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Review Article

PGPR Induced Systemic Tolerance in Plant

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A B S T R A C T

Plant Growth Promoting Rhizobacteria (PGPR) has secured worldwide importance and acceptance for agricultural and environmental benefits very recently. Plant growth promoting rhizobacteria (PGPR) are precious bacteria that colonize plant roots and enhance plant growth by a wide variety of mechanisms. PGPR affect plant growth in two different ways, directly indirectly. These microorganisms have the potential tools for disease control and growth promotion in various crops and patho-systems which involve multidisciplinary approaches to understand adaptation of PGPR to the rhizosphere, mechanisms of root colonization, effects on plant physiology and growth, bio fertilization, induced systemic resistance, bio control of plant pathogens, production of determinants *etc.* However, fewer reports have been published on PGPR‘s as elicitors of tolerance to abiotic stresses, such as drought, salt and nutrient deficiency or excess. PGPR are the potential tools for sustainable agriculture and trend for the future.

Introduction

Over the last decades, world agriculture experienced high increase in crop yield. This was achieved through high input of inorganic fertilizers and pesticides, and mechanization driven by fossil fuel. Over the years this led to serious environmental problems such as depletion of soil quality and health, ocean and ground water pollution, and emergence of resistant pathogens. It is a big challenge to feed the increasing world population on decreasing farmland areas without damaging environment. One efficient way to decrease negative environmental impact created from continued use of chemical fertilizers, herbicides and pesticides, by the use of plant growth promoting rhizobacteria (PGPR). This term was first defined by Kloepper and Schroth (1978) to describe soil bacteria that colonize the rhizosphere of plants, growing in, on or around plant tissues that stimulate plant growth by several mechanisms. PGPR help for the crops by maintaining soil health through versatile mechanisms are nutrient cycling and uptake of nutrients, suppression of plant pathogens, induction of resistance in plant host, direct stimulation of plant growth (Kloepper *et al.*, 2004; Haas and Defago, 2005).

The term induced resistance is a generic term for the induced state of resistance in plants triggered by biological or chemical inducers, which protects nonexposed plant parts against future attack by pathogenic microbes and herbivorous insects (Kuc, 1982). Beneficial microbes in the microbiome of plant roots improve plant health. The root system plays a vital role in uptake of water and nutrients, mechanical support providing anchorage to the ground, and for food and nutrient storage. Some PGPR also elicit physical or chemical changes related to plant defense, a process referred to as 'induced systemic resistance' (ISR) (Loon, *et al.*, 2004). Induced systemic resistance (ISR) as an important mechanism by which selected plant growth promoting bacteria and fungi in the rhizosphere prime the whole plant body for enhanced defense mechanism against a broad range of pathogens and insects. A wide variety of root associated mutualists, including *Pseudomonas*, *Bacillus*, *Trichoderma*, and mycorrhiza species sensitize the plant immune system for enhanced defense without directly activating costly defenses (Pieterse *et al.,* 2014)

The role of plant growth promoting rhizobacteria in promotion of plant growth as well as in reducing biotic stress has been well documented earlier itself.

The bacterial determinants of "induced systemic resistance" (ISR) as well as its activation pathways in plants have been significantly evaluated during the past decade. The role of PGPRs in "induced systemic tolerance" (IST) to abiotic stresses has only been revealed or studied very recently. The whole impact of microbe mediated elicitation responses in plants, whether at the biochemical, the molecular, or the physical level may lead to protection against biotic and abiotic stresses and, in a cumulative manner, constitutes the basis of eco-friendly stress management strategy. Only fewer reports have been published on PGPR as elicitors of tolerance to abiotic stresses, such as drought, salt and nutrient deficiency or excess. Induced systemic tolerance (IST) for PGPR induced physical and chemical changes in plants that result in increased tolerance to abiotic stress (Yang *et al.,* 2010). This review gives brief overview of PGPR mediated stress tolerance responses in plants to abiotic stress and provides environment friendly approach to increase crop production and health, development of sustainable agriculture and commercialization by using of plant growth promoting rhizobacteria (PGPR).

Role of PGPRS in abiotic stress tolerance

Drought Stress

Drought has a major impact on plant growth and development, limiting crop production throughout the world. Soils too dry for crop production cover 28 per cent of the earth's land. Other abiotic stresses that include a component of cellular water deficit most usually noted are salinity and low temperature stresses can also severely limit crop production. Major research efforts are currently directed at understanding the mechanism of plant response to conditions in which water limits plant growth and development in order to identify gene products that confer adaptation to water deficit stress. Yamaguchi and Shinozaki (2006) observed that plant growth and productivity are adversely affected by water stress. Growing of plants with increased survivability during water stress is a major objective or goal in the breeding crops. Water use efficiency (WUE), a parameter of crop quality and performance under water deficit is an important selection trait. Survival of any plant depends on its adaptation. Ability to perceive the changes in local environment is essential for its adaptation. Upon encountering a challenge in rhizosphere, roots typically respond by secreting certain small molecules and proteins (Stintzi and Browse, 2000).

