The Pharma Innovation Journal 2022; 11(6): 1685-1692

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(6): 1685-1692
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www.thepharmajournal.com
Received: 02-03-2022
Accepted: 12-05-2022

Role of plant growth promoting rhizobacteria under saline condition: Review

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Abstract

Salinity is one of the most dreadful environmental factors limiting the productivity of crop plants because most of the crop plants are susceptible to salinity caused by high concentrations of salts in the soil, and the area of land affected by it is increasing day by day. Plant growth-promoting rhizobacteria (PGPR) are the rhizosphere bacteria that can increase plant growth by a extensive variety of mechanisms like phosphate solubilization, siderophore production, biological nitrogen fixation, rhizosphere engineering, production of 1 Aminocyclopropane-1- carboxylate deaminase (ACC), quorum sensing (QS) signal interference and inhibition of biofilm formation, phytohormone production, exhibiting antifungal activity, creation of volatile organic compounds (VOCs), induction of systemic resistance, promote beneficial plant-microbe symbioses etc. Growth promoting substances are probable to be produced in large quantities by these rhizosphere microorganisms that influence indirectly on the generally morphology of the plants. Bacterial inoculates have been applied as biofertilizers and can amplify the effectiveness of phytoremediation. Inoculating plants with non-pathogenic bacteria can provide 'bioprotection' against biotic stresses, and some root-colonizing bacteria increase tolerance against abiotic stresses such as salinity. Systematic identification of bacterial strains given that cross-protection against multiple stressors would be highly valuable for agricultural production in changing environmental conditions however, recent work shows that PGPR also elicit so-called 'induced systemic tolerance to salt. As we discuss here, PGPR might also increase nutrient uptake from soils, thus reducing the need for fertilizers and prevent the accumulation of nitrates and phosphates in agricultural soils. The progress to date in using the rhizosphere bacteria in a variety of applications related to agricultural improvement along with their mechanism of action with special reference to plant growth-promoting traits are summarized and discussed in this review.

Keywords: Plant growth promoting rhizobacteria, salt stress, bacterial strain, rhizosphere

Introduction

Approximately 11 million hectares of land are affected by salt and chemical stress, and an additional 16 million hectares are affected by flooding and physical stress. Production and cultivation of crops including salt stress is one of the most devastating environmental pressures, leading to a significant reduction in acreage, Crop productivity and quality (Yamaguchi and Blumwald, 2005) [81]; Shahbaz and Ashraf,2013) [72]. approx 20% of the world is cultivated, 33% of irrigated farmland is affected by high levels of salinity. In addition, high salinity areas increase at a rate of 10% annually for a variety of reasons, including low rainfall, high surface evaporation, weathering of pristine rocks, saltwater irrigation, and poor cultural practices. It is estimated that more than 50% of arable land will be salted by 2050. Soil salinity causes plant stress in two ways: (1) making water uptake by the roots more difficult, and (2) causing plant toxicity via accumulation of high salt concentrations in the plant (Munns and Tester, 2008) [55]. A soil is saline once its saturated paste extract EC will reach 4.00 deciSiemens/meter (dS/m). Plants growing in saline soils experience osmotic stress due to increases in the concentration of Na+ and Cl), leading to ionic imbalance in tissues and resulting inhibition of nutrient uptake (Hasegawa *et al*., 2000) [32]. Around 6.727 million ha area in India which is around 2.1% of geographical area of the country is salt affected, of which 2.956 million ha is saline and the rest 3.771 million ha is sodic (Arora *et al.*, 2016) [5] Kloepper and Schroth (1978) introduced the term 'rhizobacteria' to the soil bacterial community that competitively colonized plant roots and stimulated growth and thereby reducing the incidence of plant diseases. Kloepper and Schroth (1981) termed these beneficial rhizobacteria as plant growth-promoting rhizobacteria (PGPR). PGPR can be defined as the indispensable part of rhizosphere biota that when grow an association with the host plants can stimulate the growth of the host.

