A SEMINAR PAPER ON

Plant Growth Promoting Rhizobacteria (PGPR): Current & Future Prospective for Sustainable Agriculture

Course Title: Seminar

Course Code: SSC 598

Term: Summer, 2018

Submitted to:

Course Instructors	Major Professor
1. Dr. Md. Mizanur Rahman	Dr. Mohammad Saiful Alam
Professor	Associate Professor
BSMRAU	Department of Soil Science
2. Dr. A. K. M. Aminul Islam	BSMRAU
Professor	
BSMRAU	
3. Dr. Md. Rafiqul Islam	
Professor	
BSMRAU	
4. Dr. Dinesh Chandra Shaha	
Assistant Professor	
BSMRAU	

Submitted by:

Monjur Morshed

Reg. No: 13-05-3012

Department of Soil Science

BANGABANDHU SHEIKH MUJIBUR RAHMAN AGRICULTURAL UNIVERSITY, SALNA, GAZIPUR-1706

Abstract

Plant Growth Promoting Rhizobacteria (PGPR) are a group of bacteria that enhances plant growth and yield via various plant growth promoting substances as well as biofertilizers. Given the negative environmental impact of artificial fertilizers and their increasing costs, the use of beneficial soil microorganisms such as PGPR for sustainable and safe agriculture has increased globally during the last couple of decades. PGPR as biofertilizers are well recognized as efficient soil microbes for sustainable agriculture and hold great promise in the improvement of agriculture yields. Generally, plant growth promoting rhizobacteria facilitate the plant growth directly by either assisting in resource acquisition (nitrogen, phosphorus and essential minerals) or modulating plant hormone levels, or indirectly by decreasing the inhibitory effects of various pathogens on plant growth and development in the forms of biocontrol agents. Various studies have documented the increased health and productivity of different plant species by the application of plant growth promoting rhizobacteria under both normal and stressed conditions. The plant-beneficial rhizobacteria may decrease the global dependence on hazardous agricultural chemicals which destabilize the agro-ecosystems. This review accentuates the perception of the rhizosphere and plant growth promoting rhizobacteria under the current and future perspectives. Further, explicit outlooks on the different mechanisms of rhizobacteria mediated plant growth promotion have been described in detail with the recent development and research. Finally, the latest paradigms of applicability of these beneficial rhizobacteria in different agro-ecosystems have been presented comprehensively under both normal and stress conditions to highlight the recent trends with the aim to develop future insights.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

Introduction

1.1 General Background

The population of this entire world will be more than 10 billion mark by 2050. This rapidly increasing population is putting inviolable pressure on the existing land area for food, fiber, fuel and raw materials. New and novel solutions for plant growth enhancements are required to ease the burden imposed on our environment and other resources. Here we look at potential solutions to these issues by examining some of the research conducted regarding the biological applications of free-living plant growth promoting rhizobacteria (PGPR). The major applications of bacteria for improved plant growth include agriculture, horticulture, forestry and environmental restoration. This review presents an overview of information available on these various applications. Indirect mechanisms used by PGPR include antibiotic protection against pathogenic bacteria, reduction of iron available to phytopathogens in the rhizosphere, synthesis of fungal cell wall-lysing enzymes, and competition with detrimental microorganisms for sites on plant roots. Coordinate components of plant development by PGPR incorporate the arrangement of bioavailable phosphorus for plant take-up, nitrogen obsession for plant utilize, sequestration of iron for plants by siderophores, creation of plant hormones like auxins, cytokinins and gibberellins, and bringing down of plant ethylene levels (Glick 1995; Glick *et al.* 1999).

Plant growth promoting rhizobacteria (PGPR) are the group of bacteria that facilitate both the plant growth and yield through various plant growth promoting substances (shankar, 2013). When plant growth enhancements are required free living Plant growth promoting rhizobacteria (PGPR) can be used in a variety of ways. The rhizosphere refers to the volume of soil surrounding roots where plant root influenced chemically, physically and biologically. Microorganisms proliferate in this suitable habitat and helps to improve the soil health and soil fertility (Sorensen, 1997). Root exudates serve as the main source of nutrients which is composed of amino acids, monosaccharides and organic acids. In rhizosphere, this root exudate addresses the dynamic growth of plant and function of microorganisms. These root-colonizing microorganisms could be free-living, parasitic or saprophytic and their diversity become different with a continuous changing in community structure, and species abundance (Kunc & Macura, 1988). Joseph Kloepper and Milton Schroth first reported these microbial communities and coined the name plant growth-promoting rhizobacteria (PGPR) (Kloepper & Schroth, 1978).

1.2 Rationale of the study

Agriculture contributes to a major portion of national economy in many developing countries like ours and also ensuring food security and employment facilities. Using of improved plant varieties and modern technologies have been effective to meet the demands of the growing population of the country (Johri *et al*., 2003). Practicing more intensive agricultural operations and using more fertilizers to produce more yield is thought to have had negative effects on soil health. Sustainable agriculture is the most important system in today's world because it has the potential to meet our future agricultural needs, which is not possible through conventional agriculture. Beneficial rhizobacteria are very effective to increase plant vigor and soil fertility (Dastager *et al*., 2011. The application of plant growth promoting rhizobacteria (PGPR) as bio fertilizers, phytostimulators and biocontrol agents would be an attractive option to decrease use of chemical fertilizers which lead to environmental pollution, health hazards and destroy soil productivity (Ali *et al*., 2010). PGPR are known to improve plant growth in many ways when compared to synthetic fertilizers, insecticides and pesticides. The main aim of this review is to understand the role of PGPR in sustainable agriculture.

Plant growth enhanced by PGPR is quantified as an increase in seedling emergence, vigor, biomass, proliferation of root system and yield in various plant species. Since their recognition as an important subset of root colonizing microorganisms, in the past three decades, several studies were conducted, at an exponential rate, to identify PGPR in different cropping systems and agro ecological zones (Vessey, 2003; Zahir *et al*. 2004; Ping & Boland, 2004). Plant growth promoting rhizobacteria (PGPR) represent a wide variety of soil bacteria which, when grown in association with a host plant, result in stimulation of growth of their host. Biofertilizer is an as of late instituted term whose correct definition is as yet vague, yet which most usually alludes to the utilization of soil microorganisms to expand the accessibility and take-up of mineral supplements for plants. The focal point of this survey is the method of activity of PGPR which go about as biofertilizers, either straightforwardly by giving supplement to the host plant, or by implication by emphatically affecting root development and morphology or by supporting other gainful harmonious connections. Not all PGPR are biofertilizers. Numerous PGPR fortify the development of plants by controlling pathogenic living being (Whipps, 2001; Zehnder *et al*. 2001).

