

A Critical Review on Plant Growth Promoting Rhizobacteria

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Abstract

The microorganisms with the aim of improving nutrients availability for plants is an important practice and necessary for agriculture. During the past couple of decades, plant growth-promoting rhizobacteria (PGPR) will begin to replace the use of chemicals in agriculture, horticulture, silviculture, and environmental cleanup strategies. Scientific researches involve multidisciplinary approaches to understand adaptation of PGPR, effects on plant physiology and growth, induced systemic resistance, biocontrol of plant pathogens and biofertilization. This is due to the emerging demand for dependence diminishing of synthetic chemical products, to the growing necessity of sustainable agriculture within a holistic vision of development and to focalize environmental protection. The 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 roots and shoots growth. In this review, we have discussed about rhizobacteria which act as PGPR, mechanisms and the desirable properties exhibited by them.

Keywords: Plant growth promoting rhizobacteria; Agriculture crop production; Biofertilizer

Introduction

The rhizosphere is a nutrient-rich habitat and harbors a huge variety of bacteria and fungi that each can have neutral, beneficial or deleterious effects on the plant [1]. Some of these organisms can improve plant growth by different mechanisms [2,3]. Fluorescent *Pseudomonas* and *Trichoderma* species are important groups of plant growth-promoting microorganism reported to protect plants against pathogens by evolving various mechanisms such as antagonism, competition and Induced systemic resistance (ISR) [4-8]. Rhizosphere colonization by certain PGPR and plant growth-promoting fungi (PGPF) can elicit ISR [4,5,7,9-11]. Induced systemic resistance (ISR) triggered by plant growth-promoting fungi (PGPFs) and Plant growth promoting rhizobacteria (PGPR) confers a broad-spectrum resistance that is effective against different types of pathogens [3].

There are numerous reports of plant growth and yield stimulation by beneficial soil microorganisms [12,13]. Plant growth promoting rhizobacteria (PGPR) is one among the most effective and best studied soil microorganisms which can promote plant performance. The PGPR can be classified as extracellular bacteria (existing in the rhizosphere, on the root surface or in the spaces between cells) and intracellular bacteria (mainly N_2 fixing bacteria) [14].

The PGPR have been demonstrated to increase growth and productivity of many commercial crops including rice [15], Wheat [16], cucumber [17], maize [18], cotton [19], black pepper [20] and banana [21].

Role of PGPR

The Plant growth promoting rhizobacteria, compost and chemical fertilizers significantly affect the growth and yield of different crops. A novel approach could be that composted material may be converted into a value added product such as an effective biofertilizer by blending with PGPR which are free living soil bacteria that can either directly or indirectly facilitate rooting [22] and growth of plants [22,23].

There are several mechanisms by which PGPR effect plant growth such as ability to produce various compounds (phytohormones, organic acids, siderophores), fix atmospheric nitrogen, solubilize phosphate

and produce antibiotics that suppress deleterious rhizobacteria, and production of biologically active substances or plant growth regulators (PGRs) is one of the major mechanisms through which PGPR influence the plant growth and development [24].

Plant growth promoting rhizobacteria, having multiple activities directed toward plant growth promotion vis-a-vis exhibiting bioremediating potentials by detoxifying pollutants like, heavy metals and pesticides and controlling a range of phytopathogens as biopesticides, have shown spectacular results in different crop plants has been observed following PGPR applications (Table 1). The productive efficiency of a specific PGPR may be further enhanced with the optimization and acclimatization according to the prevailing soil conditions [25].

The bacteria lodging around/in the plant roots (rhizobacteria) are more versatile in transforming, mobilizing, solubilizing the nutrients compared to those from bulk soils [34]. Therefore, the rhizobacteria are the dominant deriving forces in recycling the soil nutrients and consequently, they are crucial for soil fertility [35].

Physiochemical Characterization of PGPR

PGPR are free-living bacteria and some of them invade the tissues of living plants and cause unapparent and symptomatic infections [36], when applied to seeds or crops, enhance the growth of the plant or reduce the damage from soil-borne plant pathogens [5].