PGPR have shown positive results in plants, some parameters like germination rate, tolerance to drought, weight of shoots and roots, yield and plant growth (Kloepper *et al.,* 2004). Results found in different cereal crops and tomato seedlings where PGPR inoculation enhanced root growth, shoot growth and uptake of mineral nutrient, the growth promoting, effects of PGPR inoculation are mainly derived from morphological and physiological changes in inoculated plant roots and enhancement in water and plant nutrient uptake (Jaizme-Vega *et al.,* 2004; Rodriguez-Romero *et al.,* 2005; Kang *et al.,* 2010). When plants are exposed to stress conditions they respond increasing ethylene levels that lead to an increase in cell and plant damage (Argueso *et al.,* 2007). A high concentration of ethylene can be harmful because it induces defoliation and other cellular processes that may affect crop development (Desbrosses *et al.,* 2009). Glick *et al.,* (2007) have proposed that some PGPR function as a sink for 1-aminocylopropane-1-carboxylate (ACC), the immediate precursor of ethylene in higher plants, by hydrolyzing it to a-ketobutyrate and ammonia, and in this way, promote root growth. They have suggested that the ACC-deaminase trait of rhizobacteria could be used for efficient isolation/selection of effective PGPR. Cho *et al.,* (2008) observed, 2R, 3R-butanediol, a volatile metabolite of *P. chlororaphis* O6 in *Arabidosis* increased in free SA after drought stress suggesting a primary role for SA signaling in induced drought tolerance.

Different groups of *Pseudomonas* are reported to be predominant in the rhizosphere regions of different crops. *Pseudomonas* strains exhibit a wide range of PGPR property by producing Indoleacetic acid (IAA), gibberellic acid and cytokinins; phosphate solubilization and other nutrients (Vyas and Gulati, 2009). Cho *et al.,* (2011) observed that root colonization of *Arabidopsis thaliana* with *Pseudomonas chlororaphis* O6 under water stress condition showed that genes encoding defense proteins in signaling pathways regulated by jasmonic acid and ethylene, such as VSP1 and PDF1.2, were up regulated.

Wang *et al.,* (2012) studied the combination of three plant growth promoting rhizobacterium (PGPR) strains (*Bacillus subtilis* SM21, *Bacillus cereus* AR156, and *Serratia* sp. XY21) termed as BBS, on cucumber plants. In water stress condition BBS treated plants decreased the leaf monodehydroascorbate (MDA) content and relative electrical conductivity by 40 per cent and 15 per cent, respectively. Increased the leaf proline content and the root recovery intension by 3.45 fold and 50 per cent. Thus conferring IST in cucumber plants in drought condition. Inoculation of two bacterial endophytes *Burkholderia phytofirmans* strain PsJN and *Enterobacter sp.*FD17 on two maize cultivars under drought stress conditions significantly increased shoot biomass, root biomass, leaf area, chlorophyll content, photosynthesis and photochemical efficiency of PSII (Naveed *et al.,* 2014). Zhou *et al.,* (2016) observed *Bacillus megaterium* BOFC15 on Arabidopsis plants showed increased levels of polyamines (PA) and abscisic acid (ABA) content under drought stress and polyethylene glycol (PEG) induced stress conditions. Inoculation with BOFC15 remarkably increased plant biomass, improved root system architecture, and augmented photosynthetic capacity in plants.

Salinity Stress

Salinity stress affects plant growth by osmotic effect of salts in the outside solution and ion toxicity due to salt build up in transpiring leaves in a second phase and also induction of nutrient deficiencies to the plants (Wyn Jones and Storey, 1981). Higher levels of soil salinity stress can suppress the seed germination and seedling growth rate due to the combined effect of high osmotic potential and specific ion toxicity (Grieve and Suarez, 1997). In addition to facilitating plant growth, PGPR can protect plants from the deleterious effects of environmental stresses including flood, drought, salinity, heavy metals and phytopathogens (Mayak *et al.,* 2004; Yildirim *et al.,* 2006). PGPR tested on the growth of pepper, bean, canola and lettuce under salt stress ameliorated deleterious effects of salinity (Glick *et al.,* 1997). Reports also show an enhancement of squash plant when applied directly or as a transplant under salinity stress (Yildirim *et al.,* 2006).

