INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 13, No. 1, p. 223-233, 2018

RESEARCH PAPER OPEN ACCESS

Weed rhizosphere: a source of novel plant growth promoting rhizobacteria (PGPR)

Muhammad Baber[1], Mahreen Fatima[1], Rameesha Abbas[1], Muther Mansoor Qaisrani[2], Sidra Naz[3], Muhammad Kashif Hanif[4], Tahir Naqqash[1*]

[1]*Institute of Molecular Biology and Biotechnology, Bahauddin Zakariya University, Multan, Pakistan*

[2]*Department of Botany, Ghazi University, Dera Ghazi Khan, Pakistan*

[3]*Department of Environmental Sciences, Sindh Madrassatul Islam University, Karachi, Pakistan*

[4]*Department of Biotechnology, University of Sargodha, Pakistan*

Key words: Weed, PGPR, IAA, Nitrogen fixation, Phosphate solubilization.

http://dx.doi.org/10.12692/ijb/13.1.223-233 Article published on July 30, 2018

Abstract

Weeds are undesirable plants usually flourish in the unfavorable environment as continuous efforts are made to control their growth. There could be many reasons for weeds survival in hostile conditions among which association of beneficial microflora with their roots is one of the reasons. Weeds rhizosphere is studied for different plant growth promoting rhizobacteria which are successfully used to engineer the rhizosphere of many agriculture crops. However, weeds rhizosphere is still underexplored. In perspective of increasing atmospheric worth and food security, the utilization of plant growth promoting rhizobacteria for diminishing chemicals contribution in agro ecosystem that is conceivably a major issue. PGPR isolated from weeds rhizosphere are being used in different crops that help them in better stand by their plant growth and development attributes i.e. biological phosphate solubilization, N_2 fixation, IAA production and as well as bio-control actives by producing different enzymes metabolites and antibiotics . While covering the success stories of association of the PGPR, isolated from weed rhizosphere of different crop plants, this review enlighten the need of research to develop further understanding of the general and functional diversity of rhizobacteria residing especially in the rhizosphere of weedy grasses. This area of research will open new horizons to utilize PGPR from weedy grasses for plant growth promotion and yield in nutrient deficient soil which will be of great value for agriculture research and applications.

* **Corresponding Author:** TahirNaqqash ✉ tahirnaqqash@gamil.com

Introduction

All organisms do not respond in the same manner in the habitats altered by the human. Several species survived with the man, whereas some moved or died and sometimes restored by other hostile colonizers. Continuous and thorough disturbance by man has eternally distressed effects on native plants communities (Adams and Hewison, 2010). However, some undesired plants managed to grow in domestic groups which are known as weeds and often grown as a crop that does not require artificial propagation. These are able to establish new populations into a man-disturbed habitat despite continuous efforts to control them. In the evolution of weeds, many factors are responsible to withstand the adverse conditions, among them the association of the beneficial micro-flora could be one of the main reasons. To sustain life on the land every organism depends upon association to its neighbors e.g. microbes-microbes, plant microbes and plant-plant interaction (Badri *et al.*, 2009). As an autotrophic life form, plant plays a vital role in managing sources of all life forms. On earth plants are immobile that released a variety of compounds to communicate with other living bodies i.e. microbes. The roots region of plant is called rhizosphere, where groups of soil bacteria that are naturally occur in a form of colonies are called plant growth promoting rhizobacteria (PGPR) which help to improve plant development and crops yield (Wu *et al.,* 2005). PGPRs promote plant developmental processes by directly and indirectly at micro-niches. PGPR are those soil bacteria that naturally live in vicinity of plant root system and cause useful effects on a plant's health (Gurska*et al.,* 2009). It would be helpful to recognize the different mechanism of PGPR that enhance the number of PGPR for plant development and growth (Fig. 1). Recently, *Pseudomonas* (Loper *et al.*, 2007), *Bacillus spp.*(Jacobsen *et al.,* 2004), *Stenotrophomonas, Klebsiella, Rhizobium*(Long, 2001), *Burkholderia, Serratia* (De Vleesschauwer and Höfte, 2003), *Azotobacter, Enterobacter, Alcaligens, Arthrobacter and Streptomyces*(Schrey and Tarkka, 2008) are used as a biofertilizer for various crops and vegetables that has been commercialized. *Bacillus* and *Pseudomonas* often range in the rhizosphere that is the most commonly investigated PGPR (Morgan *et al.,* 2005).

Forthe improvement in plant growth, development and defense, mode of action of PGPR involve complex mechanisms through the production of antibiotics and siderophore. They provoke systemic resistance as bio-protectant and control the plant diseases. However, by improving nutrient acquisition PGPR promote plant growth as a biofertilizer but as a bio-stimulant, they produce phytohormones i.e. cytokines, gibberellic acid, ethylene and indole-3-acetic acid (Mukherjee *et al.,* 2017).