Rhizobacteria that exert beneficial effects on plant growth and development are referred to as PGPR. In last few decades a wide

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Received August 09, 2014; Accepted December 20, 2014; Published December 25, 2014

Citation: Prathap M, Ranjitha Kumari BD (2015) A Critical Review on Plant Growth Promoting Rhizobacteria. J Plant Pathol Microb 6: 266. doi:10.4172/2157-7471.1000266

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| PGPR | Plant | Conditions | Results of addition of bacteria to plants | Reference |
|---|---|----------------------------------|---|--------------|
| <i>Pseudomonas</i> sp. PS1 | Greengram (<i>Vigna radiate</i> (L.) wilczek) | Pots | Significantly increased plant dry weight, nodule numbers, total chlorophyll content, leghaemoglobin, root N, shoot N, root P, shoot P, seed yield and seed protein | [26-28] |
| <i>Bradyrhizobium</i> MRM6 | Greengram (<i>Vigna radiate</i> (L.) wilczek) Soybean, Wheat | Pots | When herbicide tolerant <i>Rhizobium</i> strain MRP1 was used with herbicide, it increased the growth parameters at all tested concentrations of herbicides (quizalafop-p-ethyl and clodinafop) | [29,30] |
| <i>Pseudomonas</i> sp. <i>Paenibacillus polymyxa</i> | Pepper <i>Zea mays</i> L. (maize) | Fields Gnotobiotic conditions | Significantly increased soil enzyme activities, total productivity, and nutrient uptake. Significantly increased the biomass of plants and elicited induced systemic resistance against bacterial spot pathogen <i>Xanthomonas axonopodis</i> pv. <i>Vesicatoria</i> untreated plants. | [31] [32] |
| <i>Enterobacter sakazaki</i> 8MR5 | | Pots | Inoculation increased growth parameters | [33] |

Table 1: Examples of plant growth promoting rhizobacteria tested for various crop types.

group of bacterial species including of *Pseudomonas*, *Azospirillum*, *Azotobacter*, *Klebsiella*, *Enterobacter*, *Alcaligenes*, *Arthrobacter*, *Burkholderia*, *Bacillus* and *Serratia* have reported to enhance plant growth [36,37]. The PGPR can effect plant growth by producing and releasing secondary metabolites and facilitate the availability and uptake of certain nutrient from the root environment [38]. Unfortunately, the interaction between associative PGPR and plants can be unstable. The good results obtained from *in vitro* assays cannot be always dependably reproduced under field conditions [39].

The rhizobacterial population was slightly affected by Nickel-Cadmium exposure. However, majority of the isolated strains for both the rhizosphere possessed one or more PGP traits. Isolates tolerant to elevated levels of heavy metals and test bacterium P35 are outstanding for PGP potential. Selection of microorganisms both metal tolerant and efficient in producing PGP compounds can be useful to speed up the recolonization of the plant rhizosphere in polluted soils [40].

The presence of such growth promoting rhizoflora accountable for the beneficial effects on crop growth and yield. The significance of the study could be stated as the potential of these IAA producing isolates and optimization study for IAA production will flourish the growth and ultimately IAA production in the field and prevent environmental pollution by avoiding excessive applications of industrially produced fertilizers to cultivated fields [41].

PGPR as a Biofertilizer

Bacterial siderophores from C138 are most effective in supplying Fe to iron-starved tomato plants when delivered to the roots, independent of the bacterial presence. Furthermore, results are similar or even better than with full Hoagland solution, representing a promising candidate to develop an organic Fe chelator. The short period is needed for fermentation appears as an asset for economic feasibility. In summary, strain C138 tested in this experiment can serve as an effective organic biofertilizer [42].

The plant-PGPR cooperation plays a major role by enhancing growth and health of widely diverse plants. That plant PGPR independently produced IAA has also been revealed. It is obviously a step forward in our understanding of plant-PGPR cooperation but it does not fully clarify the bacterial functions and plant hormonal networks involved in components of hormonal pathways [43].

Phytohormone-producing *Bacillus* sp., WhIr-15 and *B. subtilis* WhIr-12, isolated in the present study, have potential at field level to improve wheat productivity and may be helpful in the formulation of an effective biofertilizer for wheat [25,44]. Expected to replace the

chemical fertilizers, pesticides and artificial growth regulators which have numerous side effects to sustainable agriculture.

Multifaceted bacterium of *Bacillus amyloliquefaciens* was improved growth, yield and nutrition of soybean through the contributions of the bacteria mediated induced mechanisms/ processes in the rhizosphere of the soybean and also as a broad-spectrum bioinoculant for soybean cultivation in India [45].

