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A BRIEF REVIEW ON PLANT GROWTH PROMOTING RHIZOBACTERIA (PGPR): A KEY ROLE IN PLANT GROWTH PROMOTION

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ABSTRACT

Demand for chemical fertilizers is enormously mounting day-by-day in developing countries like Pakistan. Chemical fertilizers not only deteriorate the soil micro flora, fauna but also cause environmental pollution, water pollution, health problems as well as increase the cost of production. So, there is an urgent need to find out the alternate to these hazardous chemicals. Plant growth-promoting rhizobacteria (PGPR) are the heterogeneous group of bacteria that rapidly colonize the rhizosphere and provide direct or indirect protection to the crop plants. Seed treatment with PGPR not only significantly enhanced the rate of seed germination but also provided protection against pathogenic microorganisms. It has been documented that PGPR significantly enhanced the nutrients and water uptake ability as well as yield of many crops. PGPR shows promising results by creating a symbiotic relationship with other beneficial microorganism, increasing nitrogen fixation and increasing the supply of primary, secondary and micronutrients. PGPR is an interesting aspect to research for scientists and now-a-days a number of PGPR formulations are commercially available. Many scientists illustrated the role of PGPR as growth promoting agents. The current review demonstrates the role of PGPR as an efficient alternate to hazardous chemical fertilizers for eco-friendly and sustainable agriculture.

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INTRODUCTION

The upper layer of the earth's crust that is composed of air, water, minerals and other living organisms carried out various significant functions termed as soil. Rhizosphere is a thin layer of soil surrounding the plant roots enriched in beneficial bacteria, which play a vital role in plants growth promotion. Rhizospheric bacteria termed as plant growth-promoting rhizobacteria (PGPR) significantly enhanced growth parameters as well as are very vital in disease suppression of many crop plants. Kloepper and Schroth (1978) coined the term PGPR for the first time to illustrate the population of beneficial microbes that showed the plants growth promotion by effectively colonizing the plant roots. Rhizosphere is a highly resourceful and active zone, containing all essential nutrients for plant growth and provides ideal zone for plant microbe interactions (Marilley and Aragno, 1999). Several significant interactions among plants and beneficial organisms occur in rhizospheric soil. In rhizospheric soil among all the coexisted microorganisms, bacteria are in high proportion (Lynch and Leij, 1990). By colonizing plant roots, bacteria releases certain enzymes and exudates that protect plant from the pathogenic microorganisms coexisted in the soil (De Garcia-Salamone et al., 2006). PGPR directly or indirectly provides protection to the plants.

Plant Growth Promoting Rhizobacteria as Bio-fertilizer: The use of pesticides and fertilizers can be replaced by PGPR. Most of the PGPR isolates not only rapidly colonize the rhizospheric soil and enhance the nutrients uptake ability of plants but also found helpful in disease suppression through multiple mechanism activities. In field condition (microplots) the efficacy of antagonistic bacteria alone and in combination with salicylic acid had great impact against karnal bunt of wheat as the results showed that the highest decrease in mean disease incidence was 0.303 with coefficient of infection of 0.116 when antagonistic bacteria (Rh-3) were applied in combination with salicylic acid (Ali et al., 2014).

Bio-available phosphorous for plant uptake: Phosphorus is an essential nutrient that is taken up from the soil by plants in the form of phosphate anions (Nautiyal et al., 2000). Due to their extremely reactive nature, phosphate anions may be attained by the plants with cations precipitation ($Al^{3+,}$ Mg^{2+})$^{.}$ The availability and unavailability of phosphorus to the plants depends on soil quality because phosphorus is very insoluble in soil, therefore only a limited amount of phosphorus is available to plants (Yadav and Dadarwal, 1997). It has been documented by many researchers that Hydroxyapatite, di-calcium phosphate, rock phosphate and tricalcium phosphate converts into soluble form by various beneficial bacterial species present in soil and these beneficial bacterial species termed as phosphate solubilizing bacteria (PSB) (Chen et al., 2006; Rodríguez and Fraga, 1999). Various mechanisms were followed by the PSB to solubilize unavailable phosphate including release of certain enzymes and acids production (Greiner et al., 2001). Inoculation of PSB not only enhances the plants growth parameter but also significantly improved the overall yield of crop (Moura et al., 2001). *Serratia, Alcaligenes, Rhizobium, Acinetobacter, Pseudomonas, Arthrobacter, Flavobacterium, Azospirillum, Erwinia, Burkholderia, Enterobacter* and *Bacillus* are some of the important bacterial genera having solubilizing ability.