Through stimulating symbiotic N_2 fixation, by asymbiotic N_2 fixation nodulation, and nodule occupancy PGPR directly promote growth of plants. The morphological, biochemical and physiological qualities of weeds are conventional means for PGPR identification and to recognize unidentified bacterium up to genus and species level but above these the 16S rRNA gene sequence analysis is become significant method (Fierer *et al.,* 2007). In an intense environment, to cultivation-based approaches most microorganisms are reluctant (Amann, 2000). In this review, we focused on the underexplored rhizosphere of weed grasses that are rich sources of novel plant growth promoting rhizobacteria that help them to survive in hostile conditions. These PGPRs from rhizosphere of weeds can be used to promote the growth of crop plants and their productivity in adverse environmental conditions. That will ultimately reduce the demand of agrochemicals and fertilizers in agriculture sector.

Plant growth promotion

Usually, PGPRs promote plant growth directly either in the form of nutrient supply (nitrogen, potassium phosphorus, and essential minerals) or by changing the levels of plant hormone and indirectly by diminishing the pathogenic effect on growth and development of plant in the forms of bio-control mediators, environmental defender and root colonizing bacteria (Table.1) (Gupta *et al.,* 2015).

Direct method

N_2 fixation

The procedure through atmospheric nitrogen (N_2) is change into ammonia (NH_3) then accessible to plants is called nitrogen fixation. This is possibly the symbiotic method to which plant supply nutrients to bacteria and these bacteria convert di-nitrogen via atmosphere for plant uptake (Fig. 2). On land after process of photosynthesis the conversion of atmospheric di-nitrogen into the ammonia is second most vital biological process (Datta *et al.,* 2015). It has been anticipated that N_2 fixation process is related with reduction of N_2 into NH_3. A complex set of enzymes is involved in this process that break N_2 bonds by 16 molecules of ATP that combined with hydrogen. The overall reduction process is given:

$$N_2 + 8\ H_2 + 16\ ATP \longrightarrow 2\ NH_3 + 2\ H_2 + 16\ ADP + 16\ Pi$$

Isopteriavariabilis, *Agrobacterium tumefaciens* stra in R6, *Bacillus safensis*and *Mesorhizobium spp*. are some isolates that are isolated from the rhizosphere of *Cyprus occidentalis* which have the capability of biological nitrogen fixation and ability to use as inoculants for further crops. This provides a new dimension to weeds in agricultural ecosystem (Thies *et al.,* 1991).

Table 1. Direct and indirect mechanisms of PGPR.

PGPR	Mechanisms	Direct role	Indirect role
Azospirillum, Azotobacter, Frankia, Mesorhizobium, Sinorhizzobium, Pseudomonas, Rhizobium	Biological Nitrogen Fixation	Flavonoids are signal molecules that increase root colonization and uptake of nutrients that enhance plant growth and development	Suppressed the attack of phytopathogens
Bacillus, Mycorrhiza Pseudomonas, Rhizobium, Serratia	P solubilizing biofertilizer	The crop yield and production can be increased by nodulation of nutrient accessibility, phosphate mineralization, recycling of nutrients.	Pathogenic infection can be suppressed by up taking of large amount of nutrients and increase tolerance to suppressed the insoluble diseases
Azotobacter, Bacillus, Pseudomonas, Rhizobium	Phytohormones	Maintain hormonal balance by up taking the nutrients from soil	Support to the plants by Provide them an water and easy flow of nutrient
Bacillus, Pseudomonas Streptomycetes	Bio-control	It enhanced the root colonization as a signal molecule that increase the supply of nutrients and H_2O	Activate defense mechanism and prevent from pathogens

Phosphate solubilization

In count of nitrogen fixation, the process of phosphate solubilization (PS) also plays important role to increase soil fertility. In crop production, lack of phosphorus is a very serious issue. Phosphorus is necessary macronutrients for the biological development (Singh and Singh, 2018). Microorganisms present a biological system to solubilizing the insoluble inorganic P by making it accessible to plants (Fig. 3). It is the process in which several micro-organisms play important role to change insoluble phosphorus (P) to the available forms (i.e. orthophosphate) that is vital quality of PGPR to enhance plant yields. Phosphate solubilizers bacteria (PSB) have economical, ecological and better agronomic function to balance the costly inorganic resources of P fertilizers (Podile and Kishore, 2007).

However, some (PSB) lives into the soil but their quantities are mostly not sufficient to compete with other different bacteria that usually reside into the root rhizosphere (Etesami and Maheshwari, 2018). Therefore, this study explores the new dimension for the phosphate solubilizing bacteria that can be isolated from the rhizospheric soil sample of local weed plants.According to the reports of Komy (2005), *Pseudomonas fluorescence*, *Bacillus megaterium, Enterobacter cancerogenus, Rhodococcus and Serratia*are phosphate solubilizing bacteria that are obtained from local weed plants, *Morinda tinctoria* (Noni) and *Prosopis juliflora* (Mesquite) (Nkoa *et al.,* 2015).

Table 2. Classification of diverse types of biofertilizer and their groups.