Recently there has been a great interest in eco-friendly and sustainable agriculture. They enhance crop growth and can help in sustainability of safe environment and crop productivity. The rhizospheric soil1 contains diverse types of PGPR communities, which exhibit beneficial effects on crop productivity. A few research examinations are led on the comprehension of the assorted variety, elements and significance of soil PGPR people group and their useful and helpful parts in agrarian profitability. So this article presents points of view on the part of PGPR in agriculture maintainability.

1.3 Objectives

The specific objectives of this review paper are given below:

- To review the role of Plant growth promoting rhizobacteria (PGPR) in agriculture,
- To observe the effect of PGPR on the growth and yield of crops, and
- To find out the present and future prospects of PGPR for sustainable agriculture.

Chapter II

Materials & Methods

This seminar paper is exclusively a review paper. Therefore, all the information was collected from secondary sources with a view to prepare this paper. Various relevant books and journals, which were available in the library of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) and BARI were used for the preparation of this paper. For collecting recent information internet browsing was also being practiced. Good suggestions, valuable information and kind consideration from my honourable major professor, course instructors and other resources personnel were taken to enrich this paper. After collecting necessary information, it has compiled and arranged chronologically for better understanding and clarification.

Chapter III

Results & Discussion

Plant Growth Promoting Rhizobacterial Forms

Two sorts of Plant growth promoting rhizobacteria (PGPR) are found in the root zone. One is extracellular plant growth promoting rhizobacteria (ePGPR) and another is intracellular plant growth promoting rhizobacteria (iPGPR) (Viveros *et al*., 2010). The essential one that is ePGPRs could exist inside the rhizosphere, on the rhizoplane or inside the territories between the cells of root cortex while another one, iPGPRs finds in some cases inside the specific nodular arrangement of root cells. The bacterial genera including *Agrobacterium*, *Arthrobacter*, *Caulobacter*, *Chromobacterium*, *Erwinia*, *Flavobacterium*, *Azotobacter*, *Azospirillum*, *Bacillus*, *Burkholderia*, *Micrococcous*, *Pseudomonas and Serratia* has a place with ePGPR (Ahemad and Kibret, 2014). The genera, for example, *Allorhizobium*, *Bradyrhizobium*, *Mesorhizobium* and *Rhizobium* has a place with iPGPR, endophytes and *Frankia* species both of which can be utilized to settle barometrical nitrogen advantageously with the higher plants (Bhattacharyya and Jha, 2012). Mechanism of PGPR (Fig 1) is complex but very effective for plant growth and development.

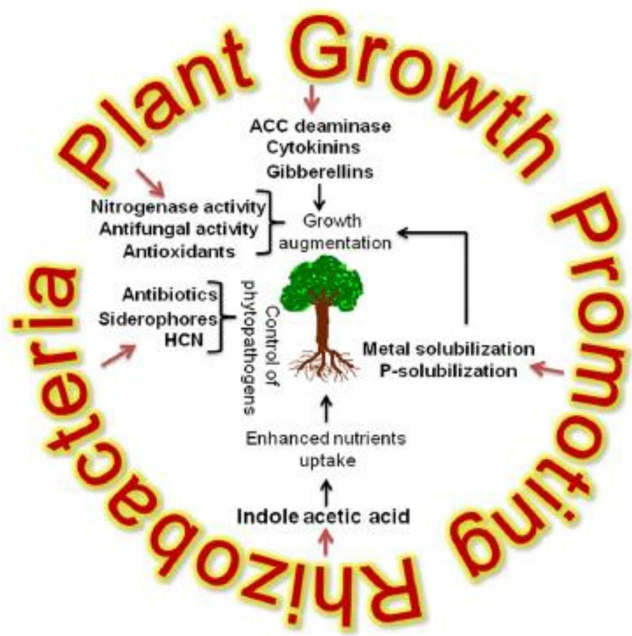
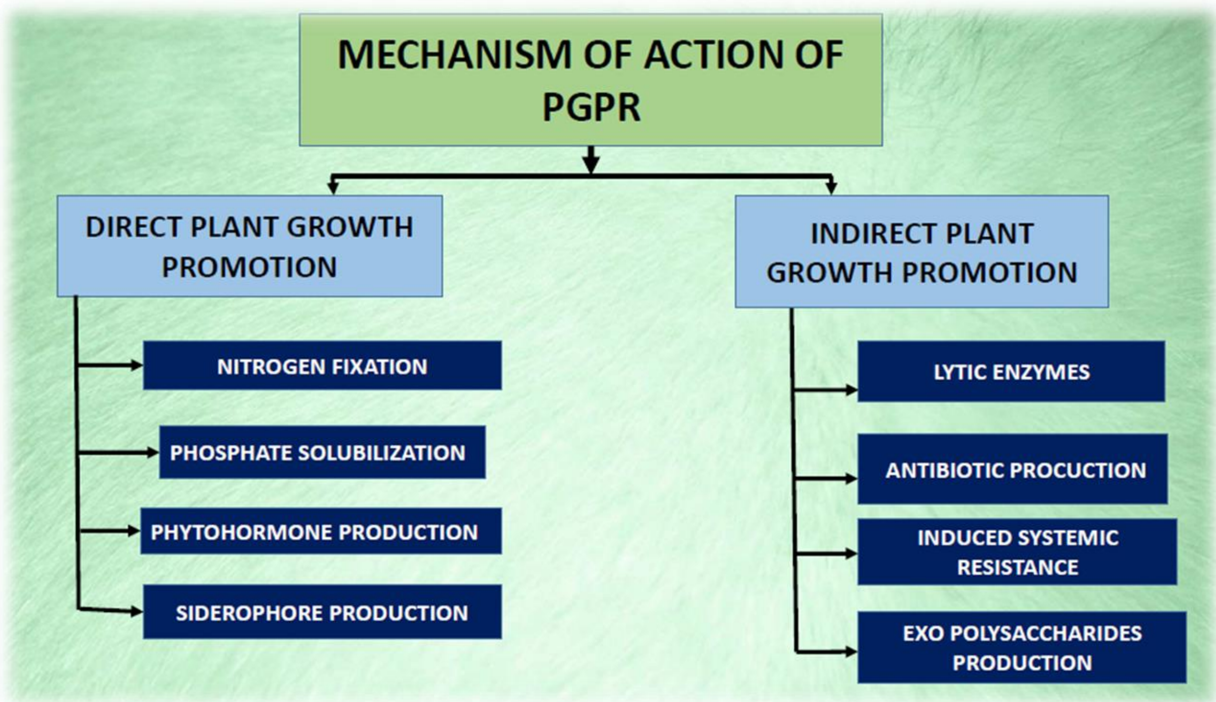


Fig 1: Mechanism of plant growth promotion by rhizobacteria.