Nitrogen fixation for plant use: Generally 16 nutrients are fundamental for the existence of any type of life; among these three (C, H and O) are taken up by atmosphere whereas rest of the 13 (N, P, K, Ca, Mg, S, B, Cl, Cu, Fe, Mo, Mn and Zn) are taken up by the plants from soil in appropriate amount. These nutrients are further subdivided into primary, secondary and micronutrients. Proteins, nucleic acid and other vital nitrogenous compounds are composed of nitrogen and other essential primary nutrients (Venturla et al., 2013). Seventy eight percent of available nitrogen in the atmosphere is not utilized by the plants directly, because there is no direct mechanism available in plants that converts dinitrogen into ammonia. The beneficial bacterial species that fix atmospheric nitrogen are termed as biological nitrogen fixing bacteria (BNF) and it is documented that BNF contributes about 180×10^{6} metric tons nitrogen per year across the globe (Cupples, 2005). The example of symbiotic BNF bacteria includes Rhizobium, whereas non-symbiotic have Cyanobacteria and Azotobacter.

Symbiotic nitrogen fixation: The leguminous crops and beneficial microbes create a mutual relationship in the rhizosphere to fix the atmospheric nitrogen into plants available form. Plants release certain exudates that stimulate the movement of beneficial microbes towards plants roots. On entering these beneficial microbes form nodules for nitrogen fixation. Frankia and rhizobia are the two most studied groups among BNF (Saharan and Nehra, 2011). From 8 woody plant families Frankia form symbiotic relationship with more than 280 woody plants species (Schwintzer, 2012). On the other hand, rhizobia form a symbiotic relationship with leguminous crops for nitrogen fixation. It is documented that 80% plant available nitrogen comes from BNF while remaining 20% is contributed by other non-symbiotic organisms (Graham et al., 1988).

Free-living nitrogen fixing: Free living nitrogen fixing bacteria holds significant importance in agriculture. These free-living nitrogen fixing bacteria does not display mutual symbiotic relationship with the plant roots. Non-symbiotic bacteria survive on plant residues. Out of total fixed nitrogen only 20% of the nitrogen is fixed by free living nitrogen fixing bacteria (Das et al., 2013). The free-living nitrogen fixing form of bacteria includes *Acetobacter diazotrophicus, Azoarcus*, and *Cyanobacteria*.

Sequestration of Iron by Siderophores: Among essential micronutrients, iron plays a key role as important growth element of all kind of organisms. The iron paucity in the soils initiates fuming competition between plants roots (Loper and Henkels, 1997). PGPR produce siderophores to compete and attain Fe^{3+} (ferric ions) from surrounding under iron scarcity (Whipps, 2001). Siderophores, derived from a Greek word meanings "iron carrier" basically are the compounds with lower molecular weight with high iron affinity and these small iron chelating compounds are released by the beneficial microorganisms (Miller and Marvin, 2008).

Ferric ion is the plants available form of iron present in soil and ferric ions are taken up by the plants from soil through active transport mechanism. PGPR not only enhanced the growth parameters but also significantly improved iron availability (Kloepper et al., 1980). It has been documented that many crop plants including cotton, peanut, sorghum and cucumber only have beneficial microbes' secreted siderophores as sole source of iron (Wang et al., 1993). Siderophores secreted by the beneficial microorganisms significantly enhance the plants biomass as well as chlorophyll content (Imsande, 1998).

Production of Plant Hormones: Hormones are basically the chemical signals which influence the plant's ability to respond environment and even a low concentration of these organic compounds are very effective. These organic compounds are synthesized and transported from higher concentration towards lower concentration. These chemical signals have the ability to inhibit or stimulate growth parameters. Two or more hormones interact with each other at particular plant's tissue to stimulate the certain physiological responses including flowering, fruit ripening or growth. Organic plant's hormones are classified into five groups named as ethylene, abscisic acid, auxins, cytokinins and gibberellins. It has been documented that a variety of auxins are produced by diverse groups of soil micro flora in soil (Barazani and Friedman, 1999). PGPR hold significant importance to enhance the plant's growth parameters by producing organic compounds like ethylene, abscisic acid, auxins, cytokinins and gibberellins. Concentration of these hormones is very important because these organic compounds are required in low concentration and a high concentration may retard the growth parameters (Sarwar and Frankenberger, 1994). Each crop reacts differently to microorganism and auxin concentration (Ahmad et al., 2005).

Both strains with high and low but continuous concentration producer of auxins displayed significant effect on the growth parameters of crop plants (Tsavkelova et al., 2007). First group of PGPR that have IAA producing ability were named as Rhizobia (Mandal et al., 2007). It has been illustrated that IAA production showed by all the isolates of Azotobacter, Pseudomonas and Bacillus species in chickpea while 85.7% rhizobium strain are capable of producing IAA (Moura et al., 2001). *P. putida* and *P. fluorescens* are the two most significant strains of Pseudomonas that presented significant outcomes in auxin production and growth promotion of crop plants (Khakipour et al., 2008). PGPR having IAA producing ability shows significant effects on plant's growth. When crop plants are inoculated with such isolates, these enhanced the nutrient uptake ability of the particular crop as well as reduced the disease incidence (Farzana and Radizah, 2005). Vegetable crops like tomato, cucumber and pepper when inoculated with diverse strains of PGPR having IAA production ability displayed considerable increase in growth parameter (Kidoglu et al., 2007). In case of rice crop IAA producing PGPR showed promising outcomes (Ashrafuzzaman et al., 2009). Similarly, certain pseudomonas strains such as *P. fluorescens* release organic compounds like cytokinin that significantly affects the cell division and enhanced cell enlargement in crop plants (De Garcia-Salamone et al., 2006).

