Beneficial Plant Growth Promoting Rhizobacteria in Rhizosphere, its Applications and Plant Growth: A Review

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ABSTRACT
Rhizosphere is soil nearest area to root system that inhabits the microorganisms and capable to colonize very well to the roots. These microorganisms are stated as plant growth promoting rhizobacteria (PGPR). Plants depend upon valuable interactions between these microbes and roots for growth promotion, nutrient availability and disease suppression and they fulfill vital functions for plant growth. Many secrets of microorganisms in the rhizosphere are recently discovered due to the massive advancement in the molecular and other microscopic tools. This paper describes current knowledge on the development, maintenance and interaction of microbial communities and the diverse mechanisms commonly used by the most PGPR in rhizosphere that are beneficial to plant growth and development. Furthermore, this study describes the plant growth development by single and number of inoculations of PGPR and mycorrhizal fungi as well as the factor affecting the microbiomes in the rhizosphere have also describe and reviewed completely.

Keywords:
Rhizosphere; Plant growth; Rhizobacteria; Nitrogen fixing bacteria; Mycorrhizae

INTRODUCTION
Rhizosphere is plant root and the surrounding soil. Hiltner described the term 'rhizosphere' for the first time as a zone of maximum microbial activity [1]. The microbial population present in this environment is relatively different from that of its surroundings due to the presence of root exudates that serve as a source of nutrition for microbial growth [2]. A number of studies have revealed that many plant-associated microorganisms can have profound effects on plant growth and development, nutrition, seed germination, diseases, and productivity [3,4]. The plant microbiome is a collective referred to communities of plant-associated microorganisms. In this context, plants can be viewed as super-organisms that rely in part on their microbiome for specific functions and traits. In return, plants deposit their photo-synthetically fixed carbon into their direct surroundings, that is rhizosphere, and mycorrhizosphere [5-7], thereby feeding the microbial community and influencing their composition and activities. To date, the interplay between plants and microorganisms has been studied in depth for various leaf pathogens, symbiotic rhizobia, and mycorrhizae. However, for the vast majority of plant-associated microorganisms, there is limited knowledge of their impact on plant growth, health, and disease. Hence, deciphering the plant microbiome is critical to recognize the microbes that could be broken by improving the plant growth. The microbes generally colonizing the plant roots consist of bacteria, actinomycetes, fungi, algae and protozoa. Improvement of the plant growth, moreover development through the use of these microbes is well known [8-11]. However, bacterial population is the most abundant in this association [12]. The present review emphasized and discusses the current understanding and role of plant growth promoting rhizobacteria and mycorrhiza in developing the plant growth. Furthermore, we have highlighted the basic mechanisms used by plant growth promoting rhizobacteria (PGPR) and fungal species for supporting the plant growth and the relationships between these useful microbial communities. More importantly, the usefulness
of inoculation with plant growth promoting rhizobacteria and mycorrhiza alone and in combination on the plant growth have also been discussed.

LITERATURE REVIEW

Microorganisms in the rhizosphere

Culture-independent approaches have shown that microbial diversity of soil and rhizosphere microbiomes is highly underestimated. Next-generation sequencing technologies have demonstrated that only a minority of bacteria have been cultured by current methodologies and that a significant proportion of the bacterial phyla detected by these technologies has no cultured representative yet. In one of the first studies in this research field, [13] estimated that the number of bacterial species in a gram of boreal forest soil. Following the same strategy with substantial computational improvements predicted that 1 g of soil can contain more than one million distinct bacterial genomes, exceeding previous estimates by several orders of magnitude.