Plant Growth Promotion: Mechanism of Action

Plant development advancement by plant growth promoting rhizobacteria is an outstanding characteristic and this development change is because of some particular attributes of rhizobacteria. There is assortment of systems used by PGPR for upgrading plant development and improvement in various ecological conditions through direct or indirect way (Fig 2).



(Source: King et al., 2010)

Fig 2: Schematic diagram showing plant growth promoting bacteria affect plant growth directly and indirectly.

Plant development advancement interceded by plant development advancing rhizobacteria through the progressions of aggregate microbial group in root territory and creation of different substances (Gupta et al., 2105). For the most part, plant development advancing rhizobacteria advance plant development straightforwardly or in a roundabout way.

Several mechanisms have been suggested by which PGPR can promote plant growth efficiently (*Table* 1); Some important ones are as follows:

Table 1: PGPR and their effect on growth parameters/ yields of crop/fruit plants

PGPR	Crop parameters
Rhizobium leguminosarum	Direct growth promotion of canola and lettuce
Pseudomonas putida	Early development of canola seedlings, growth stimulation of tomato plant
Azospirillum brasilense* and *A. irakense	Growth of wheat and maize plants
P. flurescens	Growth of pearl millet, increase in growth, leaf nutrient contents and yield of banana
Azotobacter* and *Azospirillum spp.	Growth and productivity of canola
Pseudomonas, Azotobacter* and *Azospirillum spp.	Stimulates growth and yield of chick pea
R. leguminosarum* and *Pseudomonas spp.	Improves the yield and P uptake in wheat
P. putida, P. flurescens, A.brasilense and A. lipoferum	Improves seed germination, seedling growth and yield of maize
P. alcaligens, Bacillus polymyxa,* and *Mycobacterium phlei	Enhances uptake of N,P and k by maize crop

(Source: Singh, 2013)

Direct mechanisms

Plant development advancing rhizobacteria having direct systems which help to supplement take-up or increment supplement accessibility by nitrogen obsession from the climate, solubilization of mineral supplements, mineralize natural mixes and creation of a few vital phytohormones (Bhardwaj *et al*., 2014).

Nitrogen fixation

Nitrogen is a fundamental component for all assortments of life and it is the most extreme indispensable supplement for plant blast and yield productiveness. Despite the fact that the nitrogen offers 78 % of the earth, it stays inside the type of inaccessible to the vegetation. Appallingly there is no plant species is fit for tackling climatic dinitrogen into ammonia and offer it immediately for its expansion. Biological Nitrogen Fixation (BNF) is the main framework by means of which environmental nitrogen can be changed into ammonia through an unpredictable catalyst called nitrogenase (Gaby and Buckley, 2012). Plant growth promoting rhizobacteria (PGPR) have the ability to repair climatic nitrogen and offer it to vegetation. PGPR keep up two ways here: symbiotic and non-symbiotic. There are some nitrogen explaining microorganisms and their seeking with the host plants (table 2).

Table 2: Nitrogen fixing bacteria and their relationship with the host plants

PGPR	Relationship	Host Plant
Azospirillum sp.	Non-symbiotic	Rice, wheat, maize, sugarcane
Azotobacter sp.	Non-symbiotic (aerobic)	Paspalumnotatum grass, maize, wheat
Azoarcus sp.	Non-symbiotic (aerobic)	Kallar grass, sorghum
Acetobacter	Non-symbiotic (Obligatory aerobic)	Sugarcane
Rhizobium leguminosarum	Symbiotic (endo-symbiotic)	Wheat, maize, barley
Bradyrhizobium betae	Symbiotic	Sugar beets
Bradyrhizobium japonicum	Symbiotic	Cowpeas, mungbeans, soybeans
Burkholderia sp.	Symbiotic(endo)	Rice

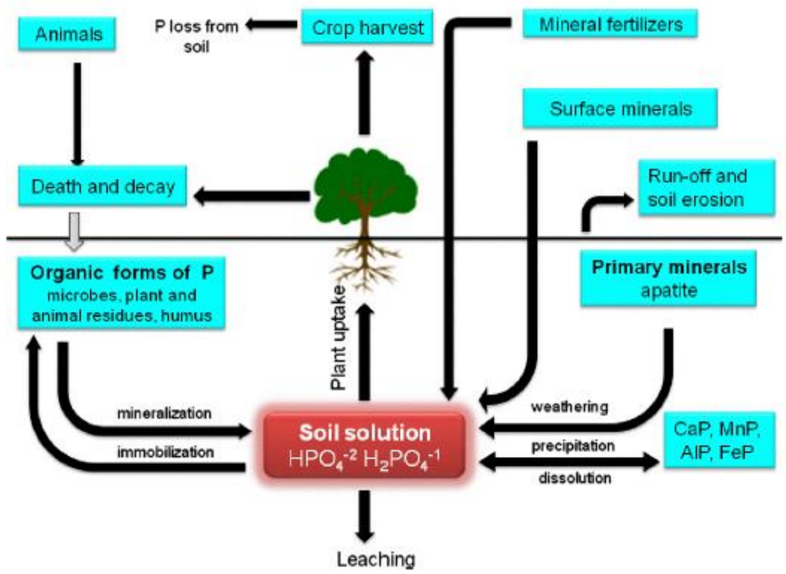
(Source: Kundan *et al*., 2015)

Harmonious nitrogen obsession is a mutualistic relationship among an organism and the plant. The organism first enters the establishment and later on shape knobs in which nitrogen fixation happens. Rhizobia are a gigantic establishment of rhizobacteria that can give harmonious collaborations by the colonization and development of root knobs with leguminous vegetation, wherein nitrogen is settled to alkali and make it to be had for the plant blast and at the same time for developing the efficiency (Ahemad and Kibret, 2014).

The plant development advancing rhizobacteria broadly introduced as symbionts are *Rhizobium, Bradyrhizobium, Sinorhizobium,* and *Mesorhizobium* with leguminous plants, *Frankia* with non-leguminous trees and bushes. Then again, non-symbiotic nitrogen fixation is completed by free living diazotrophs and this can fortify non-vegetable plants development, for example, radish and rice. Non-advantageous Nitrogen settling rhizospheric microscopic organisms having a place with genera including *Azoarcus, Azotobacter, Acetobacter, Azospirillum, Burkholderia, Diazotrophicus, Enterobacter, Gluconacetobacter, Pseudomonas* and *cyanobacteria* (Anabaena, Nostoc). In both symbiotic and free living system "nif" genes are found for nitrogen fixation (Reed *et al*., 2011). Nitrogenase (nif) genes incorporate auxiliary qualities, associated with actuation of the Fe protein, press molybdenum cofactor biosynthesis, electron gift, and administrative qualities required for the combination and capacity of the enzyme. Immunization by natural nitrogen settling plant development advancing rhizobacteria on trim give a coordinated way to deal for diseases management, development advancement action, keep up the nitrogen level in agrarian soil.