PGPR seemed as successful rhizobacteria in getting established in soil ecosystem due to their high adaptability in a wide variety of environments, faster growth rate and biochemical versatility to metabolize a wide range of natural and biotic compounds. Plant growth-promoting rhizobacteria (PGPR) are the rhizosphere bacteria that can enhance plant growth by a wide variety of mechanisms like phosphate solubilization, siderophore production, biological nitrogen fixation, rhizosphere engineering, production of 1 Aminocyclopropane-1- carboxylate deaminase (ACC), quorum sensing (QS) signal interference and inhibition of biofilm formation, phytohormone production, exhibiting antifungal activity, production of volatile organic compounds (VOCs), induction of systemic resistance, promoting beneficial plant-microbe symbioses, interference with pathogen toxin production etc. Growth promoting substances are likely to be produced in large quantities by these rhizosphere microorganisms that influence indirectly on the overall morphology of the plants. The problem of soil salinization is a scourge for agricultural productivity worldwide. Crops grown on saline soils suffer on an account of high osmotic stress, nutritional disorders and toxicities, poor soil physical conditions and reduced crop productivity. The present review focuses on the enhancement of productivity under stressed conditions and increased resistance of plants against salinity stress by application of plant growth promoting microorganisms.

Issues of soil salinization

Salinity of soil is an massive problem for agriculture under irrigation. The soils are frequently saline In the hot and dry regions of the world with low agricultural prospective. In these areas most crops are grown under irrigation, and to aggravate the trouble, insufficient irrigation management leads to secondary salinization that affects 20% of irrigated land worldwide (Glick *et al.*, 2007) [24]. a major human activity is Irrigation of agricultural land, which repeatedly leads to secondary salinization of land and water resources in arid and semi-arid conditions. Salts in the soil transpire as ions (electrically charged forms of atoms or compounds). Ions are free from weathering minerals in the soil. They may also be functional through irrigation water or as fertilizers, or sometimes migrate upward in the soil from shallow groundwater. When precipitation is inadequate to leach ions from the soil profile, salts gather in the soil consequential soil salinization (Blaylock *et al.*, 1994) [12]. All soils restrain some water-soluble salts. Plants absorb essential nutrients in the form of soluble salts, but disproportionate increment strongly suppresses the plant growth. During the last century, physical, chemical and/or biological land degradation processes have resulted in serious consequences to global natural resources (e.g. compaction, inorganic/organic contamination, and diminished microbial activity/diversity). The area under the affected soils continues to intensify each year due to introduction of irrigation in new areas (Patel *et al.*, 2011) [63]. Salinization is recognized as the major threats to environmental resources and human health in numerous countries, disturbing almost 1 billion ha worldwide/globally instead of about 7% of earth's continental extent, just about 10 times the size of a country like Venezuela or 20 times the size of France (Metternicht and Zinck, 2003) [50]. It has been estimated that an probable area of 7 million hectares of land is covered by saline soil in India (Patel *et al.*, 2011) [63].

Impact of salinity on plants

Agricultural plants show off a spectrum of responses below salt stress. Salinity now no longer best decreases the rural manufacturing of maximum plants, however also, consequences soil physiochemical properties, and ecological stability of the area. The affects of salinity include-low agricultural productivity, low financial returns and soil erosions, (Hu and Schmidhalter, 2002) [35] Salinity consequences are the effects of complicated interactions amongst morphological, physiological, and biochemical strategies such as seed germination, plant growth, and water and nutrient uptake (Akbarimoghaddam *et al.*, 2011; Singh and Chatrath, 2001) [2, 73] Salt affects almost every aspect of plant development, including germination, vegetative growth, and reproductive development. Soil salt leads to ionic toxicity, osmotic stress and nutrients (N, Ca, K, P, Fe, Zn) Limits plant deficiency and oxidative stress, and thus water intake from the soil. Soil salt significantly reduces plant uptake of phosphorus (P), as phosphate ions precipitate with Ca ions (Bano and Fatima, 2009) [9]. Some elements, such as sodium, chlorine, and boron, have certain toxic effects on plants. Excessive accumulation of sodium in the cell wall can quickly lead to osmotic stress and cell death (Munns, 2002) [52]. Plants sensitive to these elements can be affected by relatively low salinity if the soil contains sufficient toxic elements. High levels of soil salt can upset the nutrient balance of plants and impair the uptake of some nutrients, as many salts are also plant nutrients (Blaylock *et al.*, 1994) [12].