Groups	Examples
N_2 Fixing biofertilizer Free-living,Symbiotic, Associative symbiotic	*Azotobacter, Rhizobium, Azospirillum, Frankia, Azospirillum, Mesorhizobium, Sinorhizzobium, Pseudomonas*
P solubilizing biofertilizer P solubilizing Biofertilizers, P Mobilizing Biofertilizers	*Bacillus cirulans, Pseudomonas, Rhizobium, Serratia, Mycorrhiza*
Biofertilizers for mono-nutrients Silicates and zinc solubilizers	*Bacillus spp., Burkholderia spp., Pseudomonas*
Phytohormones Siderophore	*Pseudomonas, Rhizobium, Bacillus, Azotobacter*
Bio-control Antifungal	*Streptomycetes, Bacillus, Pseudomonas*

Phytohormones production

The function of phytohormones is to help in growth of plants and produce responses. These are commonly chemical messengers that are produced and translocate hormones to boost up the growth of plants and yield. For example auxin, cytokines, gibberellins, ethylene, abscisic acid (ABA) and Indole-3-acetic acid etc.(Ahmad *et al.,* 2008).

Production of Indole-3-acetic acid

A natural auxin that has functional effects on the plant root development is called indole acetic acid (IAA). Almost 80% soil rhizobacteria have capability to generate (IAA) indole acetic acid. The functions of IAA is to increase cell proliferation and stimulate the plant hormones to take up the minerals from soil and enhance the root growth (Datta and Basu, 2000).

Table 3. Study of PGPR isolated from the rhizosphere of weeds and their inoculated into crop to check the response.

Bacteria	Source of isolation	Inoculated plants	Growth promotion mechanism	Reference
Acinetobacter spp.	*Spergula arvensis, Sonchus spp., Lolium multiflorum, Agropyron repens*	Maize	Increase plant growth and chlorophyll contents	(Sarathambal *et al.,* 2014)
Arthrobacter spp.	Barnyard grass, *Lamb's-quarters*	Potato	Potato plant growth promotion	(Sarathambal *et al.,* 2014)
Azospirillum spp.	Guinea grass, Fountaingrass Sorghum, Sudangrass, Tall fescue, Kentucky Bluegrass, Wild rye	Maize, Wheat, Millet, Mustard, Rice, Barley, Beet	Increase dry matter yield, plant height, primary root length and root fresh weight and dry weight.	(Dobbelaere*et al.* 2001) (Smith *et al.,* 1978), (Huang *et al.,* 2004)
Azotobacter spp.	*Amaranthus paniculatus*	Barley, Rice	Increased the plant growth and nitrogen content	(Pandey *et al.,* 1999)
Bacillus spp.	*Prosopisjulifera, Parthenium hysterophorus, Echinochloa crus galli, Spergula arvensis, Sonchu ssp., Lolium multiflorum, Chenopodium album, Agropyron repens*	Sorghum, Onion, Wheat, Sugar beet	Increase shoot, root dry weight of plants and level of phytohormone production	(Cibichakravarthy *et al.,* 2012). (Sarathambal *et al.,* 2014), (Turner and Backman 1991)
Beijerinckia spp.	*Echinochloa crus galli, Spergula arvensis, Sonchus spp., Lolium multiflorum, Agropyron repens*	Beet, Barley Radish, Cucumber	Plant growth promotion by increasing seed germination rate	(Polyanskaya *et al.,* 2002)
Burkholderia spp.	Italian ryegrass	Rice, Sugar beet	Increase in shoot and root yield, improved by N and P use efficiency	(Sturz *et al.,* 2001) (Tran Van *et al.,* 2000)

Enterobacter spp.	*Psoralea corylifolia, Moriinda tincttoriia, Prosopiis julliifflora, Alternanthera sessilis, Cyperus esculentus, S. vetricillata,*	Rice, Tomato, Pepper, Mung bean	Increase in root length, leaf area and chlorophyll content	(Harinathan *et al.*, 2014), (Alam*et al.*, 2001), (Mayak*et al.*, 2001.)
Klebsiella spp.	*Alternanthera sessilis, Cyperus esculentus, Triticum aestivum*	Potato, Sugar beet	Increased seedling mass by all strains	(Gontia-Mishra *et al.*, 2016)
Pantoea spp.	*Panicum repens*	Maize	Used as maize seed treatments	(Lucy *et al.*, 2004)
Pseudomonas spp.	Perennial native, Quack grasses.	Potato, Winter wheat, Tomato	A significant increase in plant height, number of tillers, and grain yield.	(Sarathambal *et al.*, 2014),(Kong *et al.*, 2017), (McCullaugh*et al.*, 2001)
Rkh1,Rkh2,Rkh3,Rkh 4	*Chrysopogon aucher, Lactuca dissecta, Solanum surattense, Sonchus arvensis*	Soybean	Increase proline content	(Naz *et al.*, 2009)
Serratia spp.	*Cyperus glaucus, Cyperus rufipogon, Cyperus dactylon, Bermuda grass, Cyprus barbata, Cyperusrotundus,*	Maize, Soybean, Rice	Growth development (plant height, dry weight, and chlorophyll, content) of rice in saline condition	(Sarathambal, 2013), (Pan *et al.*, 2002)
Staphylococcus spp.	*Saccharum spontaneum*	Brown mustard	Increase number of seed and yield	(Mukherjee *et al.*, 2017)
Stenotrophomonas spp.	*Echinochloa crus galli, Spergula arvensis, Sonchus spp., Lolium multiflorum, Chenopodium album, Agropyron repens*	Rice, Maize, Millet	Plant growth promotion and development	(Sarathambal *et al.*, 2014)
Stenotrophomonas spp.	Goldenrod, Quackgrass	Potato	Promote potato growth.	(Sturz *et al.*, 2001)
Xanthobacter spp.	Perennial native grasses	Rice, Sunflower	Increase the rice grain yield by increasing root length, leaf area and chlorophyll contents	(Alam *et al.*, 2001)
Zooglea spp.	*Leptochoa Fusca*	Rye, Barley, Maize, Rice	Change the morphology of root and raise their biomass	(Malik *et al.*, 1997)

It involves in plant cell differentiation, proliferation and extension; initiates the tuber and seed development; mediate the vegetative growth processes ; formation of lateral and adventitious root ;control all responses towards the light, fluorescence and graviy; change photosynthesis processes, formation of pigments, produce a variety of metabolites, and resistance in abiotic and biotic stresses. An amino acid that is usually present in root exudates is known as tryptophan.

