azospirillum* as *Azopirillum largomobile* comb. nov., and elevation of *Conglomeromonas largomobilis* subsp. *parooensis* to the new type species of *Conglomeromonas, Conglomeromonas parooensis* sp. nov. Systematic and Applied Microbiology, 20: 72-77.
90. Eckert B, Weber OB, Kirchof G, Halbritter A, Stoffels M, Hartmann A, 2001. *Azospirillum doebereinerae* sp. nov., a nitrogen-fixing bacterium associated with the C4-grass *Miscanthus*. International Journal of Systematic Evolutionary Microbiology, 51 (Suppl 1): 17-26.
91. Xie CH, Yokota A, 2005. *Azospirillum oryzae* sp. nov., a nitrogen-fixing bacterium isolated from the roots of the rice plant *Oryza sativa*. International Journal of Systematic and Evolutionary Microbiology, 55 (Suppl 4): 1435-1438.
92. Peng G, Wang H, Zhang G, Hou W, Liu Y, Wang ET, Tan Z, 2006. *Azospirillum melinis* sp. nov., a group of diazotrophs isolated from tropical molasses grass. International Journal of Systematic and Evolutionary Microbiology, 56 (Suppl 6): 1263-1271.
93. Mehnaz S, Weselowski B, Lazarovits G, 2007. *Azospirillum canadense* sp. nov., a nitrogen-fixing bacterium isolated from corn rhizosphere. International Journal of Systematic and Evolutionary Microbiology, 57: 620-624.
94. Bashan Y, Holguin G, 1997. *Azospirillum*–plant relations: environmental and physiological advances (1990–1996). Canadian Journal of Microbiology, 43: 103–121.
95. Bashan Y, Holguin G, de-Bashan LE, 2004. *Azospirillum*-plant relationships: physiological, molecular, agricultural, and environmental advances (1997-2003). Canadian Journal of Microbiololagy, 50 (Suppl 8): 521-577.
96. Sen J, 1929. The role of associated nitrogen-fixing bacteria on nitrogen nutrition of cereal crops. Agricultural Journal of India, 24: 967– 980.
97. Okon Y, 1985. *Azospirillum* as a potential inoculant for agriculture. Trends in Biotechnology, 3 (Suppl 9): 223–228.
98. Tilak KVBR, Subba Rao NS, 1987. Association of *Azospirillum brasilense* with pearlmillet (*Pennisetum americanum* (L) Leeke). Biology and Fertility of Soils, 4 (Suppl 1-2): 97–102.
99. Dewan GI, Subba Rao NS, 1979. Seed inoculation with *Azospirillum brasilense* and *Azotobacter chroococcum* and the root biomass of rice (*Oryza sativa* L). Plant and Soil, 53 (Suppl 3): 295– 302.
100. Okon Y, Kapulnik Y, 1986. Development and function of *Azospirillum* inoculated roots. Plant and Soil, 90 (Suppl 1-3): 3–16.
101. Fallik E, Sarig S, Okon Y, 1994. Morphology and physiology of plant roots associated with *Azospirillum*. *In Azospirillum*–Plant Associations, CRC Press, Boca Raton. Edited by Okon Y, 77–84.
102. Gangwar M, Kaur G, 2009. Isolation and characterization of endophytic bacteria from endorhizosphere of sugarcane and ryegrass. The Internet Journal of Microbiology, 7 (Suppl 1).
103. Gillis M, Kersters K, Hoste B, Janssens D, Kroppenstedt RM, Stephan MP, Teixeira KRS, Dobereiner J, De Ley J, 1989. *Acetobacter diazotrophicus* sp. nov., a nitrogen fixing acetic acid bacterium associated with sugarcane. International Journal of Systematic Bacteriology, 39: 361–364.
104. Muthukumarasamy R, Revathi G, Vadivelu M, 2000. *Acetobacter diazoptrophicus*: prospects and potentialities– An overview. *In* Recent Advances in Biofertilizer Technology, Society for Promotion & Utilization Resources & Technology, New Delhi. Edited by Yadav AK, Motsara MR, Ray Chaudhury S, 126–153.
105. Ashbolt NJ, Inkerman PA, 1990. Acetic acid bacterial biota of the pink sugarcane mealy bug, *Saccharococcus sacchari*, and its environs. Applied and Environmental Microbiology, 56 (Suppl 3): 707–712.

106. Yamada Y, Hoshino K, Ishikawa T, 1997. The phylogeny of acetic acid bacteria based on the partial sequences of 16S ribosomal RNA: The elevation of the subgenus *Gluconoacetobacter* to generic level. Bioscience, Biotechnology, and Biochemistry, 61 (Suppl 8): 1244–1251.
107. Salgado JT, Fuentes-Ramirez LE, Hernandez TA, Mascarua MA, Martinez-Romero E, Caballero-Mellado J, 1997. *Coffea arabica* L a new host plant for *Acetobacter diazotrophicus* and isolation of other nitrogen fixing acetobacteria. Applied and Environmental Microbiology, 63 (Suppl 9): 3676–3683.
108. Cabellaro-Mellado J, Martinez-Romero E, 1994. Limited genetic diversity in the endophytic sugarcane bacterium *Acetobacter diazotrophicus*. Applied and Environmental Microbiology, 60 (Suppl 5): 1532–1537.
109. Suman A, Shasany AK, Singh M, Shahi HN, Gaur A, Khanuja SPS, 2001. Molecular assessment of diversity in endophytic diazotrophs of sub-tropical Indian sugarcane. World Journal of Microbiology and Biotechnology, 17 (Suppl 1): 39–45.
110. Tapia-Hernandez A, Bustillos-Cristales MR, Jimenezsalgado T, Cabellaro-Mellado J, Fuentes-Ramirez LE, 2002. Endophytic *nifH* gene diversity in African Sweet potato. Canadian Journal of Microiology, 44: 162–167.
111. Teixiera KRS, Galler R, Kennedy C, 1994. Plasmid contents and *nif* gene detection in *Acetobacter diazotrophicus* strains. *In* Nitrogen Fixation with Non-legumes. The American University Press. Edited by Hegazi NA, Fayz M, Monib MC, 274–281.
112. Reinhold B, Hurek T, Niemann EG, Fendrik I, 1986. Close association of *Azospirillum* and diazotrophic rods with different root zones of Kallar grass. Applied and Environmental Microbiology, 52 (Suppl 3): 520.
113. Probanza A, Lucas García JA, Ruiz Palomino M, Ramos B, Gutiérrez Mañero FJ, 2002. *Pinus pinea* L seedling growth and bacterial rhizosphere structure after inoculation with PGPR Bacillus (*B. licheniformis* CECT 5106 and *B. pumilus* CECT 5105). Applied Soil Ecology, 20 (Suppl 2): 75–84.
114. Gutiérrez Mañero FJ, Probanza A, Ramos B, Colón Flores JJ, Lucas García JA, 2003. Ecology, Genetic Diversity and Screening Strategies of Plant Growth Promoting Rhizobacteria (PGPR). Journal of Plant Nutrition, 26 (Suppl 5): 1101–1115.
115. Charest MH, Beauchamp CJ, Antoun H, 2005. Effects of the humic substances of de- inking paper sludge on the antagonism between two compost bacteria and *Pythium ultimum*. FEMS Microbiology Ecology, 52(Suppl 2): 219–227.
116. García JAL, Probanza A, Ramos B, Palomino MR, Mañero FJG, 2004. Effect of inoculation of *Bacillus licheniformis* on tomato and pepper. Agronomie for Sustainable Development, 24 (Suppl 4): 169-176.
117. Jaizme-Vega MDC, Rodríguez-Romero AS, Guerra MSP, 2004. Potential use of rhizobacteria from the *Bacillus* genus to stimulate the plant growth of micropropagated bananas. Fruits, 59 (Suppl 2): 83-90.
118. Orhan E, Esitken A, Ercisli S, Turan M, Sahin F, 2006. Effects of plant growth promoting rhizobacteria (PGPR) on yield, growth and nutrient contents in organically growing raspberry. Scientia Horticulturae, 111 (suppl 1): 38-43.
119. Kaymak HC, Yarali F, Guvenc I, Donmez MF, 2008. The effect of inoculation with plant growth Rhizobacteria (PGPR) on root formation of mint (*Mentha piperita* L) Cuttings. African Journal of Biotechnology, 7 (Suppl 24): 4479-4483.
120. Han HS, Supanjani, Lee KD, 2006. Effect of co-inoculation with phosphate and potassium solubilizing bacteria on mineral uptake and growth of pepper and cucumber. Plant soil and Environment, 52 (Suppl 3): 130–136.
121. Supanjani, Han HS, Jung JS, Lee K. D. 2006. Rock phosphate-potassium and rock-solubilising bacteria as alternative, sustainable fertilisers. Agronomy for Sustainable Development, 26 (Suppl 4): 233-240.
122. Hafeez FY, Yasmin S, Ariani D, Mehboob-ur-Rahman Zafar Y, Malik KA, 2006. Plant growth-promoting bacteria as biofertilizer. Agronomy for Sustainable Development, 26:143-150.