Phosphate solubilization

Phosphorus is the most essential key component in the nourishment of plants, alongside nitrogen (N). It assumes a vital part in for all intents and purposes all major metabolic procedures in plant including photosynthesis, vitality exchange, flag transduction, macromolecular biosynthesis and breath (Khan et al., 2010). It is inexhaustibly accessible in soils in both natural and inorganic structures. Plants can't use phosphate in light of the fact that 95-99% phosphate exhibit in the insoluble, immobilized, and in the form of precipitation (Pandey and Maheshwari, 2007)). Plants retain phosphate just in two solvent structures, monobasic ($H2PO_4$) and diabasic (HPO_4^{2-}) particles (Fig 3). Plant development advancing rhizobacteria show in the dirt utilize diverse systems to make utilization of inaccessible types of phosphorus and thus additionally help in making phosphorus accessible for plants to assimilate.

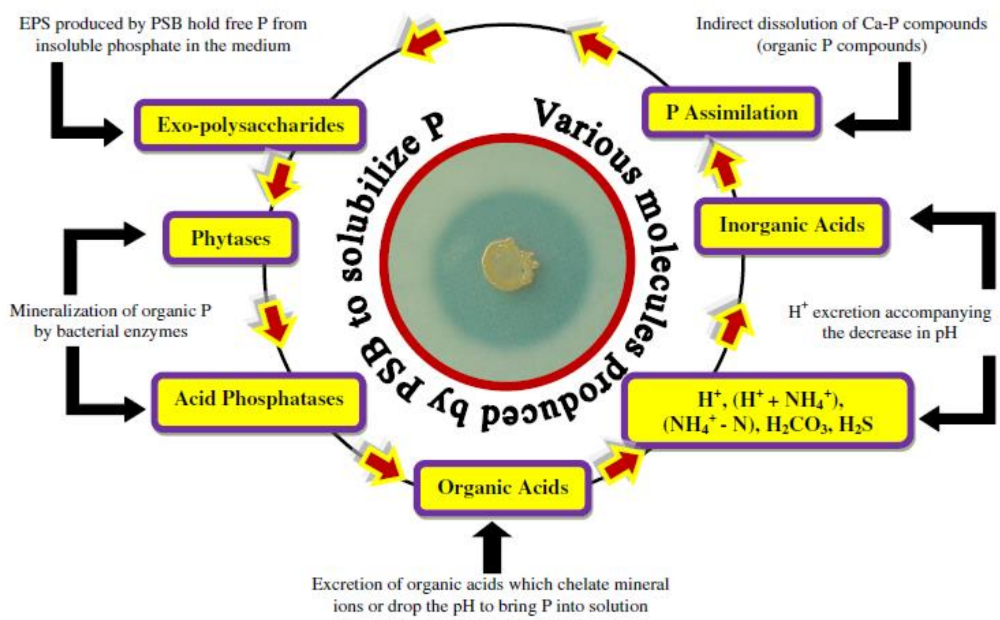


(Source: Ahemad & Kibret, 2014)

Fig3: Movement of phosphorous in soil.

The standard phosphate solubilization segments used by plant improvement progressing rhizobacteria include: (1) landing of complexing or mineral dissolving blends e.g. normal destructive anions, protons, hydroxyl particles, CO2, (2) flexibility of extracellular mixes (biochemical phosphate mineralization) and (3) the entry of phosphate at the season of substrate diminishment (natural phosphate mineralization) (Sharma, 2013). Life forms combined with phosphate solubilizing movement, frequently named as phosphate solubilizing microorganisms (PSM), may give the accessible types of P to the plants and subsequently a practical substitute to compound phosphatic manures (Khan et al., 2006). Of the different PSM(s) occupying the rhizosphere, phosphate-solubilizing microorganisms (PSB) are considered as promising biofertilizers since they can supply plants with P from sources generally inadequately accessible by different systems (Fig 4).

Phosphate solubilizing PGPR bind into the genera *Arthrobacter, Bacillus, Beijerinckia, Burkholderia, Enterobacter, Erwinia, Flavobacterium, Microbacterium Pseudomonas, Rhizobium, Rhodococcus*, and *Serratia* have pulled in the thought of agriculturists as soil inoculums to improve plant advancement and yield. In any case, the beneficial effects of the immunization with phosphate solubilizing tiny life forms used alone or in mix with other rhizospheric microorganisms have been moreover uncovered (Zaidi *et al.*, 2009).