Most studies so far about rhizosphere have concentrate on number as well as diversity of the bacterial taxa to a certain extent on other rhizosphere populations. Depending on techniques used, numbers of microbes reported in rhizosphere studies range from <100 to more than 55,000 OTUs. For example, a meta-analysis of 19 clone libraries obtained from the rhizosphere of 14 plant species revealed more than 1200 distinguishable bacterial taxa from 35 different taxonomic orders, with the Proteobacteria as the most dominant phylum [14]. In most of the rhizosphere samples isolated from the Antarctic, Firmicutes were the most abundant phylum, whereas in many other rhizosphere studies, the Proteobacteria are commonly more abundant. Using a high-density 16S rRNA gene oligonucleotide microarray, De Angelis et al. detected 2595 OTUs in the oat rhizosphere with 1917 OTUs consistently present in all three replicate samples [15]. The dynamic subset (147 OTUs) responsive to root growth was dominated by the Alpha proteobacteria, Firmicutes, and Actinobacteria [15]. Based on the 454 pyrosequencing, Uroz et al. showed that ectomycorrhizospheres of the Xerocomus pruinatus as well as Scleroderma citrinum hosted more significant number of Alpha (α), Beta (β), and Gamma (γ) proteobacteria of rhizosphere soil [16]. In the rhizosphere of sugar beet seedlings grown in agricultural soils, study detected 70 archeal OTUs representing 0.21% of the total archaean and bacterial community accessed by phylo chip analysis. Interestingly, this study found an association in composition among the Archeal populations to Rhizoctonia level in suppressive of the soil damping-off disease. Whether Archeal populations play a role to plants protection against soil borne pathogens is so far not known. Therefore, to study potential beneficial properties of the culture able and non-culture able microbial diversity of rhizosphere, it is necessary to develop the screening and identifying technology and sequencing techniques.

Dynamics like soil type, pH, soil moisture, temperature, humidity, plant age also several other aspects are identified to affect the rhizosphere affect. The rhizosphere effect is expressed in terms of R/S ratio [17].

Plant growth promoting rhizobacteria (PGPR)

An essential microscopic population that exerts positive effects on the plant growth as well as development is named as plant growth promoting rhizobacteria [18]. Rhizosphere is effected by many processes like physical, biological also chemical practices of root, which is perfect environment for propagation of the beneficial microbes [19]. These microorganisms normally occur more or less close to the plant roots because of roots exudates, are source of food for growth [20,21].

Several bacterial genera like Bacillus, Variononas, Pseudomonas, Klebsiella, Enterobacter, Azotopilum, Burkholderia, and Azotobacter, causes distinct effect on the plant growth, termed as PGPR. Plant growth promoting rhizobacteria play an important role in increasing growth as well as development in both stress as well normal environments through number of defensive mechanisms [22-24]. Mechanisms that support plant growth comprise nitrogen fixation practice, phosphorus solubilization, plant growth regulators, siderophores production, organic acids, as well protect via enzymes alike ACC-deaminase, glucanase as well as chitinase [9,23,25]. Further, along the bacteriological population, fungal species also play a significant role in rhizosphere, its microflora also affect the growth. Symbiotic relationship of fungi with the roots (mycorrhiza) raises the root surface area, hence supports the plant to absorb water, nutrients more powerfully from the huge soil bulk. The ecto-mycorrhizae as well as endo-mycorrhizae association are two common types and have been described in many plant species. Mycorrhizal relationship not only raises nutrient as well water accessibility, further protect plants from a various abiotic factors.

Significant features of plant growth promoting rhizobacteria

PGPR living in soil surroundings (rhizosphere) could cause dramatic variations in the plant growth through synthesis of growth regulators similarly via refining nutrients through distributing and enabling nutrient uptake from soil [22]. Furthermore, numerous rhizobacterial bacteria can increase plant tolerance in response to soil salinity, flooding, dearth and soil heavy metal toxicity, thus assist the plants to live under harsh environmental conditions [26-28]. Even though numbers of free-living bacteria are term as PGPR, many bacterial strains of specific genus do not have same metabolic proficiencies for refining the growth to some extent [29]. Many studies have described the beneficial properties of rhizobacteria for developing the plant growth in normal also in stressful condition [30-32]. Plant Growth occurs as PGPR inhibit or decrease the injurious effects of the pathogens through one or numerous mechanisms. The beneficial mechanisms comprise of pathogen's inhibition via making defensive substances also by raises the host plant resistance to pathogenic microorganisms [33]. Plant growth occurs in many ways via the production valuable compounds of beneficial bacteria to host plant also via enabling the uptake of the food from the soil [18]. More they ease the development of plant via fixing atmospheric nitrogen as well as help in secreting siderophores compounds which could solubilize sequester iron, phytohormones production similarly.
solubilizing mineral deposits like phosphorus so as to increase its accessibility for plants, [34,35]. Regardless of these mechanisms, the beneficial microbes (PGPR) can increase plant growth through its important enzymes like ACC-deaminase and chitinase similarly via production of exopolysaccharides, rhizobitoxine substances that support the plants to survive in stress environments [23,27,36].

