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Review

Novel plant growth promoting rhizobacteria—Prospects and potential

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ABSTRACT

Sustainability in agricultural production has emerged as one of the most significant concerns of present times. Commensurate with the present day aversion to the use of chemical fertilizers and pesticides; there is an overt emphasis on use of organic inputs and microbial inoculants which play an important role in sustainable agriculture. Plant growth promoting rhizobacteria (PGPR) are an important group of microbial inoculants that have been studied extensively for their ability to promote plant growth and improve productivity. PGPR operate through either direct or indirect mechanisms or a combination of both, and there by minimize the environmental impact of chemical intensive farming practices. Direct mechanisms of plant growth promotion include the secretion of plant growth promoting metabolites like indole acetic acid (IAA), cytokinins, gibberellins, etc., and facilitating the uptake of essential nutrients (N, P, Fe, Zn, etc.) from the atmospheric air and soil. Indirect promotion of the plant growth occurs when PGPR lessen or prevent the deleterious effect of phytopathogenic organisms by the production of antibiotics, siderophores, hydrogen cyanide (HCN), etc. Well known PGPRs that have reached the stage of commercial success, include *Azospirillium, Azotobacter, Bacillus Burkholderia, Pseudomonas, Rhizobium*, and *Serratia*. But there are several novel PGPR on which considerable information is available, but such organisms have not attained commercial scales of production unlike their better known predecessors. PGPRs like *Azoarcus, Exiguobacterium, Methylobacterium, Paenibacillus* and *Pantoea* etc., fall in this category. The information available on these novel PGPRs with regard to their biology and utility are discussed in this review.

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1. Introduction

The rhizosphere is a thin zone of soil surrounding the root zone that is immensely influenced by the root system (Hartmann et al., 2008). Compared to the neighbouring bulk soil, this zone is rich in nutrients, due to the accumulation of a variety of organic compounds released by the roots through exudation, secretion and rhizodeposition. These organic compounds can be used as carbon and energy sources by microorganisms and microbial activity is particularly intense in the rhizosphere. The rhizosphere is therefore home to a variety of root associated bacteria commonly referred to as rhizobacteria. Such beneficial rhizobacteria that positively influence plant growth are referred to as plant growth promoting rhizobacteria (PGPR).

The research on PGPR gains significance due to the need for development of eco-friendly and sustainable agriculture practices for feeding a rapidly growing population. Since the excessive use of chemical fertilizers and pesticides pose adverse effects on the environment, it is imperative to devise eco-friendly biological alternatives and use the best management practices in order to reduce the use of chemicals. Kloepper and coworkers coined the term PGPR (plant growth promoting rhizobacteria) in the late 1970's (Kloepper and Schroth, 1978), and ever since it has been increasingly appearing in publications from around the world. Plant growth promoting rhizobacteria include multiple genera of soil bacteria, which stimulate the growth and development of plants in whose rhizosphere they remain associated for the major part of their life cycle (Saharan and Nehra, 2011; Pandey et al., 2012). The relationship of PGPR with the host may either be restricted to the rhizosphere (some colonize the rhizosphere, rhizoplane, superficial intercellular spaces or dead root cell layers) or endophytic (while some actually reside within apoplastic spaces inside the host plant with or without forming specialized structures such as nodules) (Vessey, 2003). Bashan and Holguin (1998) proposed the division of PGPR into two classes: viz., biocontrol-PGPB (plant growth promoting bacteria) and PGPB but this classification is difficult to follow due to the overlapping features of most PGPR. A more feasible classification of PGPR, is their separation as extracellular (e-PGPR), to denote those existing in the rhizosphere, on the rhizoplane, and intracellular (i-PGPR), to denote bacteria that exist in the spaces between the cells of the root cortex or in specialized nodular structures (Gray and Smith, 2005).