Role of PGPR under stressed conditions: Biotic and abiotic factors exposed agricultural crops to many stresses and ultimately reduced the crops yield. These factors significantly affect the microbial activity and incidence. Biotic factors include fungi, bacteria, nematodes and viruses whereas abiotic factors include drought, air pollution, low or high temperature, moisture and salinity. As in case of biotic stresses, in wheat maximum disease prevalence was observed in Chakwal (50%) as compared to Rawalpindi (35%). Village Chakri in Rawalpindi and Village Mangwal in Chakwal exhibited highest disease incidence of 9.98% and 10.34% respectively (Ahmed et al., 2013). Abiotic factors lead a crop towards reduced yield and in severe case yield may be reduced up to 50%-82%. Soil and water salinity is the major issue that reduces the yield in arid and semi-arid zones across the globe. Deprived seeds germination, small leaves, reduced roots growth restricts plant's photosynthesis ability under high salinity conditions. Various physiological and metabolic changes occur in plants under stress condition (Hu, 2005). Inoculation of PGPR to such stressed plants eases their stress. Soybean crop is sensitive to soil salinity, nutrient and water uptake, nodule formation and ultimately yield is reduced under salt stressed conditions (Han and Lee, 2005). The presence of PGPR having ACC deaminase enzyme in a range a soil significantly improves the growth parameters under abiotic conditions. An organic compound known as ethylene holds key importance but the excessive secretion of ethylene leads towards rapid seedling death and deprived growth (Belimov et al., 2001). The Rhizospheric soil is rapidly colonized by the beneficial microorganism such as arbuscular mycorrhizal fungi (AMF), plant growth promoting rhizobacteria, mycorrhizal-helping bacteria (MHB) and P-solubilizing bacteria. These not only enhanced the nutrient uptake ability but also helped in phytoremediation of contaminated soils (Khan, 2005). The ability to tolerate many heavy metals makes Pseudomonads an exceptional entrant under field condition for phytoremediation (Chacko et al., 2009). The results of various researchers illustrated the ability of PGPR as a positive entrant under biotic and biotic conditions. Seeds treatment with PGPR showed excellent results in many crop plants such as chickpea, maize and asparagus under water deficient condition (Liddycoat et al., 2009). The positive interaction of P- solubilizing organisms not only enhanced the growth parameters but also increased the P uptake under abiotic conditions in maize (Ehteshami et al., 2007).

Conclusions

Rhizospheric soils enriched with the heterogeneous group of bacteria (PGPR) directly or indirectly provide protection to the cultivated plants. Many researchers documented that a number of PGPR species including *Bacillus*, *Pseudomonas, Rhizobium, Azotobacter, Enterobacter* and *Azospirillum* displayed excellent outcomes against biotic and abiotic factors. The mechanism of PGPR includes

a) PGPR have the ability to stimulate the release of certain organic compounds (Plants hormones) such as ethylene, IAA, cytokinins and gibberellic acid.
b) PGPR have nitrogen fixing ability
c) By enhancing nutrients and water uptake ability provide direct benefit to plants.
d) By producing antibodies and siderophores provide indirect protection from phytopathogenic microorganisms.

Regrettably due to the unstable interaction between PGPR and host plants the outcomes of *in vitro* cannot efficiently achieved under *in vivo* conditions. Abiotic factors during crops germination play a key role in this inconsistency of PGPR. So, for successful *in vivo* interaction between plants and PGPR, one should have to find out the exit mechanism of PGPR along with the effect of abiotic factors on PGPR under *in vivo* conditions. So, there is a need to find out specific bacterial strain that displayed promising result under both conditions. Therefore, by understanding the exact mechanism of PGPR and the effect of abiotic stresses on the interaction of host and PGPR, we can anticipate seeing environment friendly PGPR products that will be more reliable than the chemicals. The survival of beneficial microorganisms in rhizoplane and success of these products will depend on our managing abilities that how we manage rhizospheric soil. Cultural practices along with PGPR formulations will help to enhance the amount of PGPR inoculum in soils. So, by utilizing all available resources including printing media, extension workers and internet, farmers must be educated about the hazardous effects of chemical fertilizers and encouraging impacts of the use of PGPR as bio-fertilizer.

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