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PLANT GROWTH-PROMOTING RHIZOBACTERIA (PGPR): EMERGENCE IN AGRICULTURE

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ABSTRACT

Plant Growth-Promoting Rhizobacteria (PGPR) are beneficial bacteria that colonize plant roots and that controls soil borne disease and enhance plant growth through various mechanisms. These bacteria are found in the rhizosphere, the soil region near plant roots, where they establish symbiotic or associative relationships with plants. Plant growth benefits due to the addition of PGPR include increase in germination rates, root growth and yield including grain, increase in leaf area, chlorophyll content, magnesium, nitrogen and protein content, hydraulic activity, tolerance to drought and salt stress, shoot and root weights and delayed leaf senescence.

***Keywords* :** Plant Growth-Promoting Rhizobacteria (PGPR), Rhizosphere.

Introduction

Plant growth-promoting rhizobacteria (PGPR) (Kloepper *et al*., 1980) are non-pathogenic, beneficial soil-rhizobacteria that play a key role in plant health and nutrition (Lynch, 1990). These may benefit plant growth, either by improving plant nutrition or producing plant growth regulators (Gutierrez *et al*., 1996; Gutierrez *et al*., 2001). They may also prevent attack from pathogenic microorganisms (Van-Loon *et al.*, 1998; Bowen and Rovira, 1999) or help in the establishment of symbiosis with rhizobia or with mycorrhiza (Frey-Klett, 1997). PGPRs have been reported to directly enhance plant growth by a variety of mechanisms, such as fixation of atmospheric nitrogen that is transferred to the plants, production of siderophores that chelate iron and make it available to the plant roots, solubilization of minerals such as phosphorous and synthesis of phytohormones (Glick, 1995). Direct enhancement of mineral uptake due to increase in specific ion fluxes at the root surface in the presence of PGPRs has also been reported (Bashan and Levanony, 1991; Bertrand *et al.*, 2000). PGPR strains may use one or more of these mechanisms in the rhizosphere. PGPRs that synthesize auxins and cytokinins or those that interface with plant ethylene synthesis have been identified (Glick, 1995; Garcia *et al.*, 2001; Percello-Carticaux, *et al.*, 2003). The indirect means by which PGPRs enhance plant growth is through suppression of phytopathogens by a variety of mechanisms. These include the ability to produce siderophores that chelate iron, making it unavailable to pathogens, the ability to synthesize anti-fungal metabolites such as antibiotics, fungal cell wall lysing enzymes or hydrogen cyanide, which suppress the growth of fungal pathogens (Bloemberg and Lugtenberg, 2001; Persello-Carticaux *et al.*, 2003).

Plant growth benefits due to the addition of PGPR include increase in germination rates, root growth and yield including grain, increase in leaf area, chlorophyll content, magnesium, nitrogen and protein content, hydraulic activity, tolerance to drought and salt stress, shoot and root weights and delayed leaf senescence (Lucy *et al.*, 2004).

The plant growth promoting activity of the beneficial rhizobacteria was also due to the production of some plant growth promoting substances, production of enzymes, and production of some antifungal and antibacterial secondary metabolites

(Weller, 1988). Among PGPR, fluorescent pseudomonads have been reported to be effective against a broad spectrum of plant pathogens including fungi, bacteria and viruses in many plant species e.g. bean, carnation, cucumber, radish, tobacco and tomato (Van Loon *et al.*, 1998).

Soil microorganisms (free-living, associative, and symbiotic rhizobacteria) belonging to the genera like *Actinetobacter*, *Burkholderia*, *Enterobacter*, *Alcaligenes*, *Arthrobacter*, *Azospirillum*, *Azotobacter*, *Bacillus*, *Erwinia*, *Flavobacterium*, *Rhizobium*, *Serratia*, *Xanthomonas*, *Proteus*, and *Pseudomonas* are the integral parts of rhizosphere biota (Glick, 1995; Kaymak, 2011) and exhibit successful rhizosphere colonization.

PGPR and their hosts: rhizospheric and endophytic region

For PGPR to have effect on plant growth via an enhancement of the nutrient status of their host, there obvious need to be an initimate relationship between the PGPR and the host plant. However, the degree of intimacy between the PGPR and the host plant can vary depending on where and how the PGPR colonizes the host plant. Relationships between PGPR and their hosts can be categorized into two levels of complexity (1) rhizospheric (2) endophytic.

Rhizospheric region

The rhizosphere can be defined as any volume of soil specifically influenced by plant roots and in association with roots and hairs and plant–produced material (Andrade *et al*., 1997 and Bringhurst *et al*., 2001). This space includes soil bound by plant roots, often extending a few mm from the root surface (Bringhurst *et al*., 2001) and can include the plant root epidermal layer (Mahafee and Kloepper, 1997). Plant exudates in the rhizosphere, such as amino acids and sugars, provide a rich source of energy and nutrients for bacteria, resulting in bacterial populations greater in this area than outside the rhizosphere. Extracellular PGPR (ePGPR) which exist in rhizosphere increase plant growth through variety of mechanisms, these include genera such as *Bacillus*, *Pseudomonas*, *Chromobacterium*, *Agrobacterium* and free- living nitrogenfixing bacteria (*Azotobacter* and *Azospirillum*) (Prithviraj *et al*., 2003 and Gray and Smith, 2005).