PGPR improve plant growth by indirect or direct mechanisms although the difference between the two is not always distinct (Lugtenberg and Kamilova, 2009; Ashraf et al., 2013). Direct mechanisms include the improvement of nutrient availability to the plant by the fixation of atmospheric nitrogen, production of iron chelating siderophores, organic matter mineralization (thereby meeting the nitrogen, sulfur, phosphorus nutrition of plants), and solubilization of insoluble phosphates. Another important direct mechanism involves the production of plant growth hormones and the stress regulating hormone 1-aminocyclopropane -1-carboxylate (ACC) deaminase. Indirect mechanisms include inhibition of microorganisms that have a negative effect on the plant (by niche exclusion) viz. hydrolysis of molecules released by pathogens, synthesis of enzymes that hydrolyze fungal cell walls, synthesis of HCN, improvement of symbiotic relationships with rhizobia and mycorrhizal fungi, and insect pest control (Das et al., 2013). The number of bacterial species identified as PGPR has increased greatly in the recent past due to the increased availability of molecular tools, for the study of various habitats and the revelation of modes of action of various bacterial species. The term PGPR presently encompasses diverse genera from different sources and habitats representing great physiological, functional, ecological and molecular diversity and their absence from one such source/habitat was more likely due to inadequate techniques of isolation and detection.

Numerous laboratory, greenhouse and field studies are available on the screening and utilization of PGPR for plant growth and a number of PGPR strains have been commercialized. The commercially utilized PGPR strains include species of *Agrobacterium, Azospirillum, Azotobacter, Bacillus, Burkholderia, Delftia, Paenibacillus macerans, Pantoea agglomerans, Pseudomonas, Rhizobium* and *Serratia* (Glick, 2012). However PGPR inoculated crops represents only a small fraction of worldwide agricultural practice. Another issue that needs to be considered here is that many highly efficient strains reported in literature have remained as artifacts of academic value only and have not metamorphosized as commercial products (Bashan et al., 2014). This is due to inconsistent and varied responses obtained in field trials, which are largely influenced by the growing conditions and crop in which they were inoculated. The successful establishment of an introduced bacterial inoculant therefore depends on its survival in soil and the compatibility with the crop on which it is inoculated, besides its interaction with indigenous microflora while several other environmental factors also play an important role in determining the final outcome of the inoculation (Martínez-Viveros et al., 2010). Glick (2012) listed some important aspects to be considered for extensive commercialization of PGPR which include (i) determination of the traits that are most important for efficacious functioning and the subsequent selection of PGPR strains (ii) consistency among regulatory agencies in different countries regarding release in environment and safety issues (iii) better understanding of advantage and disadvantage of using rhizospheric/endophytic bacteria (iv) selection of the strain that works well in a specific environment i.e. those that work in warm and sandy soil versus those that work well in cold and wet environment (v) development of more effective means of application in different setting e.g. nursery versus field (vi) better understanding of the possible interaction between PGPR and soil fungi and host. An ideal PGPR should possess high rhizosphere competence, enhanced plant growth capabilities, ease of mass multiplication, a broad spectrum of action, excellent and reliable biological control activity (wherever applicable), should be safe for environment, should be compatible with other rhizobacteria, and must tolerate desiccation, heat, oxidizing agents and UV radiations (Nakkeeran et al., 2005). Considering the factors discussed above it is quite obvious that the search for functional PGPR inoculants is a dynamic process with ample scope for refinement both in strain selection and inoculant technology. This review will therefore attempt to throw some more light on some novel and lesser utilized PGPR with special reference to the genera *Azoarcus, Exiguobacterium, Methylobacterium, Paenibacillus* and *Pantoea*. The most important features of these PGPR that make them potential candidates for application and future commercialization are listed in Fig. 1.

1.1. *Azoarcus*

Azoarcus spp. were originally isolated as endophytic diazotrophs from *Kallar* grass, an undomesticated C_4 plant highly tolerant to soil salinity, alkalinity and water lodged conditions, and widely distributed in tropical to subtropical regions ranging from Australia to Africa. In the Punjab province of Pakistan, it grows as a pioneer plant on saline-sodic, alkaline soils having low fertility (Sandhu and Malik 1975). It grows luxuriantly without the addition of any nitrogenous fertilizer, giving harvests of 20–40 metric tons of hay per ha per year (Sandhu et al., 1981). Though it is associated with several nitrogen-fixing bacteria (Zafar et al., 1987), the diazotrophs that predominate inside the roots were Gram-negative rods which could not be assigned to any previously described taxa and thus a new genus *Azoarcus* was proposed consisting of two