It is a major molecule that involved in the production of IAA in weed rhizospheric PGPRs, like *Rhizobium, Agrobacterium, Enterobacter Bradyrhizobium, Klebsiella* and *Pseudomonas* (Camerini *et al.*, 2008).

In-direct mechanisms

This is an approach that explores the novel plant PGPRs to reduce the utility of agrochemicals like pesticides fungicides and fertilizers. However, soil enrichment can be improved by the number of mechanisms for examples production of siderophore, antibiotics, HCN, and hydrolytic enzymes.

Antagonistic activity

PGPRs can decrease or stop the growth of pathogens in different means such as competition for resources, Fe supply by the production of siderophore, produced different enzymes and antibiotics (Niu *et al.*, 2011).

In different PGPRs, *Pseudomonades fluorescent* is generally described for their wide range of hostile activity against many pathogens of plants. Different types of PGPR are isolate from the rhizosphere of weed grasses. In recent researches these diverse rhizospheric and endophytic PGPRs used to manage the rice plant pathogens i.e. *S. oryzae ,P. oryzae and R. solani* and various PGPRs have biocontrol activity against different pathogens (Cibichakravarthy *et al.*, 2012).

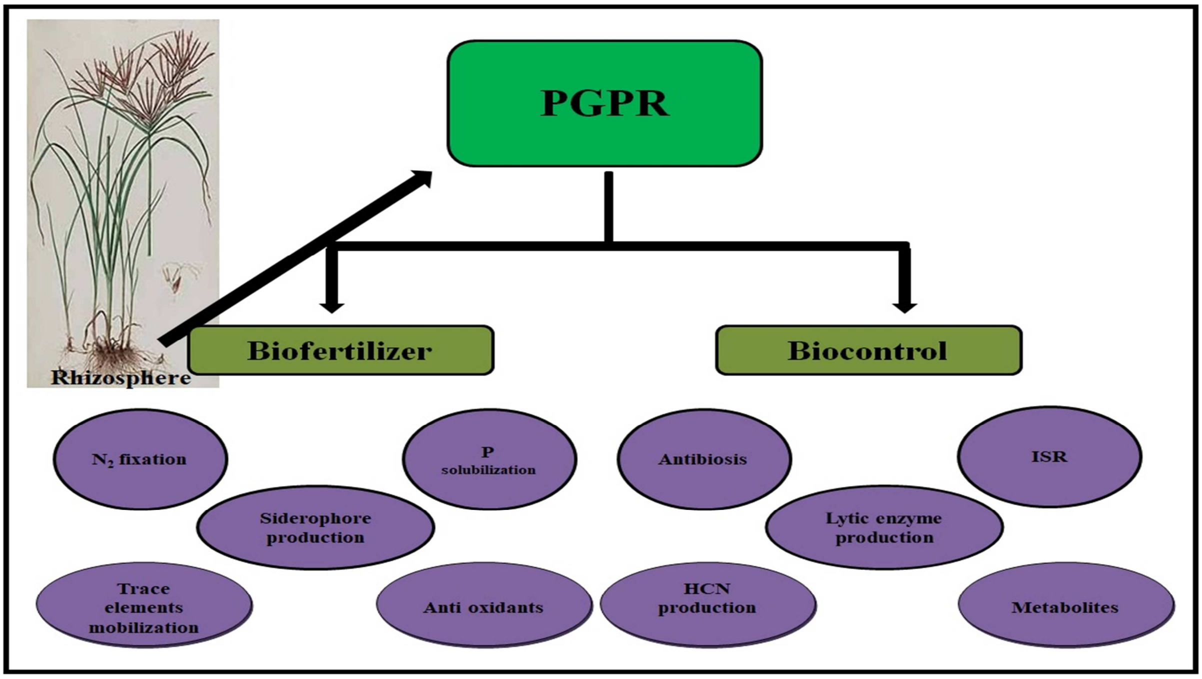

Fig. 1. General mechanism of weed PGPR.

The *Parthenium*r hizosp here is a source of *Bacillus* spp. which have capability to repress phytopathogens, for example, *Sclerotiumrolfsi, Macrophomina phaseolina, Colletotrichum gloeosporioides, Alternariasolani* and *Lasiodiplodia theobromae.*

Siderophore production

Iron is a necessary growth factor of living organisms. At neutral and alkaline pH the accessibility of soil solubilized ferric ion is inadequate for the soil microorganisms. Siderophore generating by PGPRs that may stop the production of pathogenic organisms through the production of Fe3+ in a region about the root (Wandersman and Delepelaire, 2004).