Avoiding salt damage is always a challenge for increasing plant production. Strategies for alleviating salt stress involves, developing salt resistant cultivars, leaching excess soluble salts from the upper to the lower layer of soil and ameliorating saline soils under cultivation (Yue *et al.,* 2007). In recent years, a new approach has been developed to alleviate salt stress in plants by incorporating the crop seeds and seedlings with plant growth promoting rhizobacteria (PGPR). Many researchers reported that the seeds inoculated with PGPR increase the plant height, leaf size, root length and dry matter of tomato (Mayak *et al.,* 2004), groundnut (Saravanakumar and Samiyappan, 2007), red pepper (Siddikee *et al.,* 2011) and rice (Nautiyal *et al.,*2013; Nakbanpote *et al.,* 2014) in the saline soils. PGPR found in association with plants grown under chronically stressful conditions including high salinity may have been adapted to the stress conditions and could provide a significant benefit to the plants. The diversity of the *Pseudomonas* populations assessed from three different plant rhizospheres, namely pearl millet, cotton and paddy, grown in increased salinity along the coastline of Southern India caused a predominant selection of salt tolerant species, in particular *P. pseudoalcaligenes* and *P. alcaligenes*, irrespective of the host rhizosphere. (Rangarajan *et al.,* 2002).

Total 102 strains genotyping patterns analyzed through BOX-PCR using BOX primer 5‘-ACGGCAAGGCG ACGCTGACG- and saline tolerant *Pseudomonas* spp. with tolerance to salinity upto 2M was observed. The saline tolerant *P. aeruginosa, P. alcaligenes, P. fluorescens* and *P. pseudoalcaligenes* controlled Bacterial blight (*X. oryzaea*) of rice in ADT-36 and yield increase upto to 20 to 30 per cent and disease reduction up to 50 per cent (Prabavathy *et al.,* 2011). Thus identifying appropriate strains for specific ecological niches is in urgent need to address the issues related to the use of PGPR for good agriculture practices.

Plant growth promoting rhizobacterial strains can produce certain enzymes such as chitinases, dehydrogenase, β-glucanase, lipases, phosphatases, proteases *etc.* (Joshi *et al.,* 2012, Hayat *et al.,* 2010) exhibit hyperparasitic activity, attacking pathogens by excreting cell wall hydrolases. Through the activity of these enzymes, plant growth promoting rhizobacteria play a very significant role in plant growth promotion particularly to protect them from biotic and abiotic stresses by suppression of pathogenic fungi including *Botrytis cinerea, Sclerotium rolfsii, Fusarium oxysporum, Phytophthora* sp., *Rhizoctonia solani,* and *Pythium ultimum* (Nadeem, *et al.,* 2013, Upadyay *et al.,* 2012). Upadhyay *et al.,* (2012a) investigated the effects of two salt tolerant PGPR (*B. subtilis* and *Arthobacter sp*.) on wheat plants under different salinity regimes. The consortium inoculation of PGPR found to alleviate salt tolerance in plants.

Plant growth promoting rhizobacterial (not all PGPR) producing exo polysaccharides can also bind cations, including Na^+ suggesting a role in salinity stress reduction by decreasing the Na^+ content available for plant uptake (Arora *et al.*, 2013). PGPR also help plants resist salt stress by increasing the activity of both antioxidant enzymes and non-enzymatic antioxidants (Gururani *et al.*, 2012: Habib *et al.*, 2016). Another study showed that inoculation with PGPR, including *Bacillus subtilis, Bacillus atrophaeus, Bacillus sphaericus, Staphylococcus kloosii, and Kocuria erythromyxa*, increased both the shoot and root weights (fresh and dry) of strawberry plants growing under high salinity conditions (Karlidag *et al.*,2013).

Water Logged Condition

Water logging means, displacement of oxygen by excess water in soil pores hinders root respiration. Other gases detrimental to root growth, such as carbon dioxide and ethylene, also accumulate in the root zone and affect the plants. Flooding is a common abiotic stress that can deleteriously affect the growth of many different plants. As a consequence of flooding, plant roots typically become hypoxic or oxygen limited. This leads to a plant stress response including the synthesis of increased amounts of the enzyme ACC synthase as well as other stress proteins (Li *et al.*, 2012). However, it is possible to protect plants from a significant portion of the damage caused by flooding by treating them with ACC deaminase-producing plant growth promoting bacteria (Barnawal *et al.*, 2012; Grichko and Glick 2001; Li *et al.*, 2013).

Grichko and Glick (2001) studied the effect of inoculation with ACC deaminase PGPR on tomato subjected to flooding. Seeds of wild type tomato plants were inoculated either with *Pseudomonas putida* UW4, *Enterobacter cloacae* CAL2, *P. putida* (ATCC17399/pRKACC) or *P. putida* (ATCC17399/ pRK415); the first three of these bacterial strains were carrying and expressing the gene for ACC deaminase. Tomato plants inoculated with ACC deaminase PGPR showed substantial tolerance to flooding implying that bacterial ACC deaminase lowering the effects of ethylene induced stress.