Salt also affects photosynthesis primarily by reducing leaf area and chlorophyll content. To a lesser extent due to reduced stomatal conductivity and efficiency of Photosystem II (Netondo *et al.*, 2004) [61]. Salt inhabits microspore formation and ovary elongation and adversely affects reproductive development by promoting programmed cell death, oocyte abortion, and fertilized embryo aging in some tissue types. salt water growth medium has many adverse effects on plant growth due to the low osmotic potential of soil solutions (osmotic stress). Specific ionic effects (salt stress), nutritional imbalances, or a combination of these factors (Ashraf, 2004) [1] All these factors adversely affect plant growth and development At the physiological and biochemical levels (Munns and James, 2003) [53]. and at the molecular level (Tester and Davenport, 2003) [76]. To assess a plant's tolerance to salt stress, plant growth or survival is measured when integrating upregulation or down regulation of many physiological mechanisms that occur within the plant. Osmolality balance is essential for plants growing in saline medium. When this balance is lost, turbidity is lost, cells become dehydrated, and eventually cell death occurs. On the other hand, the adverse effects of salt on plant growth can also result from impaired delivery of photosynthetic anabolic or hormones to growing tissues (Ashraf, 2004) [1]. Ion toxicity is the result of Na + substitution of K + in biochemical reactions and Na + and Cl-induced protein conformational changes. For some enzymes, K + acts as a cofactor and cannot be replaced by Na +. High K + concentrations are also required for tRNA binding to the ribosome and therefore for protein synthesis (Zhu, 2002) [89].

The adverse effect of salinity content on plant development is low during the reproductive period. Wheat plants highlighted at 100 to 175 mm have a significant decrease in the tip of the tip, delaying the appearance of spikes, and show a decrease in fertility, resulting in a decrease in cereal yield. But, The Na +

and CL concentration at the injection tip of these wheat plants are less than 50 and 30 mm, respectively, which is too low to limit the metabolic response (Munns and Rawson, 1999) [54]. Thus, the adverse effect of salt content may be attributed to the salt stress effect on cell cycle and differentiation. Salt is temporarily blocked cell cycle by reducing the formula Activity of cycles and cycle kinases that result in cells in mitotic tissue, thereby limiting growth. It also reduces the activity of cycle-independent kinases Post-translational inhibition in salt stress. Recent reports have also shown that salt adversely affects plant growth and development, impeding seed germination and seedling growth. Enzyme activity (Seckin *et al.*, 2009) [71].

Microorganisms a powerful tools of stress alleviation

Several strategies have been developed to reduce the toxic effects of saline stress (Dimkpa *et al.*, 2009) [18]. For the reduction of abiotic stress in crops the use of plant genetic engineering and more recently plant growth-promoting bacteria (PGB) are the main source. (Wang *et al.*, 2003) [80]. The role of microorganisms in promoting plant growth, nutritional management and disease control is well known and established. These beneficial microorganisms It colonizes the rhizosphere / endoderm of plants and promotes plant growth through a variety of direct and indirect mechanisms (Nia *et al.*, 2012; Ramadoss *et al.*, 2013) [62, 66]. Previous studies have shown that the use of PGPB has become a promising alternative to reducing salt-induced plant stress (Yao *et al.*, 2010) [83], and the role of microorganisms in the management of biological and abiotic stress. It suggests that it is important the subject of PGPR-induced abiological stress tolerance is Recently reviewed (Dodd and Perez Alfocea, 2012; Yang *et al.*, 2009) [19, 82]. The term induced systemic tolerance (IST) has been anticipated for physical and chemical changes in PGPR induction that result in amplified tolerance to abiotic stress. PGPR indirectly by reducing phytopathogens or by promoting the uptake of nutrients through the production of phytohormones (auxin, cytokinin, gibberellin, etc.), the enzymatic reduction of plant ethylene levels, and / or the production of siderophore. Promotes plant growth (Kohler *et al.*, 2006) [42]. demonstrated the beneficial effect of the PGPR *pseudomonas mendocina* strain on the stabilization of soil aggregates. These rhizobacteria can be used in different ways when plant growth promotion is required (Lucy *et al.*, 2004) [42]. The two major ways through which PGPR can facilitate plant growth and development include direct and indirect mechanisms (Glick *et al.*, 1995) [27]. Indirect growth encouragement occurs when PGPR prevent or reduce some of the harmful effects of plant pathogens by one or more of the several different mechanisms (Glick and Bashan, 1997) [23]. These include inhibition of pathogens by the production of substances or by increasing the resistance of the host plant against pathogenic organisms (Cartieaux *et al.*, 2003; Nehl *et al.*, 1997) [13, 60]. For example, PGPR produce metabolites which reduce pathogen population and/or produce siderophores that reduce the iron availability for certain pathogens thereby causing reduced plant growth (Arora *et al.*, 2001; Bhattacharyya and Jha, 2012; Kloepper, 1996) [5, 11, 41]. The Plants inoculated with *P. mendocina* had significantly larger shoot biomass than controls, suggesting that inoculation with selected PGPR may be an effective means of reducing salt stress in salt-sensitive plants. Bacteria isolated from various stressed habitats have stress-tolerant abilities as well as plant growth-promoting properties. It is a potential candidate for bacterial bacterialization. When inoculated with these isolates, the plant exhibits improvements in root and sprout length, biomass, chlorophyll and other biochemical levels. Carotenoids and proteins (Tiwari *et al.*, 2011) [77]. They also assist the growth of their host plant by fixing atmospheric nitrogen, and synthesizing and secreting siderophores which may solubilize and sequester iron thereby increasing its availability for plant uptake, producing phytohormones, and solubilizing minerals such as phosphorus so as to increase its availability Studies on the interaction of PGPR with other microorganisms and their effect on the physiological response of crops between different The soil salinization system is still in its infancy. Vaccination with selected PGPR and other microorganisms may serve as a potential tool for reducing salt stress in salt-sensitive animals. grain. Therefore, extensive research is needed in this area, and the use of PGPR and other symbiotic microorganisms may help develop strategies to promote sustainable agriculture in salt soils.