123. Lata, Saxena AK, Tilak KVBR, 2002. Biofertilizers to augment soil fertility and crop production. *In* Soil Fertility and Crop Production Science Publishers, USA. Edited by Krishna KR, 279–312.
124. Lugtenberg BJJ, Dekkers LC, 1999. What makes Pseudomonas bacteria rhizosphere competent? Environmental Microbiology, 1 (Suppl 1): 9–13.
125. Mehnaz S, Weselowski B, Aftab F, Zahid S, Lazarovits G, Iqbal J, 2009. Isolation, characterization, and effect of *fluorescent pseudomonads* on micropropagated sugarcane. Canadian Journal of Microbiology, 55 (Suppl 8): 1007–1011.
126. Johri BN, 2001. Technology development and demonstration of a new bacterial inoculant (GRP3) for improved legume production. Uttar Pradesh Govternment, Project report.
127. Kloepper JW, Schroth MN, 1978. Plant growth promoting rhizobacteria on radishes. *In* Station de pathologie vegetale et phyto-bacteriologie (ed.), Proceedings of the 4th International Conference on Plant Pathogenic Bacteria, vol. II. Gilbert-Clarey, Tours, France, 879-882.
128. Kloepper JW, Reddy MS, Rodríguez-Kabana R, Kenney DS, Kokalis-Burelle N, Martinez-Ochoa N, Vavrina CS, 2004. Application of Rhizobacteria in transplant production and yield enhancement. Acta Horticulturae, 631: 217-229.
129. Kloepper JW, Scrhoth MN, Miller TD, 1980a. Effects of rhizosphere colonization by plant growth promoting Rhizobacteria on potato plant development and yield. Journal of Phytopathology, 70 (Suppl 11): 1078–1082.
130. Suslow TV, 1980. Thesis, University of California.
131. Suslow TV, Kloepper JW, Schroth MN, Burr TJ, 1979. Beneficial bacteria enhance plant growth. California Agriculture Online, 33 (Suppl 11): 15–17.
132. Burr TJ, Schroth MN, Suslow T, 1978. Increased potato yields by treatment of seed pieces with specific strains of *Pseudomonas fluorescens* and *P. putida*. Journal of Phytopathology, 68: 1377–1383.

133. Wachowska U, Okorski A, Głowacka K, 2006. Population structure of microorganisms colonizing the soil environment of winter wheat. Plant, Soil and Environment, 52: 39–44.
134. Suslow TV, Schroth MN, 1982. Role of deleterious rhizobacteria as minor pathogens in reducing crop growth. Journal of Phytopathology, 72 (Suppl 1): 111-115.
135. Schippers B, Bakker AW and Bakker PA, 1987. Interaction of deleterious and beneficial rhizosphere microorganisms and the effect of cropping practices. Annual Review of Phytopathology, 25: 339-358.
136. Zeller SL, Brand H, Schmid B, 2007. Host-Plant Selectivity of Rhizobacteria in a Crop/Weed Model System. Plos One, 2 (Suppl 9): 846.
137. Schippers B, Bakker A, Bakker P, van Peer R, 1990. Beneficial and deleterious effects of HCN-producing pseudomonads on rhizosphere interactions. Plant and Soil, 129 (Suppl 1): 75-83.
138. Heydari S, Moghadam PR, Arab SM, 2008. Hydrogen Cyanide Production Ability by *Pseudomonas Fluorescence* Bacteria and their Inhibition Potential on Weed. *In* Proceedings "Competition for Resources in a Changing World: New Drive for Rural Development": 7- 9 October 2008, Tropentag, Hohenheim.
139. Ahmad F, Ahmad I, Khan MS, 2008. Screening of free-living rhizospheric bacteria for their multiple plant growth promoting activities. Microbial Research, 163 (Suppl 2): 173-81.
140. Castric PA, 1977. Glycine Metabolism by *Pseudomonas aeruginosa*: Hydrogen Cyanide Biosynthesis. The Journal of Bacteriology, 130 (Suppl 2): 826-831.
141. Owen A, Zdor R, 2001. Effect of cyanogenic rhizobacteria on the growth of velvetleaf (*Abutilon theophrasti*) and corn (*Zea mays*) in autoclaved soil and the influence of supplemental glycine. Soil Microbiology and Biochemistry, 33 (Suppl 6): 801-809.
142. Funnell-Harris DL, Jeffrey F, Pedersen JF, Marx DB, 2008. Effect of sorghum seedlings, and previous crop, on soil *fluorescent Pseudomonas* spp. Plant and soil, 311 (Suppl 1-2): 173-187.
143. Wani PA, Khan MS, Zaidi A, 2007. Co-inoculation of nitrogen-fixing and phosphate-solubilizing bacteria to promote growth, yield and nutrient uptake in chickpea. Acta Agronomica Hungarica, 55 (Suppl 3): 315-323.
144. Chandra S, Choure K, Dubey RC, Maheshwari DK, 2007. Rhizosphere competent *Mesorhizobium loti* MP6 induces root hair curling, inhibits *Sclerotinia sclerotiorum* and enhances growth of Indian mustard (*Brassica campestris*). Brazilian Journal of Microbiology, 38 (Suppl 1): 124-130.
145. Munees A, Mohammad SK, 2009. Effects of Quizalafop-p-Ethyl and Clodinafop on Plant Growth Promoting activities of Rhizobacteria from Mustard Rhizosphere. Annals of Plant Protection Sciences, 17 (Suppl 1): 175-180.
146. Ryall B, Mitchell H, Mossialos D, Williams HD, 2009. Cyanogenesis by the entomopathogenic bacterium *Pseudomonas entomophila*. Letters in Applied Microbiology, 49 (Suppl 1): 131-135.
147. Selvakumar G, Joshi P, Nazim S, Mishra PK, Bisht JK, Gupta HS, 2009. Phosphate solubilization and growth promotion by *Pseudomonas fragi* CS11RH1 (MTCC 8984), a psychrotolerant bacterium isolated from a high altitude Himalayan rhizosphere. Biologia, 64 (Suppl 2): 239-245.
148. Ryu R, Patten CL, 2008a. Aromatic amino acid-dependent expression of indole-3-pyruvate decarboxylase is regulated by 4 TyrR in Enterobacter cloacae UW5. American Society for Microbiology, 190 (Suppl 21): 1-35.
149. Spaepen S, Vanderleyden J, Remans R, 2007. Indole-3-acetic acid in microbial and microorganism-plant signalling. FEMS Microbiology Reviews, 31 (Suppl 4): 425-448.
150. Barazani OZ, Friedman J, 1999. Is IAA the major root growth factor secreted from plant-growth-mediating bacteria? Journal of Chemical Ecology, 25 (Suppl 10): 2397- 2406.
151. Khalid A, Arshad M, Zahir ZA, 2004. Screening plant growth-promoting rhizobacteria for improving growth and yield of wheat. Journal of Applied Microbiology, 96 (Suppl 3): 473-480(8).
152. Arshad M, Frankenberger WT, 1991. Microbial production of plant hormones. Plant and Soil, 133 (Suppl 1): 1-8.
153. Sarwar M, Frankenberger WT, 1994. Influence of L-tryptophan and auxins applied to the rhizosphere on the vegetative growth of Zea mays L. Plant and Soil, 160 (Suppl 1): 97-104.
154. Ahmad F, Ahmad I, Khan MS, 2005. Indole Acetic Acid Production by the Indigenous Isolates of *Azotobacter* and *Fluorescent Pseudomonas* in the Presence and absence of Tryptophan. Turkish Journal of Biology, 29: 29-34.
155. Tsavkelova EA, Cherdyntseva TA, Klimova SY, Shestakov AI, Botina SG, Netrusov AI, 2007. Orchid-associated bacteria produce indole-3-acetic acid, promote seed germination, and increase their microbial yield in response to exogenous auxin. Archives of Microbiology, 188 (Suppl 6): 655-664.
156. Giongo A, Beneduzi A, Ambrosini A, Vargas LK, Stroschein MR, Eltz F L, Zanettini MHB, Passaglia LMP, 2007. Plant growth promoting bacteria isolated from the rhizoplane of *Lupinus al.bescens* H. et Arn. XXXI Congresso Brasileiro De Ciencia Do Solo.
157. Narula N, Deubel A, Gans W, Behl RK, Merbach W, 2006. Paranodules and colonization of wheat roots by phytohormone producing bacteria in soiL Plant Soil and Environment, 52 (Suppl 3): 119–129.

158. Mandal SM, Mondal KC, Dey S, Pati BR, 2007. Optimization of Cultural and Nutritional conditions for Indol-3-Acetic acid (IAA) production by a *Rhizobium* sp. isolated from rot nodules of *Vigna mungo* (L) hepper. Research Journal of Microbiology, 2 (Suppl 3): 239-246.
159. Basu PS, Ghosh AC, 2001. Production of Indole Acetic Acid in cultures by a *Rhizobium* species from the root nodules of a mono cotyledonous tree, *Roystonea regia*. Acta Biotechnologica, 21(Suppl 1): 65-72.