Furthermore, several rhizobacteria might have numerous traits also affect the plant development by one or other mechanisms. Effectiveness of the beneficial strains likewise rely on host plant similarly on soil characteristics [37]. Overall, PGPR might support the growth of plants via different methods. Several species have more than one beneficial mechanism likewise can survive not only in normal however, they survive in stressful atmosphere. Effectiveness of PGPR in supporting plant growth rely on its interactions with host plant, soil atmosphere. Some of the significant features of plant growth promoting rhizobacteria (PGPR) are shown in Figure 1.

Figure 1: Schematic outline showing the beneficial features of plant growth promoting rhizobacteria (PGPR).

**Mycorrhizae**

Is a symbiotic relationship between the roots of vascular plant and fungi. The most common types of such relationship are arbuscular mycorrhizae and ectomycorrhizae. Arbuscular mycorrhiza (AM) is the most abundant fungus which is normally present in the agricultural dirt. It forms the relationship with terrestrial as well as aquatic plants [38,39]. It is reported that around 80% of terrestrial plants, comprising the most agricultural plants, horticultural as well as hardwood crops are capable to form the mutualistic relationship [40]. This fungus penetrate in the roots cortical cells and procedure a specific haustoria-like structure termed as 'arbuscule' which functions as a mediator for interchange of metabolites among the fungus as well as host cytoplasm [41]. Further mycorrhiza can raise the accessibility also transport the diffusing ions, like phosphate to plants [42,43]. Likewise, it plays a vital role in refining the soil physical features. The peripheral mycorrhizal mycelium beside the other soil microbes forms a stable aggregate thus improving the soil aggregation [44-48]. This progress in the soil aggregation occurs because of mass production of an unsolvable glycoprotein glomalin by the mycorrhiza [49], which plays a significant role in firmness of soil [50]. The hyphae (AM) also boom into the soil [51], which benefits the plants to get nutrients also water from soil besides it also improve the soil structure [52]. Moreover, it shows a significant role in ecosystem via nutrient cycling [53,54]. Studies have shown that almost 80% of phosphorus (P) taken up by a plant is provided by the mycorrhizal fungus [55]. In addition, AM could also distribute other nutrients (macro and micro) like N, Mg, K, Zn as well as Cu, mainly in soils where it exist in the less soluble forms [55-57]. Overall, mycorrhizal association supports the plant growth not only providing the nutrients required for plant development, besides it also support the plant to tolerate in the stress environment. Studies are required with mechanisms which could validate this growth elevation.