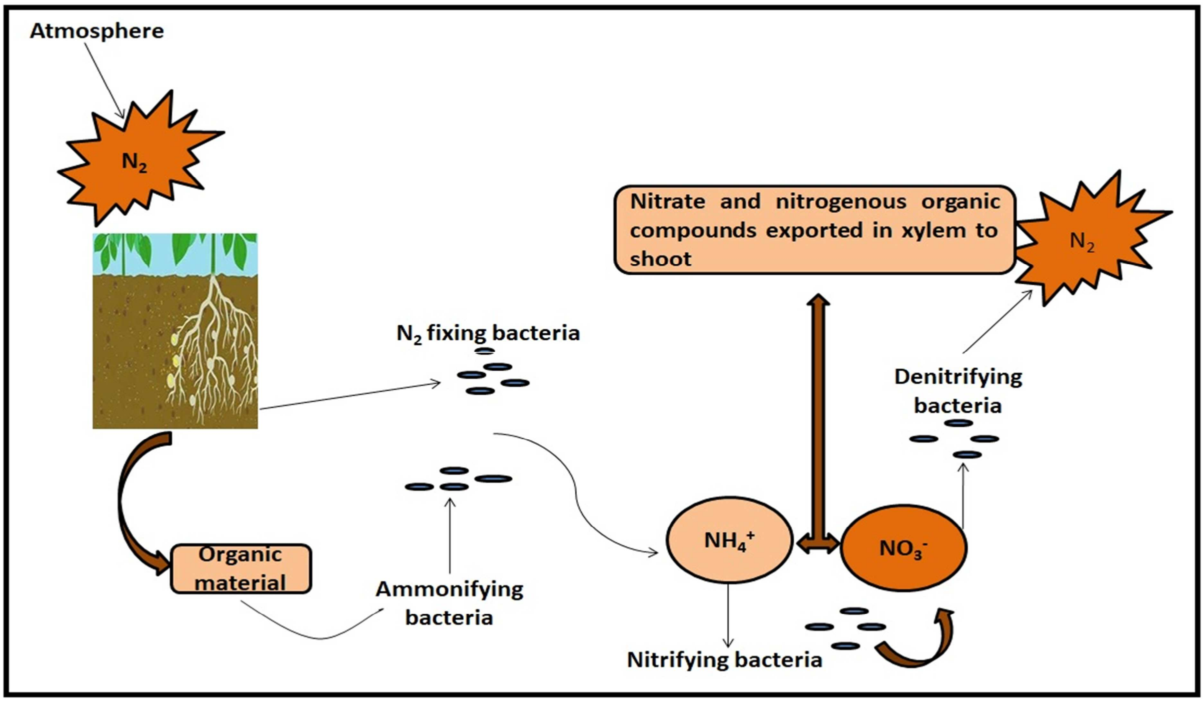

Fig. 2. Biological Nitrogen Fixation by PGPR.

Siderophore have ability to bind with the ferric ion and as a result it builds the siderophore-ferric complex that later attached with the bacterial cell surface with the iron limitation- dependent receptors. The Ferric ion activated into the cytoplasm in the form of the ferrous ion. Various plants may use different bacterial siderophore as sources of iron, while the total quantity is possibly too low. Different studies elucidate the isolation of siderophore-producing bacteria from the rhizosphere of weed species i.e. *Bradyrhizobium, Pseudomonas, Rhizobium, Serratia* and *Streptomyces* genera.

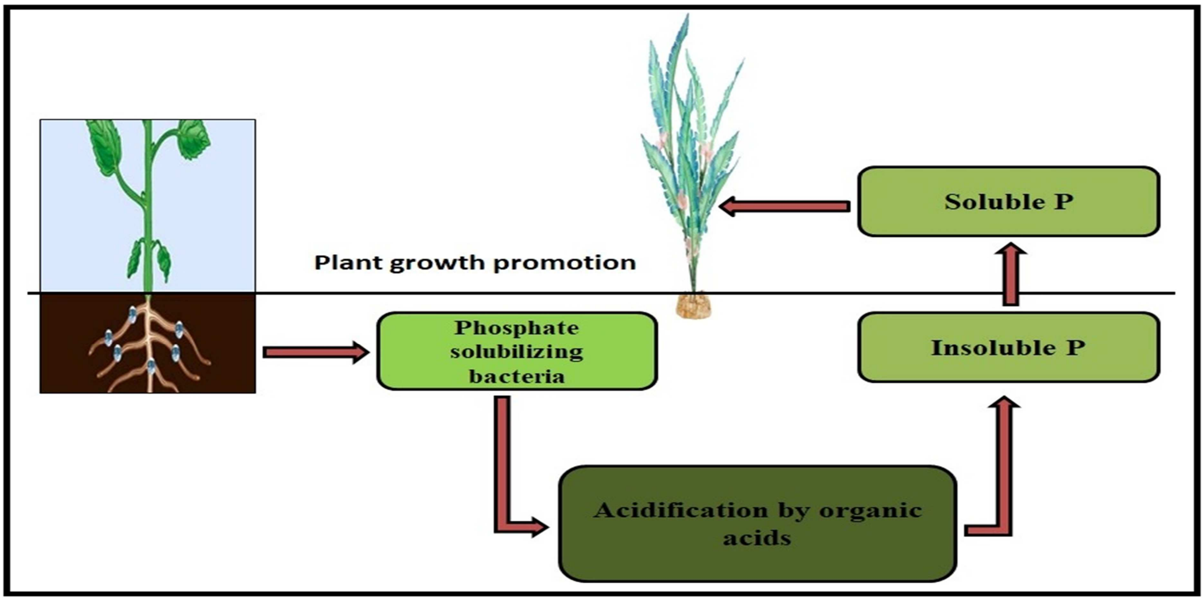

Fig. 3. PGPR help in the mechanism of phosphate solubilization.