Exopolysaccharide production play a central role maintaining water potential, aggregating soil particles, ensuring obligate contact between plant roots and rhizobacteria, sustaining the host under conditions of stress (saline soil, dry weather, or water logging) or pathogenesis and thus are directly responsible for plant growth and crop production (Pawar *et al.*, 2016).

Freezing Injury

Low temperature is one of the most important stress factors limiting the growth and productivity of plants. Low temperature freezes the cells in a plant, causing damage and interrupts the pathways for nutrients and water to flow. This occurs on clear nights without wind when plants radiate more heat to the atmosphere than they received. Chilling alters the physical properties of the walls of extending cells within the meristematic zone. Selvakumar *et al.*, (2008) show that cold tolerance of *Serratia marcescens* strain SRM (MTCC 8708) was most effective in decreasing the freezing injury. Similar data by Taulavuori *et al.,* (2005) and Olgun *et al.,* (2005) stated that mineral application to plant reduced frost injury of plants. Bensalim *et al.,* (1998) revealed that a plant growth promoting rhizobacterium, *Pseudomonas sp* strain PsJN helped potato plants in maintaining normal growth under heat stress.

The beneficial effect of endophyte bacteria may be through their induction of the synthesis of proteins, which reduces the development of symptoms, and also through the prevention of some sets of reactions, produce the symptoms of chilling injury. Because the nucleation temperature of plants increases with increasing population sizes of Ice^+ bacteria, preemptive competitive exclusion of Ice^+ bacteria with naturally occurring non-ice nucleation-active bacteria could be an effective and practical means of frost control. The management of frost injury by reducing Ice^+ bacterial populations might become an important new method of frost control. Some findings indicate that PGPRs also helps in resistance to cold stress. Barka *et al.,* (2006) reported that seed inoculation with PGPB has an early effect on root and shoots growth of plants. The positive effect of the PGPR on alleviation of cold stress could be attributed to the bacterial ability to produce or modify plant hormones including gibberellins, which play a key role in germination.

Barka *et al.,* (2006) stated that In vitro inoculation of *Vitis vinifera* L. cv. with a PGPR; *Burkholderia phytofirmans* strain PsJN, increased grapevine growth and physiological activity at a low temperature (4^0C). The benefits of bacterization were noticed on root growth, plantlet biomass and improved plantlets. They concluded that *B. phytofirmans* strain PsJN inoculation enhances grapevine growth and improves its ability to withstand cold stress. Cheng *et al.,* (2007) has also reported that a psychrotolerant ACC deaminase bacterium *P*seudomonas *putida* UW4 promoted canola plant growth at low temperature under salt stress. These few studies clearly demonstrated the potential of ACC deaminase in normalizing plant growth exposed to temperature extremes by lowering the accelerated ethylene induced by temperature stress. PGPB application may also assist growth by alleviating negative effects of cold stress via promoting accumulation of antioxidant enzyme activities, decreasing reactive oxidative oxygen species (ROS) such as H_2O_2, O_2, and OH in response to cold stress.

Microbial interaction with plants is an integral part of the living ecosystem and also natural partners that modulate local and systemic mechanisms in plants to offer defense under adverse external conditions. Under the continuous pressure of increasing climatic alterations, it now becomes more imperative to define and interpret plant microbe relationships in terms of protection against abiotic stresses. Abiotic stresses are the most critical constraints which hampers agricultural productions in many areas worldwide. ISR inducing PGPR is a useful tool to reduce diseases caused by pathogens and increases abiotic stress tolerance capacity to plants. There are only few research studies related to PGPR‘s as elicitors of tolerance to abiotic stresse.

So mainly we need focused research on related abiotic stress tolerance with the help of PGPRs by using biotechnological tools. Multiomics approaches comprising genomics, transcriptomics, proteomics, metabolomics and phenomics integrate studies on the interaction of plants with microbes and their external environment and generate multi layered information that is use full for development of sustainable agriculture.

Future Prospects

Future research in PGPR will rely on the development of molecular and biotechnological approaches to increase our knowledge of PGPR and to achieve an integrated management of soil microbial populations.

Identification of efficient location/crop/soil specific strains for N-fixing, P, Zn-solubilizing and absorbing to suit different agro climatic conditions.

Improvement of strains through biotechnological methods.

Integrating ISR-triggering PGPR into abiotic management programs in conjunction with other strategies will be a worthwhile approach to explore.

Optimizing growth condition and increased self-life of PGPR products, tolerate adverse environmental condition, higher yield and cost effective PGPR products for use of agricultural farmer will be also helpful.

Identifying the key regulatory factor that enables plant PGPR interaction and clearly mapping out the molecular interaction between a plant microbe interaction using omic approaches.

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