160. Ghosh AC, Basu PS, 2002. Growth behaviour and bioproduction of indole acetic acid by *a Rhizobium* species isolated from root nodules of a leguminous tree *Dal.bergia lanceolarea*. Indian Journal of Experimental Biology, 40: 796-801.
161. Roy M, Basu PS, 2004. Studies on root nodules of leguminous plants bioproduction of indole acetic acid by a *Rhizobium* sp. from a twiner *Clitorea ternatea* L Acta Biotechnologica, 12 (Suppl 6): 453-460.
162. Sridevi M, Mallaiah KV, 2007. Bioproduction of indole acetic acid by *Rhizobium* strains isolated from root nodules of green manure crop, *Sesbania sesban* (L) *Merr*. Iranian Journal of Biotechnology, 5 (Suppl 3): 178-182.
163. Etesami H, Alikhani HA, Jadidi M, Aliakbari A, 2009. Effect of superior IAA producing *rhizobia* on N, P, K uptake by Wheat grown under greenhouse condition. World Journal of Applied Sciences, 6 (Suppl 12): 1629-1633.
164. Sridevi M, Yadav NCS, Mallaiah KV, 2008. Production of Indol-acetic acid by *Rhizobium* isolates from *Crotalaria* Species. Research Journal of Microbiology, 3 (Suppl 4): 276- 281.
165. Egamberdieva D, 2008. Plant Growth Promoting properties of rhizobacteria isolated from Wheat and Pea grown in loamy sand soil. Turkish Journal of Biology, 32: 9-15.
166. Choi O, Kim J, Kim J, Jeong Y, Moon JS, Park CS, Hwang I, 2008. Pyrroloquinoline Quinone is a plant growth promotion factor produced by *Pseudomonas fluorescens* B16. Plant Physiology, 146: 657-668.
167. Khakipour N, Khavazi K, Mojallali H, Pazira E, Asadirahmani H, 2008. Production of Auxin hormone by *Fluorescent Pseudomonads*. American-Eurasian Journal of Agricultural & Environmental Sciences, 4 (Suppl 6): 687-692.
168. Costacurta A, Keijers V, Vanderleyden J, 1994. Molecular cloning and sequence analysis of an *Azospirillum brasilense* indole-3-acetic pyruvate decarboxylase gene. Molecular and General Genetics, 243 (Suppl 4): 463-472.
169. Martínez-Morales LJ, Soto-Urzúa L, Baca BE, Sánchez-Ahédo JA, 2003. Indole-3-butyric acid (IBA) production in culture medium by wild strain *Azospirillum brasilense*. FEMS Microbiology Letters, 228 (Suppl 2): 167-173.
170. Horemans S, de Koninck K, Neuray J, Hermans R, Valassak K, 1986. Production of plant growth substances by *Azospirillum* sp. and other rhizosphere bacteria. Symbiosis, 2: 341-346.
171. Cacciari I, Lippi D, Ippoliti S, Pietrosanti W, Pietrosanti W, 1989. Response to oxygen of diazotrophic *Azospirillum brasiliense-Arthobacter giacomelloi* mixed batch culture. Archives of Microbiology, 152: 111-114.
172. Bottini R, Fulchieri M, Pearce D, and Pharis RP, 1989. Identification of gibberellins A1, A3 and iso-A3 in culture of *Azospirillum lipoferum*. Plant Physiology, 90 (Suppl 1):45-47.
173. Barassi CA, Sueldo RJ, Creus CM, Carrozzi LE, Casanovas EM, Pereyra MA, 2007. *Azospirillum* spp., a dynamic soil bacterium favourable to vegetable crop production. Dynamic Soil, Dynamic Plant, 1 (suppl 2): 68-82.
174. Malhotra M, Srivastava S, 2008. Stress-responsive indole-3-acetic acid biosynthesis by *Azospirillum brasilense* SM and its ability to modulate plant growth. European Journal of Soil Biology, 45 (Suppl 1): 73-80.
175. Souchie EL, Azcón R, Barea JM, Saggin-Júnior OJ, da Silva EMR, 2007. Indolacetic acid production by P-solubilizing microorganisms and interaction with *arbuscular mycorrhizal* fungi. Acta Scientiarum - Biological Sciences, 29 (Suppl 3): 315-320.
176. Chakraborty U, Chakraborty B, Basnet M, 2006. Plant growth promotion and induction of resistance in *Camellia sinensis* by *Bacillus megaterium.* Journal of Basic Microbiology, 46 (Suppl 3): 186 – 195.
177. Ortíz-Castro R, Valencia-Cantero E, López-Bucio J, 2008. Plant growth promotion by *Bacillus megaterium* involves cytokinin signalling. Plant Signaling & Behavior, 3 (Suppl 4): 263-265.
178. Idris SE, Iglesias DJ, Talon M, Borriss R, 2007. Tryptophan-dependent production of Indole-3-Acetic Acid (IAA) affects level of plant growth promotion by *Bacillus amyloliquefaciens* FZB42. Molecular Plant-Microbe Interactions, 20 (Suppl 6): 619–626.
179. Tien TM, Gaskin MH, Hubbell DH, 1979. Plant growth substances produced by *Azospirillum brasilense* and their effect on the growth of pearl millet (*Pennisetum americanum* L). Applied and Environmental Microbiology, 37 (Suppl 5): 1016-1024.
180. Karnwal A, 2009. Production of indol acetic acid by *Fluorescent Pseudomonas* in the prescence of L-Tryptophan and Rice root exudates. Journal of Plant Pathology, 91 (Suppl 1): 61-63.
181. Farzana Y, Radizah O, 2005. Influence of rhizobacterial inoculation on growth of the sweet potato cultivar. On Line Journal of Biological Science, 1 (Suppl 3): 176-179.
182. Teixeira DA, Alfenas AC, Mafia RG, Ferreira EM, Siqueira LD, Luiz A, Maffia LA, Mounteer AH, 2007. Rhizobacterial promotion of eucalypt rooting and growth. Brazilian Journal of Microbiology, 38 (Suppl 1): 118-123.
183. Kidoglu F, Gül A, Ozaktan H, Tüzel Y, 2007. Effect of rhizobacteria on plant growth of different vegetables. ISHS Acta Horticulturae 801: International. Symposium on High Technology for Greenhouse System Management: Greensys 2007.

184. Cassa´na F, Perriga D, Sgroya V, Masciarellia O, Pennab C, Lunaa V, 2009. *Azospirillum brasilense* Az39 and *Bradyrhizobium japonicum* E 109, inoculated singly or in combination, promote seed germination and early seedling growth in corn (*Zea mays* L) and soybean (*Glycine max* L). European Journal of Soil Biology, 45: 28–35.
185. Pandey P, Maheshwari DK, 2007. Two-species microbial consortium for growth promotion of *Cajanus cajan.* Current Science, 92 (Suppl 8): 25.
186. Loper JE, Henkels MD, 1997. Availability of iron to *Pseudomonas fluorescens* in rhizosphere and bulk soil evaluated with an ice nucleation reporter gene. Applied and Environmental Microbiology, 63 (Suppl 1): 99-105.
187. Whipps JM, 2001. Microbial interactions and biocontrol in the rhizosphere. Journal of Experimental Botany, 52 (Suppl 1): 487-511.
188. Neilands JB, 1952. A Crystalline Organo-iron pigment from a Rust Fungus (*Ustilago sphaerogena*). Journal of the American Chemical Society, 74 (Suppl 19): 4846–4847.
189. Neilands JB, 1995. Siderophores: Structure and Function of Microbial Iron Transport Compounds. The Journal of Biological Chemistry, 270 (Suppl 45): 26723–26726.
190. Miller, Marvin J, 2008. Siderophores (microbial iron chelators) and siderophore-drug conjugates (new methods for microbially selective drug delivery). University of Notre Dame. Dame, 4/21/2008. http://www.nd.edu/~mmiller1/page2.html
191. Miethke M, Marahiel M, 2007. Siderophore-based iron acquistion and pathogen control. Microbiology and Molecular Biology Reviews, 71(Suppl 3): 413–451.
192. Challis GL, 2005. A widely distributed bacterial pathway for siderophore biosynthesis independent of non ribosomal peptide synthetases. ChemBioChem, 6 (Suppl 4): 601–611.
193. Raymond KN, Dertz EA, Kim SS, 2003. Enterobactin: An archetype for microbial iron transport. Proceedings of the National Academy of Sciences, 100 (Suppl 7): 3584–3588.
194. Tian F, Ding Y, Zhu H, Yao L, Du B, 2009. Genetic diversity of siderophore-producing bacteria of tobacco rhizosphere. Brazilian Journal of Microbiology, 40 (Suppl 2): 276-284.
195. Duffy BK, Défago G 1999. Environmental factors modulating antibiotic and siderophore biosynthesis by *Pseudomonas fluorescens* biocontrol strains. Applied and Environmental Microbiology, 65 (Suppl 6): 2429-2438.