**Microbial interactions in the rhizosphere**

Rhizosphere is the most complex atmosphere for biological association as well as chemical and physical interactions. Roots excrete many compounds into rhizosphere [58]. The root exudates are important source for development of microbial populations in rhizosphere. Exudates mainly comprise of ions, water, enzymes, mucilage as well as different metabolites (primary also secondary) [59]. Primary metabolites include organic acids, amino acids, sugars, lipids, flavonoids, proteins, aliphatics aromatics are found by soil-root association. In these metabolites, organic acids (substrate) play a significant role in microbial metabolism as well as in biogeochemical reactions (intermediates) in the soil. Further it is specific in plant species in quantity as well as composition. Moreover, it is common in plants which grow in fewer nutrients atmosphere and use the plant root exudates other than than symbiotic association with microbial inhabitants in rhizosphere [59]. Hypothetically, composition of microbial population that inhabits rhizosphere might be due to inappropriate selection methods. However, the detailed is still mysterious and many new dynamics remain still to be revealed. Stenotrophomonas maltophilia produce compounds particularly sulphur-containing compounds (methionine) [60]. As roots exudates are extremely species specific, the roots exudates can elucidate the specificity of the microbial population’s to plant. A complete genome study of gene expression of P. putida has shown its importance as stress adopters [61]. Some bacterial species are normally related with a small number of or a single plant species. Like, Rhizobium-legumes association. Similarly, Sinorhizobium meliloti efficiently colonize the genera of plant Medicago, Melilotus likewise Trigonella, where Rhizobium leguminosarum produce the nodules in Pisum vicia also Lathyrus plants. Nevertheless, it is still promising to identify novel taxonomic groups in rhizosphere for example non-thermophilic population of archaeal division Crenarchaeota [62]. Further rhizosphere colonization and its formation in the plant root is important for effective functioning of rhizosphere microbial population [63]. Phases of the microbial colonization consist of recognition of the specific host, adherence, and invasion on the host plant roots, colonization, progression as well as several other approaches to start interactions. Normally roots start cross talk to soil microbes by making signals that are identify by other microbes, in response produce explicit signals that pledge colonization. Motile organisms are mostly preferred as they participate moreover react in the cross talk [63]. For instance, teeming of the Senatia liquefaciens seemed to be precisely induced by the exudates of Pisum sativum [64]. Similarly, phenotypes of the P. fluorescens F113 with higher motility were chosen in rhizosphere colonization of the alfalfa. Aspects that help in recognition are
its ability to sense as well as the use of root exudates that are made up organic acids e.g., carbonic acids as well as amino acids, sugars etc. Chemotaxis particularly root exudates are significant feature for colonization of microbes in the rhizosphere. The initial step in formation of plant-bacterium interface is the attachment of microbes to plant roots, in which, for example, fimbriae as well as cell-surface proteins are involved. Similarly, for the colonization of Pseudomonas on roots, the flagella, pili, O-antigen of lipopolysaccharides are involved [65]. In addition not only bacteria, still fungi also attach to plant root surface. Fungal adhesion to plants root is a significant step for formation of symbiotic interaction [66]. Certain plant microbes interactions have developed complex mechanisms like signal exchange which tolerates a particular microbial population in the rhizosphere, e.g., Sinorhizobium [67]. But, not simply plant microbe’s interaction is significant for composition of the microbial populations in rhizosphere, however microbes can also effect one another [68-70]. Further detailed studies are needed to explore these interactions with detail mechanism and study its effects on plant growth. Significant role of mycorrhizae and plant growth promoting rhizobacteria in improving plant growth via numerous mechanisms is shown in Figure 2.

**Figure 2:** Mechanisms use by plant growth promoting rhizobacteria (PGPR) and mycorrhizae (AM) for improving plant growth in stress conditions.

Role of Mycorrhizae in Nitrogen Fixation: Nitrogen is one of the major element for the plant growth and compulsory for synthesis of nucleic acids, proteins and chlorophyll and enzymes. Even though 78% of atmosphere is consists of N, however its direct assimilation is unavailable for plants. Presently many industrial nitrogen fertilizers are used for improving agricultural yield. Still, environmental, economic as well as renewable energy fears dictate the usage of biological substitutes. Nitrogen fixation is conversion of the atmospheric nitrogen into ammonia via the cascade of reactions using the complex enzyme systems [71]. Currently in agriculture about 65% of nitrogen is produced by the BNF. Leguminous plants shows BNF, proficient also meet its own nitrogen requisites. Large amount of nitrogen is fixed by legumes is collected as grains, whereas soil as well as succeeding harvests get benefited from it in the form of root as well as shoot deposits. Therefore legume plants significantly decrease the nitrogen requirements from the peripheral sources [11]. Rhizobia can be used for improving the nitrogen fixation and studies have proved that they are effectively colonized in the soil for several years even in the absence of plant host [72]. The Rhizobium-legume symbioses (Rhizobium/Mesorhizobium/Bradyrhizobium) is a source of N\textsubscript{2} also an effective agronomic approach ensuring adequate supply of N\textsubscript{2} than the use of N-fertilizer. But, several environmental aspects limit the nitrogen fixation, for example deficiency of soil moisture, excesses temperature, osmotic stress, acidity, salinity, insufficiency of nutrient, soil alkalinity, overdoses of fertilizers as well as pesticides; as all these aspects affect the persistence as well as infectivity rate of the rhizobia, which is vital for the process of nitrogen fixation [73]. Studies have shown that a strain of AM increases plants growth in several environmental stresses [74]. Furthermore, AM has high potential to improve the nodulation, nitrogen fixation process in legumes. BNF Increase in phosphorus availability as well as other nutrients and its
synergistic interactions to rhizospheric microbes might be very effective for getting maximum grain yield in legumes under stressful atmospheres. Studies in laboratory as well as in field environments have revealed that inoculation of AM with BNF bacteria was very dynamic for increasing nitrogen fixation in the leguminous plants [75]. For instance, AM naturally exists in the stressful atmospheres e.g., salinity [76]. So, its relationship with plants might be very efficient for successful of plant growth as well as development in stress environments [77]. Further root colonization via AM favors the nodulation through rhizobia [78]. Bisht et al., notices that even though AM has shown a positive result with Rhizobium leguminosarum, a parallel response was detected when P. fluorescens was used [79]. Therefore, this study proposed that plant growth enhanced with AM fungus and PGPR depends on the type of bacteria. Thus, it stress is one of the limiting feature for the nitrogen fixation; it can be overcome by combining AM into the stress soils. Further it will be more effective in stress environments when use in combinations with other bacterial populations. Nevertheless, selection of specific and suitable microbes will be determine the success of this methodology.