Endophytic region

Rhizobacteria that establish inside plant roots, forming more intimate associations, are endophytes. To aid in this conceptualization, simple terms have been adopted; intracellular PGPR (iPGPR) bacteria residing inside plant cells, producing nodules and being localized inside those specialized structures. These include a wide range of soil bacteria forming less formal associations than the rhizobia-legume symbiosis, endophytes may stimulate plant growth, directly or indirectly and include the rhizobia. Soil bacteria in the genera *Rhizobium*, *Bradyrhizobium*, *Sinorhizobium*, *Mesorhizobium* and *Allorhizobium*, belonging to the family Rhizobiaceae, invade plant root systems and form root nodules (Martinez- Romero and Wang, 2000).

PGPR as biocontrol

PGPR are free living, root colonizing bacteria that have beneficial effects on plants. They reduce disease severity and enhance yield of many crops (Murphy *et al*., 2000). Zheng and Sinclair (2000) showed that *Bacillus megaterium* is a potential bacterial biocontrol agent against *Rhizoctonia solani*. Estevez *et al*. (2002) evaluated the effect of *Bacillus subtils* and *Trichoderma harizianum* alone or in combination with Captan 400 and Vitavax 200 as biocontrol treatments against the dry bean root rot pathogens and reported that seed application of both the biocontrol agents increased plant biomass and decreased disease severity, under greenhouse conditions. They further reported that use of seeds treated with *B. subtilis* in field experiment reduced bean root rot and increased yield (31%) as compared to untreated control. Among the PGPR, fluorescent pseudomonads are the most exploited bacteria for biological control. In the past three decades, numerous strains of fluorescent pseudomonads have been isolated from soil and plant roots by several workers and their biocontrol activity against soil borne and foliar pathogens assessed (Rosales *et al.*, 1995; Rabindran and Vidhyasekaran, 1996; Vidhyasekaran and Muthamilan, 1999; Ramamoorthy *et al.*, 2001). PGPR is 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 (Kloepper *et al.*, 2004). Biological control of plant diseases is a result of different types of interactions among microorganisms and can occur through different mechanisms, which are generally classified as: parasitism/predation, antibiosis, competition, lysis and induced resistance (Pal and Gardener, 2006). Root exudates provide energy-rich organic acids, sugars and amino acids that are metabolized within a short time by soil microorganisms, while specialized microorganisms generate an array of biologically active compounds that elicit plant growth promotion (Sivasakthi, *et al*., 2014).

Many biocontrol agents from *P. fluorescens* and closely related species are well characterized for their ability to produce antimicrobial compounds, including 2,4-diacetylphloroglucinol (DAPG), phenazines, hydrogen cyanide and surfactants (Haas and De´fago, 2005). The use of biological control agents as an alternative to fungicides is increasing rapidly in the present day agriculture due to the deleterious effects of chemical pesticides on human health and environment (Maurya *et al*., 2014). Rhizosphere competence of antagonists is a pre-requisite for the biological control of soil borne plant pathogens and this phenomenon was associated with the production of higher amounts of cellulolytic enzymes and increased saprophytic ability manipulating the environment around a crop plant to favour organisms that contribute to crop health and vigour rather than pesticides, which destroy a range of micro-organisms including the fungal pathogens (Najar *et al*., 2011).

Humus and organic rich soil of valley are found favourable for the bioagents which could easily control the wilt disease. In fact, domestic antagonists are most virulent to the soil-borne pathogens because of their persistent growth capability under soil and local climatic conditions. (Dohroo, 2001). Domestic antagonists are most virulent strains to wilt pathogen because of their persistent capability under soil and local climatic conditions of Jammu and Kashmir (Najar *et al*., 2011). A secondary metabolite produced commonly by rhizosphere pseudomonads is Hydrogen Cyanide (HCN), a gas known to negatively affect root metabolism and root growth and is a potential and environmentally compatible mechanism for biological control of weeds (Schippers *et al*., 1990; Heydari, *et al*., 2008).