196. Sayyed RZ, Badguzar MD, Sonawane HM, Mhaske MM, Chincholkar SB, 2005. Production of microbial iron chelators (siderophores) by *fluorescent Pseudomonads*. Indian Journal of Biotechnology, 4: 484-490.
197. Cattelan AJ, Hartel PG, Fuhrmann JJ, 1999. Screening for Plant Growth–Promoting Rhizobacteria to Promote Early Soybean Growth. Soil Science Society of America Journal, 63 (Suppl 6): 1670–1680.
198. Xie X, Wang J, Yuan H, 2006. High-resolution analysis of catechol-type siderophores using polyamide thin layer chromatography. Journal of Microbiological Methods, 67 (Suppl 2): 390-393.
199. Sarode PD, Rane MP, Chaudhari BL, Chincholkar SB, 2007. Screening for siderophore producing PGPR from black cotton soils of North Maharashtra. Current Trends in Biotechnology and Pharmacy, 1 (Suppl 1): 96-105.
200. Sridevi M, Mallaiah KV, 2008. Production of Hydroxamate-type of Siderophore by *Rhizobium* strains from *Sesbania sesban* (L). International Journal of Soil Science, 3 (Suppl 1): 28-34.
201. Joshi FR, Desai DK, Archana G, Desai AJ, 2009. Enhanced survival and nodule occupancy of Pigeon pea nodulating *Rhizobium* sp. ST1 expressing *fegA* gene of *Bradyrhizobium japonicum* 61A152. On Line Journal of Biological Sciences, 9 (Suppl 2): 40-51.
202. Jurkevitch E, Hadar Y, Chen Y, 1992. Differential siderophore utilization and iron uptake by soil and rhizosphere bacteria. Applied and Environmental Microbiology, 58 (Suppl 1): 119-124.
203. Prashant DS, Makarand RR, Bhushan LC, Sudhir BC, 2009. Siderophoregenic *Acinetobacter calcoaceticus* isolated from wheat rhizosphere with strong PGPR activity. Malaysian Journal of Microbiology, 5 (Suppl1): 6-12.
204. Suttiviriya P, Vajrodaya S, Thamchaipenet A, 2008. Production of plant growth promoting agents from endophytic Actinomycetes. 34th Congress on Science and Technology of Thailand: 1-5
205. Loper JE, Henkels MD, 1999. Utilization of Heterologous siderophores enhances levels of Iron available to *Pseudomonas putida* in the rhizosphere. Applied and Environmental Microbiology, 65 (Suppl 12): 5357–5363.
206. Castignetti D, Smarelli J, 1986. Siderophores, the iron nutrition of plants, and nitrate reductase. FEBS Letters, 209: 147-151.
207. Lodewyckx C, Vangronsveld J, Porteous F, Moore ERB, Taghavi S, Mezgeay M, van der Lelie D, 2002. Endophytic bacteria and their potential applications. Critical Reviews in Plant Sciences, 21 (Suppl 6): 583-606.
208. Raaijmakers JM, Vandersluis I, Koster M, Bakker PAHM, Weisbeek PJ, Schippers B, 1995. Utilization of heterologous siderophores and rhizosphere competence of *fluorescent Pseudomonas* spp. Canadian Journal of Microbiology, 41: 126-135.
209. Wang Y, Brown HN, Crowley DE, Szaniszlo PJ, 1993. Evidence for direct utilization of a siderophore, ferrioxamine B in axenically grown cucumber. Plant Cell and Environment, 16 (Suppl 5): 579-585.
210. Husen E, 2003. Screening of soil bacteria for plant growth promotion activities *in vitro*. Indonesian Journal of Agricultural Sciences, 4 (Suppl 1): 27-31.
211. Gangwar M, Kaur G, 2009. Isolation and characterization of endophytic bacteria from endorhizosphere of sugarcane and ryegrass. The Internet Journal of Microbiology, 7 (Suppl 1).

212. Kloepper JW, Leong J, Teintze M, Schroth MN, 1980. Enhanced plant growth by siderophores produced by plant growth-promoting rhizobacteria. Nature, 286: 885 – 886
213. Kloepper JW, 1979. Thesis. University of California.
214. Munees A, Mohammad SK, 2009. Effects of Quizalafop-p-Ethyl and Clodinafop on Plant Growth Promoting Activities of Rhizobacteria from Mustard Rhizosphere. Annals of Plant Protection Sciences, 17 (Suppl 1): 175-180.
215. Rodriguez H, Fraga R, Gonzalez T, Bashan Y, 2006. Genetics of phosphate solubilization and its potential applications for improving plant growth-promoting bacteria. Plant and soil, 287 (Suppl 1-2): 15-21.
216. Chen YP, Rekha PD, Arun AB, Shen FT, Lai WA, Young CC, 2006. Phosphate solubilizing bacteria from subtropical soil and their tricalcium phosphate solubilizing abilities. Applied Soil Ecology, 34 (Suppl 1): 33-41.
217. Igual JM, Valverde A, Cervantes E, Velazquez E, 2001. Phosphate-solubilizing bacteria as inoculants for agriculture: use of updated molecular techniques in their study. Agronomie, 21 (Suppl 6-7): 561-568.
218. Zaidi, Khan MS, Ahemad M, Oves M, 2009. Plant growth promotion by phosphate solubilizing bacteria. Acta Microbiologica et Immunologica Hungarica, 56 (Suppl 3): 263-284.
219. Rivas R, Peix A, Mateos PF, Trujillo ME, Martinez-Molina E, Velazqueze E, 2006. Biodiversity of populations of phosphate solubilizing rhizobia that nodulates chickpea in different spanish soils. Plant and soil, 287 (Suppl 1-2): 23-33.
220. Gyaneshwar P, Kumar GN, Parekh LJ, Poole PS, 2002. Role of soil microorganisms in improving P nutrition of plants. Plant and Soil, 245 (Suppl 1): 83-93.
221. Garbeva P, van Veen JA, van Elsas JD, 2003. Predominant *Bacillus* spp. in agricultural soil under different management regimes detected via PCR-DGGE. Microbial Ecology, 45 (Suppl 3): 302–316.
222. Timmusk S, Nicander B, Granhall U, Tillberg E, 1999. Cytokinin production by *Paenibacillus polymyxa*. Soil Biology and Biochemistry, 31 (Suppl 13): 1847–1852.
223. Kokalis-Burelle N, Vavrina CS, Roskopf EN, Shelby RA, 2002. Plant bacteria interactions-strategies and techniques to promote plant growth. Plant and Soil, 238: 257–266.
224. Goldstein AH, Rogers RD, 1999. Biomediated continuous release phosphate fertilizer. US Patent 5912398.
225. Tilak KVBR, Ranganayaki N, Pal KK, De R, Saxena AK, Nautiyal CS, Mittal S, Tripathi AK, Johri BN, 2005. Diversity of plant growth and soil health supporting bacteria. Current Science, 89 (Suppl 1): 136-150.
226. Ramachandran K, Srinivasan V, Hamza S, Anandaraj M, 2007. Phosphate solubilizing bacteria isolated from the rhizosphere soil and its growth promotion on black pepper (*Piper nigrum* L) cuttings. Developments in Plant and Soil Sciences, 102: 324-331.
227. Bodker L, Kjoller R, Rosendahl S, 1998. Effect of phosphate and Arbuscular mycorrizhal fungus *Glomus intraradices* on disease severity of root rot of peas (*Pisum Sativum*) caused by *Aphanomyces euteiches*. Mycorrhiza, 8: 169-174.
228. Yazdani M, Bahmanyar MA, Pirdashti H, Esmaili MA, 2009. Effect of Phosphate Solubilization Microorganisms (PSM) and Plant Growth Promoting Rhizobacteria (PGPR) on yield and yield components of Corn (*Zea mays L).* World Academy of Science, Engineering and Technology, 49: 90-92.
229. Attia M, Ahmed MA, El-Sonbaty MR, 2009. Use of biotechnologies to increase growth, productivity and fruit quality of Maghrabi Banana under different rates of phosphorous. World Journal of Agricultural Sciences, 5 (Suppl 2): 211-220.
230. Siddiqui Z, 2006. PGPR: Prospective Biocontrol Agents of Plant Pathogens. PGPR: Biocontrol and Biofertilization, 111-142.
231. Shoebitz M, Ribaudo CM, Pardo MA, Cantore ML, Ciampi L, Curá J A, 2007. Plant growth promoting properties of a strain of *Enterobacter ludwigii* isolated from *Lolium perenne* rhizosphere. Biochemical Journal, 41 (Suppl 9): 1768-1774.
232. Kremer RJ, Kennedy AC, 1996. Rhizobacteria as biocontrol agents of weeds. Weed Technology, 10 (Suppl 3): 601-609.
233. Weller DM, 2007. *Pseudomonas* Biocontrol agents of soilborne pathogens: Looking back over 30 years. 97 (Suppl 2): 253.