PGPR as a biofertilizer

Biofertilizers are particular types of useful microorganisms which help in growth of plants through changing unavailable nutrients in the available type. Special types of biofertilizer and their group classification are shown in Table 2. The biofertilizers induced resistance into the plant against pests and are usually called microbial inoculants that are the artificial cultures of specific soil micro flora which help in plant development and crop yield. Biofertilizers reduced the cost of chemical fertilizers and are the renewable source that help in the nutrient management of plants (Datta *et al.,* 2015).

Weeds as a source of PGPR

Weeds are the indicator of agro-ecosystem biodiversity that provides resources for food agriculture, pharmaceutics and due to these advantageous effects these are not considered just as agricultural enemies but play valuable roles in the agro-ecosystem. There are different types of PGPR strains for functional versatility that can be served as to improve soil quality. Several PGPR can work to as a major source of 1-aminocyclopropane-1-carboxylate (ACC) that hydrolyzed ethylene into α-ketobutyrate and ammonia into the vascular and in these lines to lower the indigenous ethylene levels increase the root development in rhizospheric condition. PGPR additionally facilitate the solubilization of mineral phosphates in the form of organic and many nutrients that help in the protection from different stresses balance the soil fertility enhance soil texture and natural substance content. Reduction in the requirement for fertilizer nitrogen, PGPR hold soil natural N and different supplements into a plant– soil framework. Indirect plant development consists of the availability of antagonists for phytopathogenic microbes. It can be accomplished due to the synthesis of Siderophore (the little metal-binding particles). Biological control of plant-soil born pathogen and production of the antibiotic agent has been accounted for a few PGPR strains. Another component is a production of hydrogen cyanide (HCN) that can control phytopathogens. (Sarathambal and

Ilamurugu, 2014). Microorganisms play a very important role to determine the soil productivity in plant processes. However, both the plant and soil microorganism influenced on diversity and community structures (Cocking, 2005).

It considered that inspection of weed advantageous and modification into rhizobacterial biodiversity for the crops, soil conditioning treatment should not be excluded. The types of plant growth promoting bacterial strains by weeds rhizosphere can serve to improve soil quality and ultimately plant yield for functional versatility.

Conclusion

In this study, it is assessed that weeds provides an opportunities to explore the soil microflora for crop production and yield enhancement. Weed rhizosphere is a rich source of novel PGPRs that help crops to survive in unfavorable environment. However, weeds are under explored for development of potential PGPR that are useful growth stimulator and biocontrol as compare to chemical fertilizers and pesticides. For further exploitation, these potential PGPRs can be used to engineer the rhizosphere of agronomic important crops under biotic and abiotic stresses.

Author's conflict of Interest

There is no conflict of interest between all authors related to financial and commercial issues and research is conducted without potential conflict and personal biasness.

Reference

Ahmad F, Ahmad I, Khan M.2008. Screening of free-living rhizospheric bacteria for their multiple plant growth promoting activities. Microbiological research **163,**173-181.

Alam S, Cui Z-j, Yamagishi T, Ishii R.2001. Grain yield and related physiological characteristics of rice plants (Oryza sativa L.) inoculated with free-living rhizobacteria. Plant production science **4,** 126-130.

Amann R.2000. Microbial aspects of biodiversity. Systematic and Applied Microbiology **23,**1-8.

Badri DV, Weir TL, Van der Lelie D, Vivanco JM.2009. Rhizosphere chemical dialogues: plant–microbe interactions. Current opinion in biotechnology **20,**642-650.

Berg G, Smalla K.2009. Plant species and soil type cooperatively shape the structure and function of microbial communities in the rhizosphere. FEMS microbiology ecology **68,**1-13.

Bloemberg GV, Lugtenberg BJ.2001. Molecular basis of plant growth promotion and biocontrol by rhizobacteria. Current opinion in plant biology **4,** 343-350.

Brimecombe M, Leij Fa De, Lynch JM.2001. The effect of root exudates on rhizosphere microbial populations. The rhizosphere: biochemistry and organic substances at the soil-plant interface New York: Marcel Dekker.

Cardenas E, Tiedje JM.2008. New tools for discovering and characterizing microbial diversity. Current Opinion in Biotechnology **19,**544-549.

Camerini S, Senatore B, Lonardo E, Imperlini E, Bianco C, Moschetti G, Rotino GL, Campion B, Defez R.2008. Introduction of a novel pathway for IAA biosynthesis to rhizobia alters vetch root nodule development. Archives of microbiology **190,**67-77.