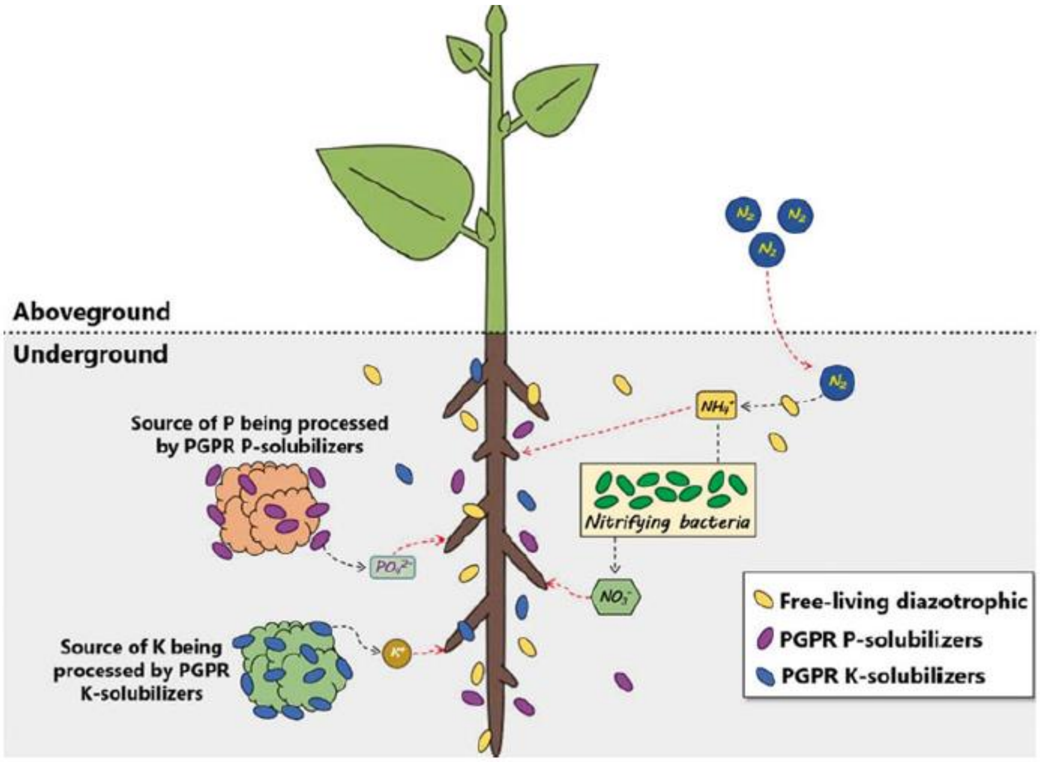


(Source: Ahemad & Kibret, 2014)

Fig.4: Various organic/inorganic substances produced by Phosphate Solubilizing Bacteria(PSB) responsible for P solubilization in soil.

Potassium solubilization:

Potassium (K) is the third significant fundamental macronutrient for plant development. The convergences of solvent potassium in the soil are generally low and over 90% of potassium in the soil exists as insoluble rocks and silicate minerals (Parmar and Sindhu, 2013). Additionally, because of imbalanced fertilizer application, potassium insufficiency is getting to be one of the significant limitations in production stage. Without sufficient potassium, the plants will have ineffectively created roots, develop gradually, produce little seeds and have bring down yields. This underscored the pursuit to locate an option indigenous wellspring of potassium for plant take-up and to keep up potassium status in soils for managing crop production (Kumar and Dubey, 2012).



(Source: Upadhyay *et al*., 2016)

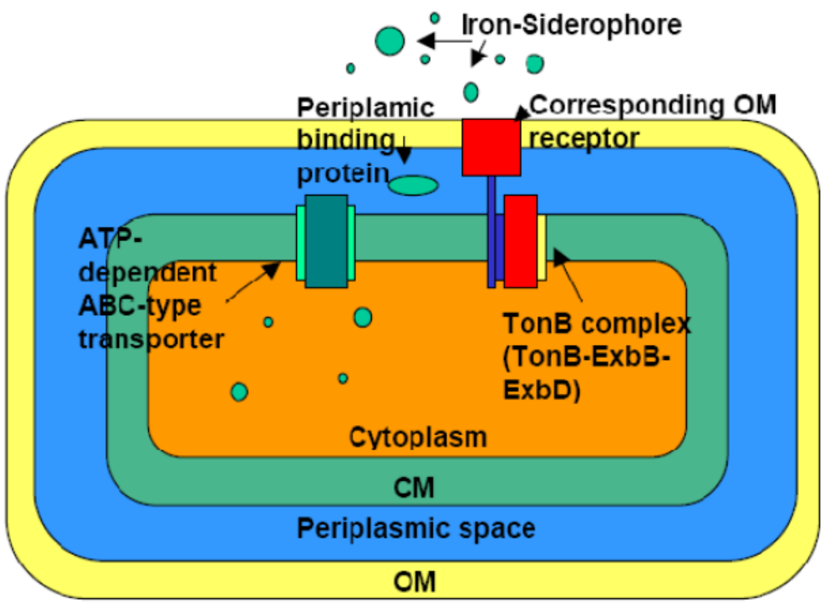
Fig.5: Modes of N, P and K improvement for soil and plants mediated by PGPR. Free living diazotrophic bacteria are able to capture N from the atmosphere and release it to plants as ammonium or nitrate.

Plant development elevating rhizobacteria can solubilize potassium rock through generation and emission of natural acids. Potassium solubilizing plant development advancing rhizobacteria, for example, *Acidothiobacillus ferrooxidans*, *Bacillus edaphicus, Bacillus mucilaginosus, Burkholderia*, *Paenibacillus* sp. what's more, *Pseudomonas* has been accounted for to discharge (Fig 5) potassium in open shape from potassium bearing minerals in soils (Wang *et al*., 2012).

Siderophore production

Iron is a fundamental micronutrient for all life forms in the biosphere. Notwithstanding the way that iron is the fourth most plenteous component on earth, in oxygen consuming soils, press isn't promptly absorbed by either microbes or plants in light of the fact that ferric particle or Fe^{+3}, which is the dominating structure in nature, is just sparingly solvent with the goal that the measure of iron accessible for osmosis by living beings is to a great degree low (Ma, 2005).

The iron-siderophore complex is then recognized by the corresponding outer membrane receptor protein. Official of the ferric-siderophore complex actuates significant conformational changes, maybe motioning to start TonB connection. Using essentialness presumably gave by the TonB complex (proton method of reasoning force), the ferric-siderophore complex is viably transported into the periplasm. Once in the periplasm, the iron-siderophore complex is bound to a periplasmic confining protein that vehicles the complex to the ABC-type transporter in the cytoplasmic film, which transports the complex into the cytoplasm utilizing essentialness from the hydrolysis of ATP (Fig 6).



(Source: Prashar, 2014)

Fig.6: General Siderophore-mediated Iron Transport in a Gram negative cell.

Microorganisms have advanced particular components for the osmosis of iron, including the generation of low atomic weight press chelating mixes known as siderophores, which transport this component into their cells. Siderophores are isolated into three principle families relying upon the trademark utilitarian gathering, i.e. hydroxamates, catecholates and carboxylates. At show in excess of 500 distinct sorts of siderophores are known, of which 270 have been fundamentally described (Cornelis, 2010). Siderophores have been involved for both immediate and backhanded upgrade of plant development by plant development advancing rhizobacteria. The immediate advantages of bacterial siderophores on the development of plants have been exhibited by utilizing radio labeled ferric Siderophore as a sole wellspring of iron demonstrated that plants can take up the named press by countless development advancing rhizobacteria including *Aeromonas, Azadirachta, Azotobacter, Bacillus, Burkholderia, Pseudomonas, Rhizobium, Serratia* and *Streptomyces* sp. (Sujatha and Ammani, 2013) and upgraded chlorophyll level contrasted with unimmunized plants.