234. Weller DM, 1988. Biological control of soil borne plant pathogens in the rhizosphere with bacteria. Annual Review of Phytopathology, 26: 379-407.
235. Weller DM, Raaijmakers JM, McSpadden Gardener BB, Thomashow LS, 2002. Microbial populations responsible for specific soil suppressiveness to plant pathogens. Annual Review of Phytopathology, 40: 309-348.
236. Banasco P, Fuente LDeLa, Gaultieri G, Noya F, Arias, A, 1998. *Fluorescent Pseudomonas* spp. as biocontrol agents against forage legume root pathogenic fungi. Soil Biology and Biochemistry, 10 (Suppl 10-11): 1317–1323.
237. Dileep C, Kumar BSD, Dube HC, 1998. Promotion of plant growth and yield by two rhizoplane *fluorescent Pseudomonas.* Indian Journal of Experimental Biology, 36 (Suppl 4): 399–402.
238. Pierson EA, Weller DM, 1994. Use of mixture of *fluorescent Pseudomonas* to suppress take-all and improve growth of wheat. Journal of Phytopathology, 84 (Suppl 9): 940–947.
239. Yeole RD, Dube HC, 1997. Increased plant growth and yield through seed bacterization. Indian Phytopathology, 50 (Suppl 3): 316–319.
240. Kraus J, Loper J, 1995. Characterization of genomic region required for production of antibiotic pyoluteorin by the biological control agent *Pseudomonas fluorescens* Pf-5. Applied and Environmental Microbiology, 61 (Suppl 3): 849–854.
241. Rodriguez H, Fraga R, 1999. Phosphate solubilizing bacteria and their role in plant growth promotion. Biotechnology Advances, 17 (Suppl 4-5): 319–339.

242. Seong KY, Shin PG, 1996. Effect of siderophore on biological control of plant pathogens and promotion of plant growth by *Pseudomonas fluorescens* ps88. Agricultural Chemistry & Biotechnology, 39: 20–24.
243. Paul D, Dineshkumar N, Nair S, 2006. Proteomics of a plant growth-promoting rhizobacterium, *Pseudomonas fluorescens* MSP-393, subjected to salt shock. World Journal of Microbiology and Biotechnology, 22 (Suppl 4): 369-374.
244. Negi YK, Garg SK, Kumar J, 2005. Cold-tolerant fluorescent *Pseudomonas* isolates from Garhwal Himalayas as potential plant growth promoting and biocontrol agents in pea. Current Sciences, 89 (Suppl 12): 25.
245. Rudrappa T, Splaine RE, Biedrzycki ML, Bais HP, 2008. Cyanogenic Pseudomonads Influence Multitrophic Interactions in the Rhizosphere. Plos One, 3 (Suppl 4): e2073.
246. Kremer RJ, Souissi T, 2001. Cyanide Production by Rhizobacteria and Potential for Suppression of Weed Seedling Growth. Current Microbiology, 43(Suppl3): 182-186.
247. Kremer RJ, Caesar AJ, Souissi T, 2004. Soil borne microorganisms of *Euphorbia* are potential biological control agents of the invasive weed leafy spurge. Applied Soil Ecology, 32 (Suppl 1): 27-37.
248. Aly H, Kamalay J, Walter N, Okubara PA, Taylor CG, 2007. Characterization of the *Pseudomonas* genus of bacteria for plant-parasitic nematode controL ASM Conference.
249. Duffy B, Keel C, Défago G, 2004. Potential role of pathogen signaling in multitrophic plant-microbe interactions involved in disease protection. Applied and Environmental Microbiology, 70 (Suupl 3): 1836-1842.
250. Ramette A, Frapolli M, Défago G, Moënne-Loccoz Y, 2003. Phylogeny of HCN synthase encoding *hcnBC* genes in biocontrol *Fluorescent Pseudomonads* and its relationship with host plant species and HCN synthesis ability. Molecular Plant-Microbe Interactions, 16 (Suppl 6): 525–535.
251. Nagórska K, Bikowski M, Obuchowski M, 2007. Multicellular behaviour and production of a wide variety of toxic substances support usage of *Bacillus subtilis* as a powerful biocontrol agent. Acta Biochimica Polonica, 54 (Suppl 3): 495–508.
252. Seshadri S, Ignacimuthu S, Vadivelu M, Lakshminarasimhan C, 2007. Inorganic phosphate solubilization by two insect pathogenic *Bacillus* sp. Developments in Plant and Soil Sciences, 102: 351-355.
253. Harrier LA, Waston CA, 2004. The Potential role of *Arbuscular mycorrhiza* (AM) fungi in the bioprotection of plants against soil-borne pathogens in organic and/or other sustainable farming systems. Pest Management Science, 60 (Suppl 2): 149-157.
254. Dehne HW, 1982. Interaction between vesicular-arbuscular mycorrhizal fungi and plant pathogens. Journal of Phytopathology, 72 (Suppl 8): 1115-1119.
255. Bakanchikova TI, Lobanok EV, Pavlova-Ivanova LK, Redkina TV, Nagapetyan Z A, Majsuryan AN, 1993. Inhibition of tumor formation process in dicotyledonous plants by *Azospirillum brasilense* strains. Mikrobiologiya, 62 (Suppl 3): 515-523.
256. Sudhakar P, Gangwar SK, Satpathy B, Sahu PK, Ghosh JK, Saratchandra B, 2000. Evaluation of some nitrogen fixing bacteria for control of foliar diseases of mulberry (*Morus al.ba*). Indian Journal of Sericulture, 39 (Suppl 1): 9-11.
257. Bashan Y, de-Bashan LE, 2002a. Reduction of bacterial speck *(Pseudomonas syringae* pv. tomato) of tomato by combined treatments of plant growth-promoting bacterium, *Azospirillum brasilense*, streptomycin sulfate, and chemothermal seed treatment. European Journal of Plant Pathology, 108: 821-829.
258. Bashan Y, de-Bashan LE, 2002b. Protection of tomato seedlings against infection by *Pseudomonas syringae* pv. tomato by using the plant growth-promoting bacterium *Azospirillum brasilense*. Applied and Environmental Microbiology, 68 (Suppl 6): 2637-2643.
259. Holguin G, Bashan Y, 1996. Nitrogen-fixation by *Azospirillum brasilense* Cd is promoted when co-cultured with a mangrove rhizosphere bacterium (*Staphylococcus* sp). Soil Biology and Biochemistry, 28 (Suppl 12): 1651-1660.
260. Oliveira RGB, Drozdowicz A, 1987. Inhibition of bacteriocin producing strains of *Azospirillum lipoferum* by their own bacteriocin. *Zentral.blatt für Mikrobiologie*, 142: 387-391.
261. Tapia-Hernández A, Mascarúa-Esparzá MA, Caballero-Mellado J, 1990. Production of bacteriocins and siderophore-like activity in *Azospirillum brasilense*. Microbios, 64 (Suppl 259):73-83.
262. Shah S, Karkhanis V, Desai A, 1992. Isolation and characterization of siderophore, with antimicrobial activity, from *Azospirillum lipoferum* M. Current Microbiology, 25 (Suppl 6): 347-351.
263. Somers E, Ptacek D, Gysegom P, Srinivasan M, Vanderleyden J, 2005. *Azospirillum brasilense* produces the auxin-like phenylacetic acid by using the key enzyme for indole-3-acetic acid biosynthesis. Applied and Environmental Microbiology, 71 (Suppl 4): 1803-1810.
264. Taechowisan T, Lu C, Shen Y, Lumyong S, 2005. Secondary metabolites from endophytic *Streptomyces aureofaciens* CMUAc130 and their antifungal activity. Microbiology, 151: 1691-1965.
265. Castillo UF, Strobel GA, Ford EJ, Hess WM, Porter H, Jensen JB, Albert H, Robison R, Condron MAM, Teplow DB, Stevens D, Yaver D, 2002. Munumbicins, wide-spectrum antibiotics produced by *Streptomyces* NRRL 30562, endophytic on *Kennedia nigriscans*. Microbiology, 148: 2675-2685.
266. Pullen C, Schmitz P, Meurer K, v. Bamberg DD, Lohmann S, De Castro França S, Groth I, Schlegel B, Möllmann U, Gollmick F, Gräfe U, Leistner E, 2002. New bioactive compounds from *Streptomyces* strains residing in the wood of celastraceae. Planta, 216 (Suppl 1): 162-167.
267. Webber J, 1981. A natural control of Dutch elm disease. Nature, 292: 449-451.

268. Nowak-Thompson B, Gould SJ, Kraus J, Loper JE, 1994. Production of 2, 4-diacetylphloroglucinol by the biocontrol agent Pseudomonas fluorescens Pf-5. Canadian Journal of Microbiology, 40 (Suppl 12): 1064–1066.
269. Toyoda H, Utsumi R, 1991. Method for the prevention of *Fusarium* diseases and microorganisms used for the same. US Patent No. 4, 988, p. 586.
270. Mauch F, Mauch-Mani B, Boller T, 1988. Antifungal hydrolases in pea tissue. II. Inhibition of fungal growth by combinations of chitinase and /3-1,3-glucanase. Plant Physiology, 88 (Suppl 3): 936–942.