Cattelan A,Hartel P, Fuhrmann J.1999. Screening for plant growth–promoting rhizobacteria to promote early soybean growth. Soil Science Society of America Journal **63,**1670-1680.

Charlesworth B.1992. Evolutionary rates in partially self-fertilizing species. The American Naturalist **140,**126-148.

Chen K, Pachter L.2005. Bioinformatics for whole-genome shotgun sequencing of microbial communities. PLoS computational biology **1,**e24.

Cibichakravarthy B, Preetha R, Sundaram S, Kumar K, Balachandar D.2012. Diazotrophic diversity in the rhizosphere of two exotic weed plants, Prosopis juliflora and Parthenium hysterophorus. World Journal of Microbiology and Biotechnology **28,**605-613.

Cocking E.2005. Intracellular colonization of cereals and other crop plants by nitrogen-fixing bacteria for reduced inputs of synthetic nitrogen fertilizers. In Vitro Cellular &Developmental Biology- Plant **41,**369-373.

Datta A, Singh RK, Kumar S, Kumar S.2015. An effective and beneficial plant growth promoting soil bacterium Rhizobium a review. Annals of Plant Sciences **4,**933-942.

Datta C, Basu P. 200. Indole acetic acid production by a Rhizobium species from root nodules of a leguminous shrub Cajanus cajan. Microbiological research **155,**123-127.

De Vleesschauwer D, Höfte M.2003. Using Serratia plymuthica to control fungal pathogens of plants. CAB Reviews 2.

Dey R, Pal K, Bhatt D, Chauhan S. 2004. Growth promotion and yield enhancement of peanut (Arachis hypogaea L.) by application of plant growth-promoting rhizobacteria. Microbiological research **159,**371-394.

Dobbelaere S, Vanderleyden J, Okon Y.2003. Plant growth-promoting effects of diazotrophs in the rhizosphere. Critical reviews in plant sciences **22,**107-149.

Doty SL, Oakley B, Xin G, Kang JW, Singleton G, Khan Z, Vajzovic A, Staley JT.2009. Diazotrophic endophytes of native black cottonwood and willow. Symbiosis **47,**23-33.

Dutta S, Podile AR.2010. Plant growth promoting rhizobacteria (PGPR) the bugs to debug the root zone. Critical reviews in microbiology **36,**232-244.

Etesami H, Maheshwari DK.2018. Use of plant growth promoting rhizobacteria (PGPRs) with multiple plant growth promoting traits in stress agriculture action mechanisms and future prospects. Ecotoxicology and environmental safety **156**, 225-246.

Fickett ND, Boerboom CM, Stoltenberg DE.2013. Predicted corn yield loss due to weed competition prior to postemergence herbicide application on Wisconsin farms. Weed technology **27,**54-62.

Fierer N, Bradford MA, Jackson RB. 2007. Toward an ecological classification of soil bacteria. Ecology **88,**1354-1364.

Glick BR.1995. The enhancement of plant growth by free-living bacteria. Canadian Journal of Microbiology **41,**109-117.

Glick BR, Penrose DM, Li J.1998. A model for the lowering of plant ethylene concentrations by plant growth-promoting bacteria. Journal of theoretical biology **190**, 63-68.

Gontia-Mishra I, Sapre S, Sharma A, Tiwari S.2016. Alleviation of mercury toxicity in wheat by the interaction of mercury-tolerant plant growth-promoting rhizobacteria. Journal of Plant Growth Regulation **35,**1000-1012.

Gurska J, Wang W, Gerhardt KE, Khalid AM, Isherwood DM, Huang XD, Glick BR, Greenberg BM. 200. Three year field test of a plant growth promoting rhizobacteria enhanced phytoremediation system at a land farm for treatment of hydrocarbon waste. Environmental science &technology **43,**4472-4479.

Gupta G, Parihar SS, Ahirwar NK, Snehi SK, Singh V. 2015. Plant growth promoting rhizobacteria (PGPR) current and future prospects for development of sustainable agriculture. J Microb Biochem Technol **7**,096-102.

Handelsman J, Rondon MR, Brady SF, Clardy J, Goodman RM.1998. Molecular biological access to the chemistry of unknown soil microbes a new frontier for natural products. Chemistry & biology 5: R245-R249.

Harinathan B, Sankaralingam S, Prabhu D, Shankar T.2014. Screening and Characterization of Phosphate Solubilizing bacterium Enterobacter cancerogenus isolated from rhizosphere soil of local weed plants. International Journal of Advanced Scientific and Technical Research **1**,721-735.

Huang XD, El-Alawi Y, Penrose DM, Glick BR, Greenberg BM.2004. A multi-process phytoremediation system for removal of polycyclic aromatic hydrocarbons from contaminated soils. Environmental pollution **130**,465-476.

Hughes DT, Terekhova DA, Liou L, Hovde CJ, Sahl JW, Patankar AV, Gonzalez JE, Edrington TS, Rasko DA, Sperandio V.2010. Chemical sensing in mammalian host–bacterial commensal associations. Proceedings of the National Academy of Sciences **107**, 9831-9836.

Jacobsen B, Zidack N, Larson B.2004. The role of Bacillus-based biological control agents in integrated pest management systems plant diseases. Phytopathology **94**,1272-1275.