Role of Soil microorganisms in Phosphate Solubilization: Phosphorus (P) is one of the most limiting nutrients for plant growth. It exists in both inorganic (bound, fixed, or labile) as well as organic (bound) forms. Its concentration is varied from 140 ppm in the carbonate rocks to above 1,000 ppm in volcanic materials [80]. Although the parent material has a strong control over the soil phosphate status of terrestrial ecosystems [81], the accessibility of P to plants is influenced by various factors like soil pH, aeration, compaction, temperature, moisture, texture, crop residues, organic matter of soils, and root exudate as well as available soil microorganisms. Soil microorganisms support in P release to the plants and plants absorb only the soluble form of P (e.g., monobasic (H$_2$PO$_4$), dibasic (H$_2$PO$_4$$^+$) forms [11]). While phosphate fertilizer provides the plants with available form of P, excessive use of it is not only expensive, but then also destructive to the environment [82]. Soil remains to be the highest source of the P supply to the plants [83]. Rhizobia, containing R. leguminosarum, M. mediterraneum, Radyrhizobium sp. as well as B. japonicum [84,85] are the possible source of P solubilizers. These beneficial bacteria produce a low molecular weight of organic acid which acts on the inorganic phosphorous [86]. Mediterraneum has been shown to play role in improving P solubilizing capability and has been studied in chick pea as well as in barley plants [87]. Further studies are required to explore the novel microbes with detail mechanisms are essential to understand its effects on plant growth.

Applications and interaction of mycorrhize and plant growth promoting rhizobacteria in environmental conditions: Studies have shown the importance of plant growth promoting rhizobacteria (PGPR) and mycorrhizae for supporting the growth and development in many plants. This beneficial interaction is mainly occurs among PGPR, the mycorrhizae fungus and plant. The cooperative effects of PGPR to mycorrhizae can be very helpful for plant growth in several ways. In combination these strain not only participates successfully to rhizosphere population, however also shows useful interactions for the development of every one. Such as, development of AM by PGPR is due to its root colonization as well as nutrient uptake [88]. Likewise, increase in root exudates size by microbe triggers the fungal hyphae and therefore root colonization rate increases [89]. In a study P. fluorescens C7R12, was shown as an effective bio control mediator in contrast to Fusarium spp. It is also useful for supporting the association between Medicago truncatula as well as G. mosseae [90]. In one former study, Barea et al. confirmed the ability of Pseudomonas spp. to produce antifungal metabolic products but these metabolites did not cause any undesirable consequence on G. mosseae [91]. Conversely, it supported the plant root colonization through hyphae. Bianciotto et al. detected the production of exopolysaccharides from PGPR, improved the attachment of the bacterial strains to mycorrhizal roots as well as fungal structure [92]. So, the combination of PGPR with arbuscular mycorrhizae can increase the AM activity in symbiosis [93]. Further manifestation of PGPR and mycorrhizal bacteria in rhizosphere can stimulate the growth of fungal hyphal by increasing cell permeability to ease the root penetration via the fungus [94], and mycorrhizae boost the activities of the bacteria which causes nitrogen fixation also solubilizing the phosphorus [95]. These studies show the importance of PGPR, mycorrhizal strains alone as well as in assortment can be useful for improving the plant growth, development both in normal and stress circumstances. However, commercially these microbial inoculants show unreliable performance. Further in certain circumstances, these strains fail to form symbiotic relationship as perceived by Corkidi et al. [96].