Mitigation of salinity stress in plants by helpful Rhizobacteria

Intense populations of microorganisms colonize the root zone of plants. The major reason the rhizosphere is a far more striking habitat than bulk soil is the organic carbon provided by plant roots. More than 85% of the total organic carbon in the rhizosphere can instigate from sloughed-off root cells and tissues. Moreover, plants supply organic carbon to their surroundings in the form of root exudates. Rhizobacteria counter to root exudates by means of chemotaxis towards the exudate source; and in such scenario, capable bacteria tend to modulate their metabolism towards optimizing nutrient achievement (Hardoim, Van Overbeek & Van Elsas 2008) [31] In this regard, the position of bacterial motility of their interplay with vegetation has been demonstrated (Lugtenberg and Kamilova 2009) [46]. The microorganisms known as PGPR residing in the soil environment can cause impressive changes in plant growth by the construction of growth regulators and/or improving plant nutrition by supplying and facilitate nutrient uptake from soil (Zahir *et al.*, 2004) [85]. moreover, many of these rhizobacterial strains can also recover plant tolerance against salinity, drought, flooding, and heavy metal toxicity and, therefore, enable plants to survive under adverse environmental conditions (Belimov *et al.*, 2001; Glick, 2010; Ma *et al.*, 2011; Mayak *et al.*, 2004a; Nadeem *et al.*, 2007; Sandhya *et al.*, 2009; Zahir *et al.*, 2008) [10, 28, 47, 49, 57, 69, 88]. Another various free-living soil bacteria are considered as plant growth promoting rhizobacteria, all bacterial strains of a exacting genus do not have identical metabolic capabilities for improving plant growth to the same extent (Gamalero *et al.*, 2009) [21]. PGPR can also enhance plant resistance against diseases by manipulating host-plant vulnerability, by a phenomenal mechanism called induced systemic resistance and so, provide protection against pathogen attack (Saravanakumar *et al.*, 2007) [70]. Direct growth promotion takes place in diverse ways like providing beneficial compounds to the host plant synthesized by the bacterium and/or facilitating the uptake of nutrients from the soil environment (Kloepper *et al.*, 1987) [38]. They also facilitate the growth of their host plant by fixing atmospheric nitrogen, and synthesize and secreting siderophores which may solubilize and sequester iron thereby rising its availability for plant uptake, producing phytohormones, and solubilizing minerals such as phosphorus for to increase its availability (Glick *et al.*,1995; Kloepper *et al.*, 1989; Patten and Glick, 2002) [25, 39, 65]. in spite of these mechanisms, PGPR may also enhance plant growth and development by the asset of their key enzymes (ACC-deaminase, chitinase) and also by the construction of compounds like wise exopolysaccharides, rhizobitoxine, etc. which can help plants to resist stress conditions (Ashraf *et al.*, 2004; Glick *et al.*, 2007; Sandhya *et al.*, 2009) [7, 24, 69]. Rhizobitoxine that is inhibitor of ethylene formulation that increases nodulation by diluting the negative contact of high ethylene concentration (Vijavan *et al.*, 2013) [79]. Moreover, different rhizobacterial strains may have numerous traits and affect plant growth by any one or more of these mechanisms. The efficiency of these strains also depends upon the host plant and soil characteristics (Gamalero *et al.*, 2010) [22]. In general, PGPR may promote plant growth and development by a number of ways. Some strains own more than one mechanism and can survive not only the normal but also stressful environment.