Phytohormone production:

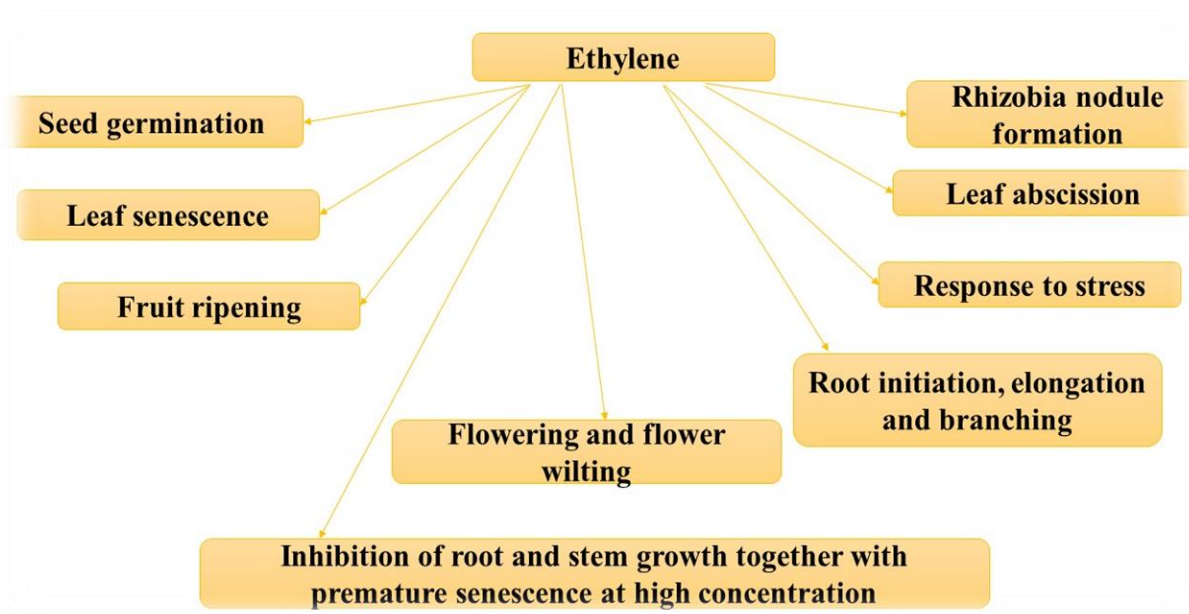
An extensive variety of microorganisms found in the rhizosphere can deliver substances that direct plant development and advancement. The upgrade in different agronomic yields because of PGPR has been accounted for in view of the creation of development animating phytohormones (Table 3, for example, indole-3-acidic corrosive (IAA), gibberellic corrosive (GA3), zeatin, ethylene and abscisic corrosive (ABA).

Table 3: Examples of different Phytohormone-producing PGPR

Phytohormones	PGPR
Indole-3-acetic acid (IAA)	*Acetobacter diazotrophicus* and *Herbaspirillum seropedicae*
Zeatin and ethylene	*Azospirillum* sp.
Gibberellic acid (GA3)	*Azospirillum lipoferum*
Abscisic acid (ABA)	*Azospirillum brasilense*

(Source: shankar, 2013)

Plant development advancing rhizobacteria deliver phytohormones, for example, auxins, cytokinins, gibberellins and Ethylene can influence cell expansion in the root design by overproduction of horizontal roots and root hairs with a resulting increment of supplement and water take-up (Arora et al., 2013).



(Source: Shilev, 2013)

Fig 7: The phytohormones ethylene affects a large no of different processes in the growth and development in the plant.

Ethylene is another plant hormone known to regulate many processes such as the ripening of fruits, the abscission of leaves, or the ripening of fruits (Fig 7). Additionally, at high focuses, ethylene incites the defoliation and cell forms that prompt the hindrance of root and stem development together with untimely senescence, all of which prompt poorer product execution. The plants integrated 1-aminocyclopropane-1-carboxylate (ACC), which is the antecedent for ethylene, in light of presentation to different kinds of ecological pressure, for example, cool, dry spell, flooding, diseases with pathogens, and the nearness of substantial metals. Elevated amounts of ethylene, created under pressure conditions, can end certain procedures, for example, root lengthening or nitrogen obsession in vegetables, and cause untimely senescence.

Indole Acetic Acid (IAA)

Among plant development controllers, indole acidic acid (IAA) is the most widely recognized common auxin found in plants and its constructive outcome on root development (Miransari and Smith, 2014). Indole acidic corrosive influences plant cell division, augmentation, and separation; invigorates seed and tuber germination; expands the rate of xylem and root advancement; controls procedures of vegetative development; starts horizontal and unusual root arrangement; intercedes reactions to light, gravity and brilliance; influences photosynthesis, shade development, biosynthesis of different metabolites, and protection from unpleasant conditions (Spaepen and Vanderleyden, 2011). Tryptophan is an amino corrosive regularly found in root exudates, has been recognized as principle antecedent atom for biosynthesis of IAA in microscopic organisms. The biosynthesis of indole acidic corrosive by plant development advancing rhizobacteria includes arrangement by means of indole-3-pyruvic corrosive and indole-3-acidic aldehyde, which is the most widely recognized instrument in microbes like *Pseudomonas, Rhizobium, Bradyrhizobium, Agrobacterium, Enterobacter* and *Klebsiella* (Shilev, 2013). Root development advancement by the free living PGPR e.g. *Alkaligenes faecalis, Enterobacter cloacae, Acetobacter dizotrophicous*, types of *Azospirillum, Pseudomonas* and *Xanthomonas* sp. has been identified with low level of IAA emission. In any case, microbially created phytohormones are more compelling because of the reason that the edge amongst inhibitory and stimulatory levels of synthetically delivered hormones is low, while microbial hormones are more powerful by excellence of their persistent moderate discharge.

Cytokinins and gibberellins

A couple of plant improvement progressing rhizobacteria Azotobacter sp., Rhizobium sp., Pantoea agglomerans, Rhodospirillum rubrum, Pseudomonas fluorescens, Bacillus subtilis and Paenibacillus polymyxa can convey cytokinins or gibberellins or both can make either cytokinins or gibberellins or both for plant advancement headway (Kang et al., 2010). A couple of strains of phytopathogens can in like manner join cytokinins. In any case, it creates the impression that plant development advancing rhizobacteria deliver bring down cytokinin levels contrasted with phytopathogens so the impact of the plant development advancing rhizobacteria on plant development is stimulatory while the impact of the cytokinins from pathogens is inhibitory. Ethylene is a key phytohormone has an extensive variety of natural exercises can influence plant development and improvement in a substantial number of various ways including advancing root start, restraining root prolongation, advancing organic product aging, advancing lower withering, fortifying seed germination, advancing leaf abscission, actuating the amalgamation of other plant hormones (Glick, 2007). The high grouping of ethylene instigates defoliation and other cell forms that may prompt diminished product execution. The catalyst 1-aminocyclopropane-1 carboxylic corrosive (ACC) is a pre-imperative for ethylene generation, catalyzed by ACC oxidase.