PGPR as a Biocontrol

The plant growth-promoting traits by a comparative genomics analysis of four representative pseudomonad PGPR strains. The genes that were conserved among the different *Pseudomonas* species have provided clues to the common characteristics of pseudomonad PGPR, such as rhizosphere competence traits (nutrient catabolism and transport, resistance to various environmental stresses and rhizosphere colonization). Recently reported genome of *P. chlororaphis*, together with other sequenced strains of different species of pseudomonad PGPR, provides insights into the genetic basis of diversity and adaptation to specific environmental niches. Genetic modification may accelerate the commercialization of PGPR as biocontrol agents, which could further contribute to sustainable development of agriculture [46].

The ability of bacterial siderophores and antibiotics to suppress phytopathogens could be the significant agronomic importance. Both mechanisms have essential functions in microbial antagonism but also the mechanisms leads to elicit induced resistance. Resistance-inducing and antagonistic rhizobacteria might be useful in formulating new inoculants, offering an attractive alternate of environmentally friendly biological control of plant disease and improving the cropping systems into which it can be most profitably applied [47].

The evolution of T3SSs in bacteria with this knowledge will contribute in the development of various biotechnological applications involving the design of efficient strategies to control plant diseases, the exploitation of T3SS as scaffold for protein delivery into eukaryotic cells, the improvement of the symbiotic properties of rhizobial species or even the expansion of the symbiotic potential towards the non-leguminous plants of agriculture importance [48].

The selected bacterial strains are feasible to be used for development of plant growth promoting or biocontrol inoculants, together with other plant growth promoting microbes [49].

Stress Study of PGPR

An ideal selection of bioagents having abiotic stress tolerance and proven antagonistic activity for their consistent performance under field conditions [50].

Water stress caused higher antioxidative activity and the highest concentration CAT and GPX activity were in W3 (Three levels of water stress $W_1=80$ (control), $W_2=60$ and $W_3=40\%$ of the field capacity (FC)) treatments. However by increasing water stress from control to W3, chlorophyll content in leaves was increased but Fv/Fm and ascorbate peroxidase (APX) activity decreased. Inoculation with rhizobacteria could be efficiently used to improve growth, antioxidant status and photosynthetic pigments in basil under water stress. *Pseudomonades* sp. under water stress, significantly improved CAT enzyme activity in the leaves and increased it. But the highest GPX and APX activity and chlorophyll content in leaves under water stress was in combination of three bacterial species (*Pseudomonades* sp., *Bacillus lentus*, *Azospirillum brasilens*) [51].

PGPR as a Bioformulation

The new challenge in the new millennium is to produce more and more food from shrinking per capita arable land, keeping the environment safe. As agricultural production intensified over the past few decades, producers became more and more dependent on agrochemicals. Chemical fertilizers and pesticides are presently accumulating in the environment harming the ecosystem, causing pollution and spreading disease [52]. Therefore, the urgent need of biological agents is accepted worldwide. Interest in biological control of plant pathogens has increased considerably over the past years, partly as a response to public concern about the use of hazardous chemical pesticides, but also because it may provide control of diseases that cannot or only partially be managed by other control strategies [53,54].

The biocontrol agents, plant growth promoting rhizobacteria such as *Pseudomonas* spp. and *Bacillus* spp. have shown activity in suppressing the fungal infection and promoting growth characteristics [55]. When PGPR are mixed with some other strains, or other bacteria or fungal antagonists the biocontrol efficacy is increased [56]. Thus, the objective of this study was study of new bioformulations efficacy in promoting growth characteristics of cotton seedlings.

Conclusion

The plant growth promoting phenomenon can be attributed to the ability of the isolate to produce IAA, as IAA positively influences root growth and development, thereby enhancing nutrient uptake [16]. It is a well established fact that improved phosphorous nutrition influences overall plant growth and root development [57]. Plant microbe interaction in Rhizosphere must increase before we can presume that utilization of PGPR as biofertilizers will determine a sustainable promotion of host plants growth. Combinations of beneficial bacterial strains that interact synergistically are currently being devised and numerous recent studies have shown a promising trend in the field of inoculation technology. PGPR are excellent model systems which can provide biotechnologist with novel genetic constituents and bioactive chemicals having diverse uses in agriculture and environmental sustainability.

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