271. Voisard C, Keel C, Haas D, Defago G, 1989. Cyanide production by *Pseudomonas fluorescens* helps suppress black root rot of tobacco under gnotobiotic conditions. The EMBO Journal, 8 (Suppl 2): 351–358.
272. Papavizas GC, Ayers WA, 1974. Aphanomyces species and their root diseases in pea and sugarbeet. A Review, US Department of Agriculture, Washington DC.
273. Garagulia AD, Kiprianova EA, Boiko OI, 1974. Antibiotic effect of bacteria from the genus *Pseudomonas* on phytopathogenic fungi. MikrobioL Zh. (Kiev), 36 (Suppl 2): 197–202.
274. Fenton AM, Stephens PM, Crowley J, O'Callaghan M, O'Gara F, 1992. Exploitation of gene(s) involved in 2,4-diacetylphloroglucinol biosynthesis to confer a new biocontrol capability to a *Pseudomonas* strain. Applied and Environmental Microbiology, 58 (Suppl 12): 3873–3878.
275. Shanahan P, O'Sullvan DJ, Simpson P, Glennon JD, O'Gara F, 1992. Isolation and characterization of an antibiotic-like compound from a *fluorescent pseudomonad* and investigation of physiological parameters influencing its production. Applied and Environmental Microbiology, 58 (Suppl 1): 353–358.
276. Kumar NR, Arasu VT, Gunasekaran P, 2002. Genotyping of antifungal compounds producing plant growth-promoting rhizobacteria, *Pseudomonas fluorescens.* Current Science, 82 (Suppl 12): 1465-1466.
277. Dowling DN, O'Gara F, 1994. Metabolites of *Pseudomonas* involved in the biocontrol of plant disease. Trends in Biotechnology, 12 (Suppl 4): 133-141.
278. Andrade G, Azcon R, Bethlenfalvey GJ, 1995. A rhizobacterium modifies plant and soil responses to the mycorrhizal fungus, *Glomus mosseae*. Applied Soil Ecology, 2: 195–202.
279. Gaur R, Shani N, Kawaljeet Johri BN, Rossi P, Aragno M, 2004. Diacetyl phloroglucinol-producing *Pseudomonas* does not influence AM fungi in wheat rhizosphere. Current Science, 86 (Suppl 3): 453–457.
280. Reddy BP, Rao KS, 2009. Biochemical and PCR- RAPD characterization of *Pseudomonas Fluorescent* produced antifungal compounds inhibit the Rice fungal pathogens *in vitro*. Electronic Journal of Environmental Agriculture and Food Chemistry, 8 (Suppl 10): 1062-1067.
281. Pal KK, Tilak KVBR, Saxena AK, Dey R, Singh CS, 2000. Antifungal characteristics of a *fluorescent Pseudomonas* strain involved in the biological control of *Rhizoctonia solani*. Research in Microbiology, 155 (Suppl 3): 233-242.
282. Kapsalis A, Gravanis F, Gowen S, 2008. Involvement of phenazine-1-carboxylic acid, siderophores and hydrogen cyanide in suppression of *Rhizoctonia solani* and *Pythium* spp. damping-off by *Pseudomonas oryzihabitans* and *Xenorhabdus nematophila.* Journal of Food Agriculture and Environment, 6 (Suppl 1): 168 – 171.
283. Rangarajan S, Loganathan P, Saleena LM, Nair S, 2001. Diversity of pseudomonads isolated from three different plant rhizospheres. Journal of Applied Microbiology, 91 (Suppl 4):742–749.
284. Reddy BP, Reddy KRN, Rao SM, Rao KS, 2008. Efficacy of antimicrobial metabolites of *Pseudomonas fluorescens* against rice fungal pathogens. Current Trends in Biotechnology and Pharmacy, 2 (Suppl 1): 178-182.
285. Zadeh HR, Khavazi K, Asgharzadeh A, Hosseinimazinani M, Mot RD, 2008. Biocontrol of *Pseudomonas Savastanoi*, causative agent of Olive Knot disease: antagonistic potential of non-pathogenic rhizosphere isolates of *Fluorescent Pseudomonas*. Communications in Agricultural and Applied Biological Sciences, 73 (Suppl 1): 199-203.
286. Pandey A, Palni LMS, 1998. Isolation of *Pseudomonas corrugate* from Sikkim, Himalaya. World Journal of Microbiology and Biotechnology, 14 (Suppl 3): 411–413.
287. Siddiqui IA, Haas D, Heeb S, 2005. Extracellular protease of *Pseudomonas fluorescens* CHA0, a biocontrol factor with activity against the root-knot nematode *Meloidogyne incognita.* Applied and Environmental Microbiology, 71(Suppl 9): 5646-5649.
288. Ramette A, Moënne-Loccoz Y, Défago G, 2006. Genetic diversity and biocontrol potential of *fluorescent pseudomonads* producing phloroglucinols and hydrogen cyanide from Swiss soils naturally suppressive or conducive to *Thielaviopsis basicola*-mediated black root rot of tobacco. FEMS Microbiology Ecology, 55 (Suppl 3): 369-381.
289. Saraf M, Thakker A, Patel BV, 2008. Biocontrol activity of different species of *Pseudomonas* against phytopathogenic Fungi *In vivo* and *In vitro* conditions. International Journal of Biotechnology & Biochemistry, 4 (Suppl 3&4).
290. Laville J, Blumer C, Schroetter CV, Gaia V, Défago G, Keel C, Haas D, 1998. Characterization of the *hcnABC* gene cluster encoding hydrogen cyanide synthase and anaerobic regulation by ANR in the strictly aerobic biocontrol agent *Pseudomonas fluorescens* CHA0. The Journal of Bacteriology, 180 (Suppl 12): 3187–3196.
291. Paul D, Sarma YR, 2006. Antagonistic effects of metabolites of *Pseudomonas fluorescens* strains on the different growth phases of *Phytophthora capsici*, foot rot pathogen of black pepper (*Piper nigrum* L). Archives of Phytopathology and Plant Protection, 39 (Suppl 2): 113–118.

292. Hassanein WA, Awny NM, El-Mougith AA, Salah El-Dien SH, 2009. The antagonistic activities of some metabolites produced by *Pseudomonas aeruginosa* Sha8. Journal of Applied Sciences Research, 5 (Suppl 4): 404-414.
293. Kim H, Sang MK, Myung I, Chun S, Kim KD, 2009. Characterization of *Bacillus luciferensis* strain KJ2C12 from pepper root, a biocontrol agent of *Phytophthora Blight* of pepper. Journal of Plant Pathology, 25 (Suppl 1): 62-69.
294. Packer A, Bittner RJ, 2009. Light, nutrients, and presence of microbial mutualist affect patterns of allocation to direct and indirect defences in lima bean (*Phaseolus lunatus).* The 94th ESA Annual Meeting: August 2-7, 2009.
295. Jousset A, Rall B, Kalinkat G, Scheu S, Brose U, 2009. Extracellular toxin production by soil bacteria cause a shift from a type III to type IV functional response by microfaunal predators [Oral presentation] The 39th Annual. Meeting of the Ecological. Society of Germany, Austria and Switzerland.
296. E-Batanony NH, Massoud ON, Mazen MM, El-Monium, 2007. The inhibitory effects of cultural filtrates of some wild *Rhizobium* spp. on some Faba bean root rot pathogens and their antimicrobial synergetic effect when combined with *Arbuscular Mycorrhiza* (AM). World Journal of Agricultural Sciences, 3 (Suppl 6): 721-730.
297. Khan MR, Khan SM, Mohiddin FA, 2007. Effect of certain fungal and bacterial phosphate solubilizing microorganisms on the fusarial wilt of tomato. Developments in Plant and Soil Sciences, 102 : 357-361.
298. Akgül DS, Mirik M, 2008. Biocontrol of *Phytophthora Capsici* on Pepper plants by *Bacillus Megnaterium* strains. Journal of Plant Patholology, 90 (Suppl 1): 29-34.
299. Hu C, 2005. Induction of growth promotion and stress tolerance in *Arabidopsis* and tomato by plant growth promoting rhizobacteria. Dissertation. http://hdl.handle.net/10415/769.
300. Han HS, Lee KD, 2005. Plant Growth Promoting Rhizobacteria effect on antioxidant status, photosynthesis, mineral uptake and growth of Lettuce under soil salinity. Research Journal of Agriculture and Biological Sciences, 1 (Suppl 3): 210-215.
301. Tripathi AK, Nagarajan T, Verma SC, Le Rudulier D, 2002. Inhibition of biosynthesis and activity of nitrogenase in *Azospirillum brasilense* Sp7 under salinity stress. Current Microbiology, 44 (Suppl 5): 363–367.
302. Tripathi AK, Mishra BM, Tripathi P, 1998. Salinity stress responses in plant growth promoting rhizobacteria. Journal of Biosciences, 23 (Suppl 4): 463–471.