Table 1: Show the Bacterial inoculate Plant species

Stress type	Bacterial inoculate	Plant species	Reference
Salt	*Aeromonas hydrophila*	Wheat (*Triticum aestivum*)	Ashraf *et al.* (2004) [7]
Salt	*Pseudomonas syringae, Pseudomonas fluorescens, Enterobacter aerogenes*	Maize (*Zea maize*)	Nadeem *et al.* (2007) [58]
Salt	Achromobacter piechaudii	Tomato (*Lycopersicon esculantum*)	Mayak, Tirosh & Glick(2004) [49]
Salt	*Pseudomonas fluorescens*	Groundnut (*Arachis hypogea*)	Saravanakumar *et al.* (2007) [70]

Tolerance to high salinity stress condition: Stress tolerance by the implementation of PGPR It is now well recognized that PGPR strains are evenly effective for improvement of growth features of cereals, legumes and vegetables that cultivated under stress conditions (Han and Lee, 2005; Mayak *et al.*, 2004a) [30, 49]. A number of researchers have confirmed the positive effect of rhizobacteria in terms of alleviate the negative impact of salinity on crop growth under laboratory as well as field conditions (Jalili *et al.*, 2009; Nadeem *et al.*, 2007, Saravanakumar *et al.*, 2007) [36, 58, 70] Among a variety of biotic and abiotic stresses, salinity is one of the main limiting factors for crop production in arid and semiarid regions of the world. a common hypotheses engaged in most of the studies conducted under salinity stress was the lowering of ethylene level by the ACC-deaminase activities of PGPR. These studies conducted under both controlled and natural environments in greenhouse showed that implementation with PGPR contain ACC-deaminase significantly improved plant growth and yield compared to that of un-inoculated control. In addition to regulating plant nutrition by increasing K+ uptake over Na+ in plants under salt stress conditions (Nadeem *et al.*, 2007) [58] inoculation with PGPR also enhances the uptake of other important nutrients as well as improves the water content of stressed plants (Mayak *et al.*, 2004a; Nadeem *et al.*, 2006b) [49, 56]. (Yue *et al.* 2007) [84] have demonstrated that inoculation with *Klebsiella oxytoca* (Rs-5) containing ACC-deaminase improved the absorption of major nutrients such as N, P, K and Ca, and promote plant growth by alleviating the negative effects of salt stress. The inoculation with *Pseudomonas* spp. enhanced the eggplant growth by suppressing the uptake of Na+ and increasing the activities of antioxidant enzymes under salinity stress conditions (Fu *et al.*, 2010) [20]. According to them, regulation of mineral uptake and increase in the antioxidant enzyme activities may be the two key mechanisms concerned in alleviation of salt stress. The PGPR strains are useful not only for improving plant growth under salinity stress but are also helpful for enhancing plant growth and progress under heavy metals, flooding and drought stress (Glick *et al.*, 2007) [24]. PGPR that contain ACC-deaminase alleviated the unfavorable effects of drought stress on the growth of pea plants (Zahir *et al.*, 2008) [88]. (Sandhya *et al.* 2009) [69] explained that rhizobacteria also having the ability to produce exopolysaccharides can be used effectively for enhancing drought resistance in sunflower plants. one of the important characteristic of PGPR is to increase resistance against pathogens and provide protection to plants from diseases. Plant growth promoting rhizobacteria have been revealed as effective biocontrol agents against a variety of plant pathogens (Kotan *et al.*, 2009; Ramos-Solano *et al.*, 2008) [44, 67]. This increament in disease tolerance may be due to several mechanisms such as enhanced nutrient availability, production of cell wall lytic enzymes, competition for nutrients, and avoidance of growth of pathogens or induction of systemic resistance (Bhattacharyya and Jha, 2012; Ramos-Solano *et al.*, 2008) [11, 67] moreover PGPR can enhance plant growth under normal as well as stress conditions however, they have disparity potential for improving plant growth and development. For example, Zahir *et al.* (2009) [86] demonstrated that *Pseudomonas putida* had improved ability to mitigate the adverse effect of salinity than that of *Serratia proteamaculans*. Similarly, *Pseudomonas fluorescens* and *Pseudomonas stutzeri* perform better in enhancing growth of canola and tomato plants, respectively (Jalili *et al.*, 2009; Tank and Saraf, 2010) [36, 75]. These changeable effects of PGPR strains might be due to difference in their specific characteristics such as ACC deaminase activity, indole acetic acid production, root colonization ability, phosphorus solubilization ability, etc. (Gamalero *et al.*, 2009; Saravanakumar. *et al.* 2007; Zahir *et al.*, 2009) [21, 70, 86], PGPR inoculation improved the proline, chlorophyll and water content of basil (*Ociumum basilicum* L.) under stress conditions (Heidari *et al.*, 2011) [34]. The PGPR is effective tools under water stress conditions and also proved helpful for enhancing plant growth under salinity stress. The growth and yield of groundnut was significantly higher under salt stress conditions when inoculated with PGPR strains. The above discussion have clearly designate that PGPR strains are very helpful to improve plant growth under stressful environments, such as drought, flooding, salinity, heavy metals, pathogen attack, etc. This growth promotion characters may take place by lowering the ethylene concentration due to their improved ACC-deaminase activity or by construction of exopolysaccharides or through induced systemic resistance.