Table 1: Role of plant growth promoting rhizobacteria in plant growth under stress situations.

| Crop species | Bacterial strain | Stress type | Response | References |
|--------------|-----------------|-------------|----------|------------|
| Tomato       | Achromobacter piechaudii ARV8 | Salinity    | Strain increased fresh, dry weight as well as water proficiency of tomato | [99] |
| Mustard      | Rhodococcus spp. | Heavy metals | This beneficial strain secures the plant from metal toxicity an important development in plant growth was detected to toxic Cd | [100] |

Nat Prod Chem Res, Vol.7 Iss.2 No:359
chickpea Mesorhizobium spp. pH Huge range of the isolate varied in growth at different pH [101]

Kidney bean Mesorhizobium spp. Temperature All strains shown more tolerance to yield shoot biomass [101]

Retama Bacillus thuringiensis Glomus intraradices Drought Improved root growth, less water needed to yield shoot biomass [102]

Maize (Zea mays) Enterobacter aerogenes, Flavobactrium fennugicum Salinity Elevate water, chlorophyll contents, also Na+/K+ ratio was detected in inoculated than uninoculated control plant [103]

Kidney bean R. tropici coinoculated with Paenibacillus polymyxa Drought Improved the plant height, dry weight, shoots also nodule number [104]

Chickpea M. ciceri, M. mediterraneum Salt resistant Keep up of the plant growth also nitrogen fixation [105]

Pea Rhizobium MRPI Herbicides Improved the biomass, leghaemoglobin content, nodulation, root and shoot P, root and shoot N, seed production [106,107]

Tomato Pseudomonas fluorescens, P. stutzeri P. aeruginosa, Salinity These PGPR improved the root and shoot growth of tomato [81]

Pea Rhizobium MRPI Fungicides Improved the biomass, leghaemoglobin content, nodulation, root and shoot P, root and shoot N, seed production [108]

Wheat Bacillus spp. Enterobacter spp., Paenibacillus spp., Salinity Produced more biomass production as related to control [109]

Lentil Rhizobium RL9 Heavy metals Increased the growth, chlorophyll, nodulation, nitrogen, seed protein as well as seed production [110,111]

Maize (Zea mays) Glomus mosseae, Acaulospora laevis Heavy metals Improved shoot length, root and shoot biomass was noted in the inoculated plants [12]

Lentil Rhizobia strains Salt/osmotic Improved the plant biomass, nodule, dry weight [113]

**DISCUSSION AND CONCLUSION**

Rhizosphere is a unique niche that gives residence and nutrition to microorganisms. These microbes produce different advantages to induced plant growth, resistance against diseases and survival under stress conditions with numerous other unknown benefits. Much research has concentrated on the potential for individual microbial strains to bring advantages to plants and it is additionally evident that microorganisms can act synergistically to impact plant health, development and abiotic factors likewise assume a vital role in root microbiome formation. The present review documents the potential of PGP rhizobia and highlights the unique properties of plant growth induction. The multipartite interactions that lead to assembly and maintenance of the root microbiome are exceedingly confusing and not completely understand. However, generation of inclusive information on identifying methods and extreme collection of best rhizobacterial bacteria for rhizosphere competency to improve the field level performance is needed to explore. Subsequently, additional inclusive study to benefit from the potential PGP rhizobacteria could offer expansion of this research area and improve sustainability in plant growth and ultimately will be increase agricultural production. Furthermore by the progress of culture-independent approaches ‘omics’ as
well as bioinformatics methods can deeper understand the beneficial aspects of rhizosphere microbes and its effects on plant growth.

DISCLAIMER

For this study no financial support was received. No conflict of interest to declare.

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