303. Saleena LM, Rangarajan S, Nair S, 2002. Diversity of *Azospirillum* strains isolated from rice plants grown in saline and non saline coastal agricultural ecosystems. Microbial Ecology, 44 (Suppl 3): 271–277.
304. Belimov AA, Safronova VI, Sergeyeva TA, Egorova TN, Matveyeva VA, Tsyganov VE, Borisov AY, Tikhonovich IA, Kluge C, Preisfeld A, Dietz K, Stepanok VV, 2001. Characterization of plant growth promoting rhizobacteria isolated from polluted soils and containing 1-aminocyclopropane-1-carboxylate deaminase. Canadian Journal of Microbiology, 47 (Suppl 7): 642–652.
305. Gaind S, Gaur AC, 1991. Thermotolerant phosphate solubilizing microorganisms and their interaction with mungbean. Plant and Soil, 133 (Suppl 1): 141–149.
306. Abd-Ila MH, 1994. Phosphatases and the utilization of organic P by *Rhizobium leguminosarum* biovar *viceae*. Letters in Applied Microbiology, 18 (Suppl 5): 294-296.
307. Castango LN, Estrela MJ, Grassano A, Ruiz OA, 2008. Biochemical and molecular characterization of phosphate solubilizing bacteria and evaluation of its efficiency promoting the growth of *Lotus tenuis.* Lotus Newsletter, 38 (Suppl 2): 53-56.
308. Jeon J, Lee S, Kim H, Ahn T, Song H, 2003. Plant Growth Promotion in Soil by Some Inoculated Microorganisms. Journal of Microbiology, 41 (Suppl 4): 271-276.
309. Rajkumar M, Freitas H, 2008. Influence of metal resistant-plant growth-promoting bacteria on the growth of *Ricinus communis* in soil contaminated with heavy metals. Chemosphere, 71 (Suppl 5): 834–842.
310. Tam PCF, 1995. Heavy metal tolerance by ectomycorrhyzal fungi and metal amelioration by *Pisolithus tinctorium*. Mycorrhiza, 5: 181–187.
311. Belimov AA, Hontzeas N, Safronova VI, Demchinskaya SV, Piluzza G, Bullitta S, Glick BR, 2005. Cadmium-tolerant plant growth-promoting bacteria associated with the roots of Indian mustard (*Brassica juncea* L Czern.). Soil Biology and Biochemesitry, 37 (Suppl 2): 241–250.
312. Denton B, 2007. Advances in phytoremediation of heavy metals using Plant Growth Promoting Bacteria and Fungi. MMG. 445 Basic Biotechnology, 3: 1 – 5.
313. Khan AG, 2005. Role of soil microbes in the rhizospheres of plants growing on trace metal contaminated soils in phytoremediation. Journal of Trace Elements in Medicine and Biology, 18 (Suppl 4): 355–364.
314. Jing Y, He Z, Yang X, 2007. Role of soil Rhizobacteria in phytoremediation of heavy metal contaminated soils. Journal of Zhejiang University-Sctence B, 8 (Suppl 3): 192-207.
315. Pennasio S, Roggero P, 1992. Effect of cadmium and nickel on ethylene biosynthesis in soybean. Plant Biology, 34 (Suppl 3-4): 345–349.
316. Amico ED, Cavalca L, Andreoni V, 2008. Improvement of *Brassica napus* growth under cadmium stress by cadmium-resistant Rhizobacteria. Soil Biology and Biochemistry, 40 (Suppl 1): 74–84.
317. Govindasamy V, Senthilkumar M, Mageshwaran V, Annapurna K, 2009. Detection and characterization of ACC in plant growth promoting Rhizobacteria. Journal of Plant Biochememistry and Biotechnology, 18 (Suppl 1): 71-76.

318. Burd GI, Dixon DG, and Glick BR, 1998. A Plant Growth-Promoting bacterium that decreases nickel toxicity in seedlings. Applied and Environmental Microbiology, 64 (Suppl 10): 3663-3668.
319. Wu SC, Cheung KC, Luo YM, Wong MH, 2006. Effects of inoculation of plant growth-promoting rhizobacteria on metal uptake by *Brassica juncea.* Environmental Pollution, 140 (Suppl 1): 124-135.
320. Chacko S, Ramteke PW, John SA, 2009. Amidase from plant growth promoting rhizobacterium. Journal of Bacteriology and Research, 1 (Suppl 4): 046-050.
321. Schnider-Keel U, Lejbø lle KB, Bachler E, Haas D, Keel C, 2001. The sigma factor Algu (Algt) controls exopolysaccharide production and tolerance towards desiccation and osmotic stress in the biocontrol agent, *Pseudomonas fluorescens* CHAO. Applied and Environmental Microbiology, 67 (Suppl 2): 5683–5693.
322. Dimkpa C, Svatoš A, Merten D, Büchel G, Kothe E, 2008. Hydroxamate siderophores produced by *Streptomyces acidiscabies* E13 bind nickel and promote growth in cowpea (*Vigna unguiculata* L) under nickel stress. Canadian Journal of Microbiology, 54 (Suppl 3): 163–172.
323. Liddycoat SM, Greenberg BM, Wolyn DJ, 2009. The effect of plant growth-promoting rhizobacteria on asparagus seedlings and germinating seeds subjected to water stress under greenhouse conditions. Canadian Journal of Microbiology, 55 (Suppl 4): 388–394.
324. Ehteshami SM R, Aghaalikhani M, Khavazi K, Chaichi MR, 2007. Effect of Phosphate Solubilizing Microorganisms on quantitative and qualitative characteristics of Maize (*Zea mays* L) under water deficit stress. Pakistan Journal of Biological Sciences, 10 (Suppl 20): 3585-3591.
325. Kadouri D, Jurkevitch E, Okon Y, 2003. Involvement of reserve material poly-â-hydroxy butyrate (PHB) in *Azospirillum brasilense* in stress endurance and colonization. Applied and Environmental Microbiology, 69: 3244–3250.
326. Alvarez MI, Sueldo RJ, Barassi CA, 1996. Effect of *Azospirillum* on coleoptiles growth in wheat seedlings under water stress. Cereal Research Communications, 24 (Suppl 1): 101-107.
327. Creus C, Graziano M, Casanovas E, Pereyra M, Simontacchi M, Puntarulo S, Barassi C, Lamattina L, 2005. Nitric oxide is involved in the *Azospirillum brasilense*-induced lateral root formation in tomato. Planta, 221 (Suppl 2): 297-303.
328. Greenberg BM, Huang XD, Gurska Y, Gerhardt KE, Lampi MA, Khalid A, Isherwood D, Chang P, Wang W, Wang H, Dixon DG, Glick BR, 2006. Development and successful field tests of a multi-process phytoremediation system for decontamination of persistent petroleum and organic contaminants in soils. *In:* CLRA 2006: Reclamation and Remediation: Policy and Practice. Canadian Land Reclamation Association (CLRA). Edited by Tisch B, Zimmerman K, White P, Beckett P, Guenther L, Macleod A, Rowsome S, Black C, 124-133.
329. Heil M, Bostock RM, 2002**.** Induced Systemic Resistance (ISR) Against Pathogens in the Context of Induced Plant Defences. Annals of Botany, 89 (Suppl 5): 503-512.
330. Van Loon LC, Bakker PAHM, Pieterse CMJ, 1998. Induction and expression of PGPR-mediated induced resistance against pathogens. Biological control of Fungal Bacterial plant pathogens, 21 (Suppl 9): 103-110.
331. Zehnder GW, Yao C, Wei G, Kloepper JW, 2000. Influence of methyl bromide fumigation on microbe-induced resistance in cucumber. Biocontrol Science and Technology, 10: 687-693.
332. Lee YH, Lee WH, Lee DK, Shim HK, 2001. Factors relating to Induced Systemic Resistance in watermelon by Plant Growth-Promoting *Pseudomonas* spp. Journal of Plant Pathology, 17 (Suppl 3)*:* 174-179.
333. Yan Z, Reddy MS, Ryu C, McInroy JA, Wilson M, Kloepper JW, 2002. Induced Systemic Protection Against Tomato Late Blight Elicited by Plant Growth-Promoting Rhizobacteria. The American Phytopathological Society, 92 (suppl 12)**:** 1329-1333.
334. Msthiyazhagan S, Kavitha K, Nakkeeran S, Chandrasekar G, Manian K, Renukadevi P, Krishnamoorthy AS, Fernando WGD, 2004. PGPR mediated management of Stem blight Of *Phyllanthus Amarus* (Schum and Thonn) caused by *Corynespora Cassiicola* (Berk and Curt) Wei. Archives of Phytopathology and Plant Protection, 37: 183–199.
335. Bakker PAHM, Pieterse CMJ, van Loon LC, 2007. Induced Systemic Resistance by *Fluorescent Pseudomonas* spp. Phytopathology, 97 (Suppl 2): 239-243.