Jasieniuk M, Maxwell BD.1994. Populations genetics and the evolution of herbicide resistance in weeds. Phytoprotection **75**,25-35.

Kaneko T, Nakamura Y, Sato S, Asamizu E, Kato T, Sasamoto S, Watanabe A, Idesawa K, Ishikawa A, Kawashima K.2000. Complete genome structure of the nitrogen-fixing symbiotic bacterium Mesorhizobium loti (supplement). DNA Research **7**, 381-406.

Kennedy IR, Choudhury A, Kecskés ML.2004. Non-symbiotic bacterial diazotrophs in crop-farming systems can their potential for plant growth promotion be better exploited? Soil Biology and Biochemistry **36**,1229-1244.

Khan N, Khan I, Khan MA, Khan H.2004. Major Rabi and Kharif weeds of agronomic crops of District Bannu. Pak J Weed Sci Res **10**,79-86.

Kong Z, Deng Z, Glick BR, Wei G, Chou M.2017. A nodule endophytic plant growth-promoting Pseudomonas and its effects on growth, nodulation and metal uptake in Medicago lupulina under copper stress. Annals of Microbiology **67**,49-58.

Kunst F, Ogasawara N, Moszer I, Albertini A, Alloni G, Azevedo V, Bertero M, Bessieres P, Bolotin A, Borchert S.1997. The complete genome sequence of the gram-positive bacterium Bacillus subtilis. Nature **390**,249-256.

Li J, Ovakim DH, Charles TC, Glick BR.2000. An ACC deaminase minus mutant of Enterobacter cloacae UW4No longer promotes root elongation. Current microbiology **41**,101-105.

Long SR.2001. Genes, signals in the Rhizobium-legume symbiosis. Plant physiology **125**,69-72.

Loper JE, Kobayashi DY, Paulsen IT.2007. The genomic sequence of Pseudomonas fluorescens Pf-5 insights into biological control. Phytopathology **97**,233-238.

Lucy M, Reed E, Glick BR.2004. Applications of free living plant growth-promoting rhizobacteria. Antonie van leeuwenhoek **86**, 1-25.

Morgan J, Bending G, White P.2005. Biological costs and benefits to plant-microbe interactions in the rhizosphere. Journal of experimental botany **56,**1729-1739.

Mukherjee P, Roychowdhury R, Roy M.2017. Phytoremediation potential of rhizobacterial isolates from Kans grass (Saccharum spontaneum) of fly ash ponds. Clean Technologies and Environmental Policy **19,**1373-1385.

Naz I, Bano A, Ul-Hassan T.2009. Isolation of phytohormones producing plant growth promoting rhizobacteria from weeds growing in Khewra salt range, Pakistan and their implication in providing salt tolerance to Glycine max L. African Journal of Biotechnology 8.

Niu DD, Liu HX, Jiang CH, Wang YP, Wang QY, Jin HL, Guo JH.2011. The plant growth–promoting rhizobacterium Bacillus cereus AR156 induces systemic resistance in Arabidopsis thaliana by simultaneously activating salicylate-and jasmonate/ethylene-dependent signaling pathways. Molecular Plant-Microbe Interactions **24,**533-542.

Nkoa R, Owen MD, Swanton CJ.2015. Weed abundance, distribution, diversity, and community analyses. Weed Science **63,**64-90.

Pandey A, Durgapal A, Joshi M, Palni LMS. 1999.Influence of Pseudomonas corrugata inoculation on root colonization and growth promotion of two important hill crops. Microbiological Research **154,**259-266.

Polyanskaya L, Vedina O, Lysak L, Zvyagintsev D. 2002. The growth-promoting effect of Beijerinckia mobilis and Clostridium sp. cultures on some agricultural crops. Microbiology **71,**109-115.

Sarathambal C, Ilamurugu K.2014. Phosphate solubilising diazotrophic bacteria associated with rhizosphere of weedy grasses. Indian Journal of Weed Science **46,**364-369.

Schrey SD, Tarkka MT.2008. Friends and foes streptomycetes as modulators of plant disease and symbiosis. Antonie Van Leeuwenhoek **94,**11-19.

Singh N, Singh G.2018. Plant growth promoting rhizobacteria and Rhizobium combinations are the key to reduce dependence on phosphorus fertilizers in lentil-A review. Agricultural Reviews 39.

Smith RL, Schank S, Bouton J, Quesenberry K. 1978. Yield increases of tropical grasses after inoculation with Spirillum lipoferum. Ecological Bulletins380-385.

Sturz A, Matheson B, Arsenault W, Kimpinski J, Christie B.2001. Weeds as a source of plant growth promoting rhizobacteria in agricultural soils. Canadian journal of microbiology **47,**1013-1024.

Thies JE, Singleton PW, Bohlool BB.1991. Influence of the size of indigenous rhizobial populations on establishment and symbiotic performance of introduced rhizobia on field-grown legumes. Applied and Environmental Microbiology **57,**19-28.

Wandersman C, Delepelaire P.2004. Bacterial iron sources from siderophores to hemophores. Annu Rev Microbiol **58,**611-647.

Wu S, Cao Z, Li Z, Cheung K, Wong M.2005. Effects of biofertilizer containing N-fixer, P and K solubilizers and AM fungi on maize growth a greenhouse trial. Geoderma **125,**155-166.