Mechanism of action

Searches for PGPR and its mechanism of action are rapidly increasing in order to use the best PGPR strains as commercial biofertilizers. Investigation of the mechanism of plant growth promotion by PGPR strains has shown that potent PGPR increases plant growth by essentially altering the overall microbial community structure of the rhizosphere (Kloepper and Schroth 1981) [40]. According to (Glick *et al.*,1999) [26], general mechanisms of plant growth promotion by PGPR include bound nitrogen fixation, decreased ethylene levels, siderophore and phytohormonal production, induction of pathogen resistance, nutrient solubilization, promotion of mycorrhizal function, contamination. Includes reduction of substance toxicity. (Castro. *et al*. 2009) [15]. it has suggested that the PGPR strain can directly or indirectly promote the growth and development of plants. Although direct stimulation includes biological nitrogen fixation, production of plant hormones such as auxin, cytokinin, and gibberellin, solubilization of minerals such as phosphorus and iron, production of rhizosphere and enzymes, and induction of systemic resistance. Indirect stimulation is essentially related to biocontrol. Antibiotic production and chelation of Fe available in the rhizosphere, synthesis of extracellular enzymes for fungal cell wall hydrolysis, and competition for rhizosphere niches (Zahir *et al*. 2004) [87]; (vanLoon 2007) [78]. PGPR strains, especially Pseudomonas fluorescens and Bacillus subtilis, are best known as the most promising candidates for indirect stimulation (Damayanti *et al*. 2007) [16]. In addition, nitrogen conversion, increased bioavailability of phosphates, iron uptake, exertion of specific enzyme activity, and protection of crops from harmful pathogens through the production of antibiotics will also improve crop quality in agriculture. Success (Spaepen *et al*. 2007) [74]. Therefore, PGPR can be categorized into three common forms, such as biofertilizers, plant stimulants, and biopesticides, based on their mechanism of action. Since PGPR has been reported to interact regularly with microbial communities in the rhizosphere, quorum regulation may affect the expression of each of these traits (Lugtenberg and Kamilova 2009) [46]. Recent studies on PGPR have shown that plant growth can be promoted primarily in the following ways: (1) Production of ACC deaminase to reduce the ethylene content of developing plant roots (Dey *et al*. 2004) [17] (2) Indore acetic acid (IAA) (Mishra *et al*. 2010) [51], diberephosphate (Narula *et al*.2006) [59], Cytokinin (Castro *et al*. 2008) [14] and Ethylene (Saleem *et al*. 2007) [68] (3) Non-symbiotic nitrogen fixation (Ardakani *et al*. 2010) [4] (4). 3 Glucanase, chitinase, antibiotics, fluorochromes and cyanides (Pathma *et al*. 2011) [64] and (5) Solubilization of inorganic phosphates and other nutrients (Hayat *et al*. 2010) [33]. Experimental evidence suggests that plant growth stimuli are the net result of multiple mechanisms that can be activated simultaneously, and PGPR may use multiple of these mechanisms to enhance plant growth (Martinez Viveros *et al.* 2010) [48]. Recently, biochemical and molecular approaches have provided new insights into the genetic basis of these biosynthetic pathways, their regulation, and their importance in biological control (Joshi and Bhatt 2011) [37].