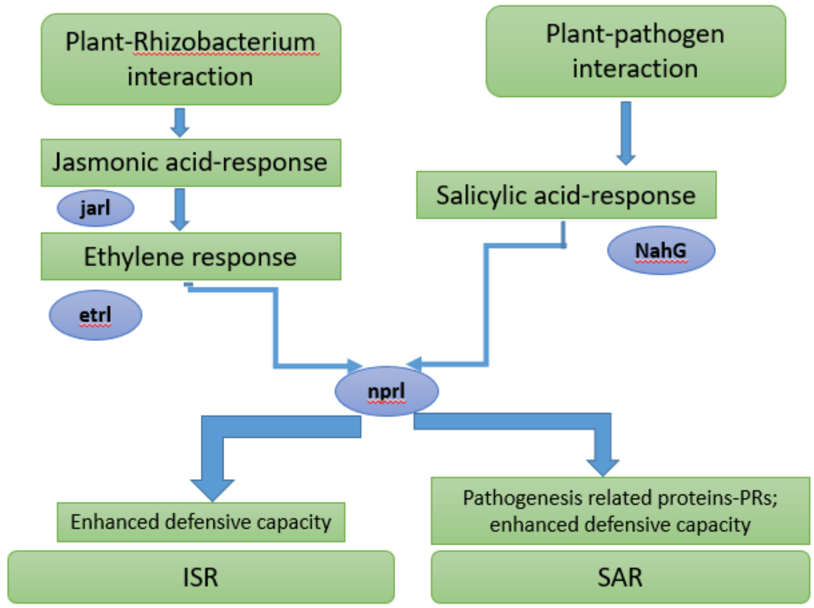
In-direct mechanisms

Phytopathogenic microorganisms are a noteworthy and endless danger to reasonable agribusiness and biological system soundness overall subverts the dirt nature, upset condition, corrupt soil richness and thusly indicate hurtful consequences for human wellbeing, alongside debasing ground water. Plant development advancing rhizobacteria is a promising reasonable and naturally neighborly way to deal with acquire maintainable richness of the dirt and plant development in a roundabout way. This approach takes move an extensive variety of misuse of plant development elevating rhizobacteria prompted lessening the requirement for agrochemicals (manures and pesticides) for enhance soil richness by an assortment of instruments that by means of creation of anti-microbials, siderophores, HCN, hydrolytic proteins and so on (Tariq *et al.*, 2013).

Induced systemic resistance (ISR)

Prompted protection might be characterized as a physiological condition of improved cautious limit evoked in light of particular ecological jolts and therefore the plant's inborn resistances are potentiated against ensuing biotic difficulties (Avis, 2008). Bio priming plants with some plant development advancing rhizobacteria can likewise give fundamental protection against a wide range of plant pathogens. Ailments of parasitic, bacterial, and viral source and in a few occasions even harm caused by creepy crawlies and nematodes can be lessened after utilization of plant development advancing rhizobacteria (Naznin, 2012). Besides, instigated foundational protection includes jasmonate and ethylene motioning inside the plant and these hormones fortify the host plant's resistance reactions against an assortment of plant pathogens. Lipopolysaccharides (LPS), flagella, siderophores, cyclic lipopeptides, 2, 4-diacetylphloroglucinol, homoserine lactones, and volatiles like, acetoin and 2, 3-butanediol prompt actuated fundamental protection.

From an experiment, Infected plants increased their levels of JA and ET as a sign of active. These flagging atoms arrange the enactment of a huge arrangement of protection reactions and when connected exogenously, can instigate protection themselves. The reliance of ISR on JA and ethylene depends on improved affectability to these hormones as opposed to on an expansion in their generation (Smith *et al.*, 2011). The Arabidopsis JA reaction mutant jar1 and the ET reaction mutant etr1 were tried in the improvement of ISR. The two mutants were not able create ISR against P. syringae pv. endless supply of the roots by WCS417r microscopic organisms (Smith et al., 2011), delineating the reliance of ISR motioning on these phytohormones. The flag transduction pathways prompting pathogen-initiated SAR and rhizobacteria intervened ISR in Arabidopsis thaliana are compressed (Fig 8).



(Source: Van Loon *et al*. 2010)

Fig. 8: Signal transduction pathways leading to pathogen-induced systemic acquired resistance(SAR) and rhizobacteria-mediated induced systemic resistance(ISR) in *Arabidopsis thaliana*.

An experiment was conducted in the field laboratory of the department of plant pathology of Bangabandhu Sheikh Mujibur Rahman Agricultural University to identify and characterize PGPR indigenous to cucumber rhizosphere in Bangladesh, and to evaluate their ability to suppress Phytophthora crown rot in cucumber. The total of 66 rhizobacterial strains were obtained from the interior of cucumber roots. PPB1, PPB2, PPB3, PPB4, PPB5, PPB8, PPB9, PPB10, PPB11, and PPB12–a total of ten isolates were selected. All isolates were rods producing fast-growing, round to irregular colonies with raised elevations and smooth surfaces.

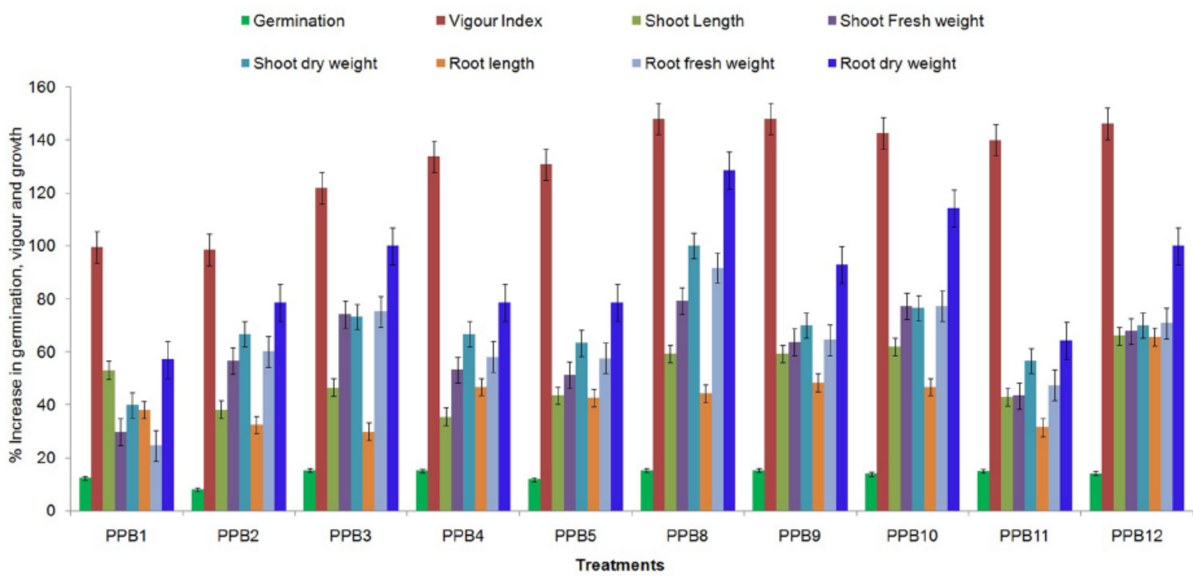
Table 4: Comparative performance of PGPR in mycelia growth inhibition of *P. capsici* and Phytophthora crown rot disease suppression in cucumber plants