336. Ryu C, Farag MA, Paré PW, Kloepper JW, 2005. Invisible signals from the underground: Bacterial volatiles elicit Plant growth promotion and Induce Systemic Resistance. Journal of Plant Pathology, 21 (Suppl 1): 7-12.
337. Floch GL, Rey P, Benizri E, Benhamou N, Tirilly Y, 2003. Impact of auxin-compounds produced by the antagonistic fungus *Pythium oligandrum* or the minor pathogen *Pythium* group F on plant growth. Plant and Soil, 257 (Suppl 2): 459–470.
338. Cipollone R, Ascenzi P, Tomao P, Imperi F, Visca P, 2008. Enzymatic Detoxification of Cyanide: Clues from *Pseudomonas aeruginosa* Rhodanese. Journal of Molecular Microbiology and Biotechnology, 15 (Suppl 2-3): 199-211.
339. Myers DF, Fry WE, 1978. Enzymatic release and metabolism of Hydrogen Cyanide in Sorghum infected by *Gloeocercospora sorghi*. Journal of Phytopathology, 68: 1717-1722.
340. Svercel M, Duffy B, Défago G, 2007. PCR amplification of hydrogen cyanide biosynthetic locus hcnAB in *Pseudomonas* spp. Journal of Microbiological Methods, 70: 209–213.
341. Blumer C, Heeb S, Pessi G, Haas D, 1999. Global GacA-steered control of cyanide and exoprotease production in *Pseudomonas fluorescens* involves specific ribosome binding sites. Proceedings of the National Academy of Sciences, 96 (Suppl 24): 14073-14078.

342. Blumer C, Haas D, 2000. Iron regulation of the *hcnABC* genes encoding hydrogen cyanide synthase depends on the anaerobic regulator ANR rather than on the global activator GacA in *Pseudomonas fluorescens* CHA0. Microbiology, 146: 2417-2424.
343. Kay E, Dubuis C, Haas D, 2005. Three small RNAs jointly ensure secondary metabolism and biocontrol in *Pseudomonas fluorescens* CHA0. Proceedings of the National Academy of Sciences, 102 (Suppl 47): 17136-17141.
344. Ryu RJ, Patten CL, 2008b. Aromatic Amino Acid-Dependent Expression of Indole-3-Pyruvate Decarboxylase Is Regulated by TyrR in *Enterobacter cloacae* UW5. Journal of Bacteriology, 190 (Suppl 21): 7200–7208.
345. Cornelis P, Matthijs S, 2002. Diversity of siderophore-mediated iron uptake systems in *fluorescent pseudomonads*: not only pyoverdines. Environmental Microbiology, 4 (Suppl 12): 787-798.
346. Ravel J, Cornelis P, 2003. Genomics of pyoverdine-mediated iron uptake in pseudomonads. Trends in Microbiology, 11 (Suppl 5): 195-200.
347. Saleh SS, Glick BR, 2001. Involvement of gacS and rpoS in enhancement of the plant growth promoting capabilities of *Enterobacter cloacae* CAL2 and UW4. Canadian Journal of Microbiology, 47 (Suppl 8): 698-705.
348. Kojic M, Degrassi G, Venturi V, 1999. Cloning and characterization of the *rpoS* gene from the plant growth-promoting *Pseudomonas putida* WCS358: RpoS is not involved in siderophore and homoserine lactone production. Biochimica et Biophysica Acta, 1489 (Suppl 2-3): 413-420.
349. Ovadis M, Liu X, Gavriel S, Ismailov Z, Chet I, Chernin L, 2004. The global regulator genes from biocontrol strain *Serratia plymuthica* IC1270: cloning, sequencing, and functional studies. Journal of Bacteriology, 186 (Suppl 15): 4986-4993.
350. Hynes RK, Leung GCY, Hirkala DLM, Nelson LM, 2008. Isolation, selection, and characterization of beneficial rhizobacteria from pea, lentil, and chickpea grown in western Canada. Canadian Journal of Microbiology, 54 (Suppl 4): 248–258.
351. Arshad, M. Frankenberger, Jr. W.T., 1993. Microbial production of plant growth regulators. Plant and Soil, 133 (Suppl 1): 1-3.
352. Glick BR 1995. The enhancement of plant growth by free living bacteria. Canadian Journal of Microbiology, 41 (Suppl 2): 109–114.
353. Boddey RM, Dobereiner J, 1995. Nitrogen fixation associated with grasses and cereals: recent progress and perspectives for the future. Plant and Soil, 108 (Suppl1): 53-65.
354. Scher FM, Baker R, 1982. Effect of *Pseudomonas putida* and a synthetic iron chelator on induction of soil suppressiveness to *Fusarium* wilt pathogens. Journal of Phytopathology, 72 (Suppl 12): 1567–1573.
355. Flaishman MA, Eyal ZA, Zilberstein A, Voisard C, Hass D, 1996. Suppression of *Septoria tritci* blotch and leaf rust of wheat by recombinant cyanide producing strains of *Pseudomonas putida*. Molecular Plant-Microbe Interactions, 9 (Suppl 7): 642–645.
356. De Freitas JR, Banerjee MR, Germida JJ, 1997. Phosphate solubilizing rhizobacteria enhance the growth and yield but not phosphorus uptake of canola (*Brassica napus* L). Biology and Fertility of Soils, 24 (Suppl 4): 358–364.
357. Gaur AC, 1990. Physiological functions of phosphate solubilizing micro-organisms. Omega Scientific Publishers, New Delhi, 16–72, Edited by Gaur AC.
358. Fuhrmann JJ, Wollum AG, 1989. Nodulation competition among *Bradyrhizobium japonicum* strains as influenced by rhizosphere bacteria and iron availability. Biology and Fertility of Soils, 7 (Suppl 2): 108–112.
359. Bakker AW, Schippers B, 1987. Microbial cyanide production in the rhizosphere in relation to potato yield reduction and *Pseudomonas* sp. mediated plant growth stimulation. Soil Biology and Biochemistry, 19 (Suppl 4): 451–457.
360. Alstrom S, Burns RG, 1989. Cyanide production by rhizobacteria as a possible mechanism of plant growth inhibition. Biology and Fertility of Soils, 7 (Suppl 3): 232–238.
361. Chanway CP, Holl FB, 1993. First year yield performance of spruce seedlings inoculated with plant growth promoting rhizobacteria. Canadian Journal of Microbiology, 39: 1084–1088.
362. Zhender GW, Yao C, Murphy JF, Sikora ER, Kloepper JW, Schuster DJ, Polston JE, 1999. Microbe induced resistance against pathogens and herbivores: evidence of effectiveness in agriculture. In Induced Plant Defenses Against Pathogens and Herbivores: Biochemistry, Ecology and Agriculture. APS Press, St Paul, MN. Edited by Agarwal AA, Tuzun S, Bent, E, 33.
363. Bent E, Tuzun S, Chanway CP, Enebak S, 2001. Alterations in plant growth and in root hormone levels of lodgepole pines inoculated with rhizobacteria. Canadian Journal of Microbiology, 47 (Suppl 9): 793–800.
364. Bowen G D, Rovira AD, 1999. The rhizosphere and its management to improve plant growth. Advances in Agronmie, 66:1-102.
365. McSpadden Gardener BB, Fravel DR, 2002. Biological control of plant pathogens: Research, commercialization, and application in the USA. Online. Plant Health Progress. doi:10.1094/PHP-2002-0510-01-RV.
366. Bloemberg GV, Lugtenberg BJJ, 2001. Molecular basis of plant growth promotion and biocontrol by rhizobacteria. Current Opinion in Plant Biology, 4 (Suppl 4): 343-350.
367. Lubeck PS, Hansen M, Sorensen J, 2000. Simultaneous detection of the establishment of seed-inoculated *Pseudomonas fluorescens* strain DR54 and native soil bacteria on sugar beet root surfaces using fluorescence antibody and in situ hybridization techniques. FEMS Microbiology Ecology, 33 (Suppl 1): 11-19.

368. Mansouri H, Petit A, Oger P, Dessaux Y, 2002. Engineered rhizosphere: the trophic bias generated by opine-producing plants is independent of the opine type, the soil origin, and the plant species. Applied and Environmental Microbiology, 68 (Suppl 5): 2562-2566.
369. Smith KP, Goodman RM, 1999. Host variation for interactions with beneficial plant-associated microbes. Annual Review of Phytopathology, 37: 473-491.
370. Jetiyanon J, Kloepper JW, 2002. Mixtures of plant growth-promoting rhizobacteria for induction of systemic resistance against multiple plant diseases. Journal of Biology, 24 (Suppl 3): 285-291.
371. Siddiqui IA, Shaukat SS, 2002. Resistance against damping-off fungus *Rhizoctonia solani* systematically induced by the plant-growth-promoting rhizobacteria *Pseudomonas aeruginosa* (1E-6S(+)) and *P. fluorescens* (CHAO). Journal of Phytopathology, 150:500-506.
372. Nelson LM, 2004. Plant growth promoting rhizobacteria (PGPR): Prospects for new inoculants. Online. Crop Management. doi:10.1094/CM-2004-0301-05-RV.