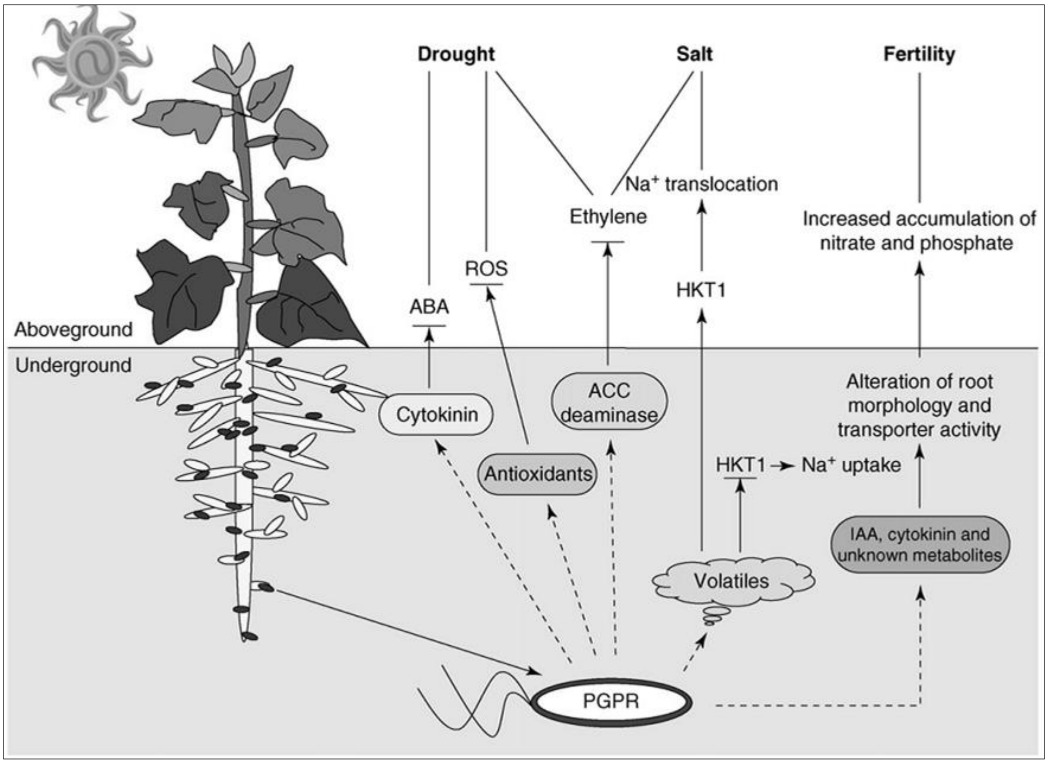

Fig 1: IST elicited by PGPR against drought, salt and fertility stresses underground (root) and aboveground (shoot). Broken arrows allocate bioactive compounds secreted by PGPR; solid arrows allocate plant compounds affected by bacterial components.

Conclusion

Saline stress is a severe environmental constraint to agricultural productivity. PGPR plays an important role in conferring resistance and adaptation of plants to saline stresses and have the potential role in solving future food security issues. The interaction between plant and PGPR under saline conditions affects not only the plant but also changes the soil properties. The mechanisms elicited by PGPR such as triggering osmotic response and induction of novel genes play a vital role in ensuring plant survival under saline stress. The development of salt tolerant crop varieties through genetic engineering and plant breeding is essential but it is a long drawn process, whereas PGPR inoculation to alleviate saline stresses in plants opens a new chapter in the application of microorganisms in agriculture. Taking the current leads available, concerted future research is needed in terms of identification of the right kind of microbes and addressing the issue of delivery systems and field evaluation of potential organisms.

Acknowledgement

The author is like to acknowledge and give grateful thanks to the Hon'ble Vice Chancellor, and HOD (Advisor), at Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj Uttar Pradesh, for providing all necessary required facilities and kind support.

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