In addition to rhizosphere and rhizoplane colonization, certain PGPR are reported to be endophytes who reside within the living plant tissues without doing substantive harm or gaining benefit other than residency (Kado, 1992). Biological control involves the use of beneficial organisms, their genes and/or products such as metabolites that reduce the negative effects of plant pathogens and promote positive responses by the plant. The use of biocontrol agents to control Fusarium wilt has been reported for many crops including tomato, cucumber, melon, strawberry, banana and carnation. Several reports have previously demonstrated the successful use of different spp. of *Trichoderma*, *Pseudomonas*, *Streptomyces*, non-pathogenic *Fusarium* (npFo) of both rhizospheric and endophytic in nature against Fusarium wilt disease under both glass house and field conditions (Getha *et al*., 2005). Biocontrol results either from competition for nutrients and space or as a result of the ability of biocontrol agents to produce and resist metabolites that either impede spore germination (fungistasis), kill the cells (antibiosis) or modify the rhizosphere e.g. by acidifying the soil so that the pathogen cannot grow. Biocontrol may also result from a direct interaction between the pathogen itself and the biocontrol agent, as in mycoparasitism, which involves physical contact and synthesis of hydrolytic enzymes, toxic compounds and antibiotics that act synergistically with the enzymes (Singh and Seneviratne, 2017).

Interaction of pathogens with biocontrol agents

The application of microorganisms as biocontrol agents is important, since they may increase beneficial microbial activity, which extends for a long period of time. Several strains of *Pseudomonas fluorescens* have been reported to suppress soil borne diseases caused by pathogens (Sullivan and Gara, 1992). Biological control plays an important role in the management of bacterial wilt (Akiew *et al.*, 1993). Alabouvette *et al.* (1996) concluded that pathogen suppression was due to nutrient competition between pathogenic and saprophytic *F. oxysporum*, whereas, Schneider (1984) proposed that suppression was due to competition for infection sites at the root surface. Two chitinolytic bacterial strains, *Paenibacillus* sp. 300 and *Streptomyces* sp. 385, suppressed Fusarium wilt of cucumber (*Cucumis sativus*) caused by *Fusarium oxysporum* f.sp. *cucumerinum* in non-sterile, soilless potting medium (Singh *et al*., 1999). Several mechanisms have been proposed to be involved in the suppression of *F. oxysporum* by these antagonistic microorganisms. Of the various bioagents, *Trichoderma* spp. have been known to suppress many soil borne fungi including *Fusarium* spp by a variety of mechanisms, such as competition for nutrients, production of inhibitory volatiles and non-volatiles, mycoparasitism involving the production of hydrolytic enzymes (Bruce *et al*., 1984; Desai and Schlosser 1999; Dhar *et al*., 2006) and production of siderophores (Rane *et al.*, 2005; Dutta *et al*., 2006).

P. fluorescens was also used as a biocontrol agent to manage Fusarium wilt in radish (Leeman *et al.*, 1995 b), bacterial wilt of tobacco (Liu *et al*., 1999), cucumber wilt (Liu *et al*., 1999), *Xanthomonas oryzae* pv. *oryzae* in rice (Vidhyasekaran *et al*., 2001), Eucalyptus wilt (Ran *et al.*, 2005), *R. solanacearum* in Chilli (Umesha *et al.*, 2005) and *Clavibacter michiganensis* (Umesha, 2006). *P. fluorescens* also improved seed quality under laboratory conditions and drastically reduced bacterial spot disease under field conditions (Kavitha and Umesha, 2007). The utilization of *P. fluorescens* for the control of *Rhizoctonia solani* is a suitable strategy for the management of the disease under field conditions (Bautista *et al*., 2007). *Ralstonia solanacearum* mostly persists through soil and crop residues (Granada and Sequeira, 1983). In crops such as tomato and eggplant, the pathogen is carried in seed (Shakya, 1993). A variety of biocontrol agents have been used by many scientists for managing bacterial wilt pathogen, *Ralstonia solanacearum* (*Pseudomonas fluorescens)* in different crops (Ciampi *et al*., 1996; Karuna *et al*., 2001), actinomycetes (Shekhawat *et al.*, 1993), avirulent strains of *R. solanacearum* (Arwiyanto *et al.*, 1994; Dong *et al.*, 1999), *Bacillus* spp. (Shekhawat *et al.*, 1993; Sunaina *et al.*, 1997; Abdalla *et al.*, 1999), *Pseudomonas aeruginosa* (Furuya *et al*., 1997; Karuna *et al*., 2001) and *Pseudomonas capaci* (Abdalla *et al*., 1999). The use of *Bacillus subtilis, P. fluorescens* and *T. viride* provide promising against wilt of tomato caused by *R. solanacearum,* and *P. fluorescens* minimizing the disease (Biswas and Singh, 2008). Attempts have also been made under greenhouse studies and field conditions alike to show the efficacy of *P. fluorescens* in the management of plant diseases (Jayashree, *et al*., 2000; Vidhyasekaran *et al.*, 2001; Umesha, 2006; Kavitha and Umesha, 2007). The biocontrol potential of fluorescent pseudomonas isolated from rhizosphere of pea and wheat *in vitro* and *in vivo* against maize sheath blight caused by *R. solani* (Tripathi and Johri, 2002). Further, the antagonistic rhizobacteria, more specifically fluorescent pseudomonads and certain *Bacillus* species possesse the ability to inhibit fungal and bacterial root diseases of agricultural crops (Ahmadzadeh *et al*., 2004).

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