Treatments	**Disease suppression (% Protectionc)**

	Pathogen suppression (% *P. capsici* mycelial growth inhibition)	500 μl Zoospores/potd	1000 μl Zoospores/pot
PPB1	67.16 ± 0.68*e*	58.33 ± 0.66*c*	33.33 ± 2.18*b*
PPB2	70.01 ± 0.85*g*	69.45 ± 0.80*e*	38.84 ± 1.70*c*
PPB3	69.08 ± 0.91*f*	50.00 ± 1.69*b*	50.00 ± 1.54*e*
PPB4	62.07 ± 0.11*c*	70.33 ± 2.37*f*	45.68 ± 2.37*d*
PPB5	65.94 ± 0.53*d*	50.00 ± 0.57*b*	33.33 ± 1.69*b*
PPB8	82.05 ± 0.55*j*	83.33 ± 0.56*h*	77.78 ± 2.25*g*
PPB9	90.08 ± 0.46*k*	66.67 ± 1.87*d*	66.67 ± 2.93*f*
PPB10	73.08 ± 0.83*h*	73.67 ± 1.53*g*	66.67 ± 0.52*f*
PPB11	58.32 ± 0.12*b*	88.83 ± 1.67*i*	86.08 ± 2.23*h*
PPB12	80.53 ± 0.69*i*	50.00 ± 1.15*b*	33.33 ± 0.43*b*
Control	0.00 ± 0.00*a*	0.00 ± 0.00*a*	0.00 ± 0.00*a*

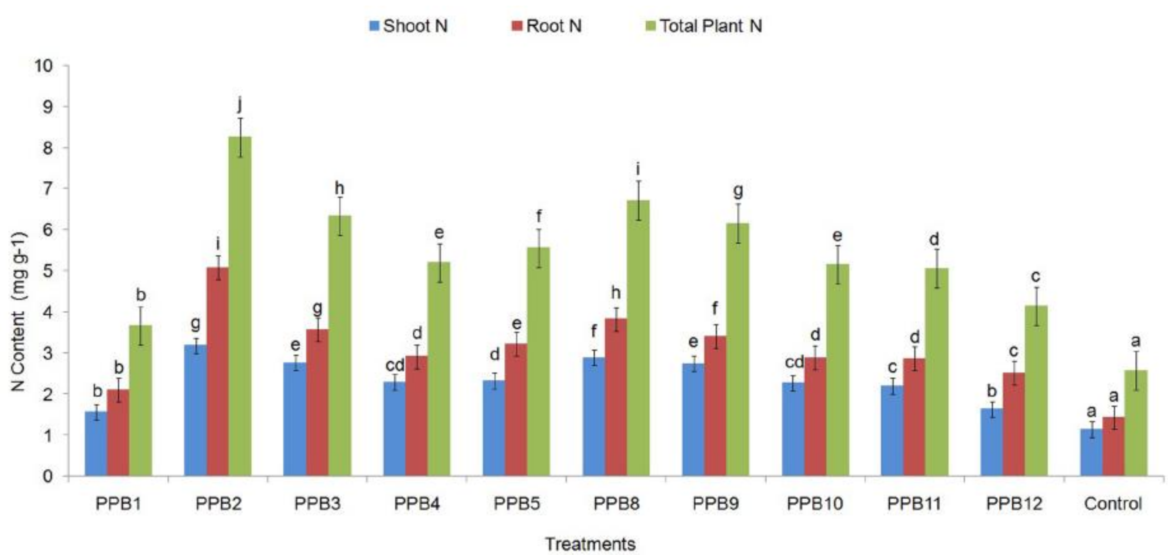
(Source: Abdul *et al.*, 2016)

All the selected PGPR strains showed consistent suppression of Phytophthora crown rot in the green house experiments.



(Source: Akanda *et al*., 2016)

Fig 9: Effect of plant growth promoting rhizobacteria(PGPR) treatments on seed germination, vigor and growth of cucumber seedlings grown in pots.



(Source: Akanda *et al*., 2016)

Fig10: Effect of inoculation with PGPR strains on shoot and root N contents of cucumber plants.

Commercialization of PGPR

The accomplishment and commercialization of plant improvement progressing rhizobacterial strains depend upon the linkages between the consistent affiliations and endeavors. Different work done demonstrated assorted stages amid the time spent commercialization fuse isolation of adversary strains, screening, maturing methodologies, extensive scale producing, enumerating reasonableness, toxicology, mechanical linkages, quality control and field reasonability. Likewise, business achievement of PGPR strains requires mild and appropriate market ask for, unsurprising and extensive territory openness of occupation materials. action, security and robustness, longer time traverse of ease of use, low capital costs and straightforward openness of livelihood materials.

Future Research and Development Strategies for Sustainable Technology

The need of the present world is high return and enhanced age of the item and also wealth of soil to get in an ecofriendly way. Thus, the investigation must be based on the new thought of rhizoengineering in light of decidedly partitioning of the interesting biomolecules, which make a stand-out setting for the correspondence among plant and microorganisms (Tewari and Arora, 2013). Future research in rhizosphere science will rely upon the change of sub-nuclear and biotechnological approaches to manage increase our understanding into rhizosphere science and to achieve a joined organization of soil microbial masses. New choices should be researched for the use of bio inoculants for other high regard items, for instance, vegetables, natural items, and blooms. The use of multi strain bacterial consortium over single vaccination could be a convincing procedure for reducing the terrible impact of weight on plant advancement. The extension of ice-nucleating plant improvement progressing rhizobacteria could be an intense advancement for updating plant improvement at low temperature. Research on nitrogen fixation and phosphate solubilization by plant improvement progressing rhizobacteria is progress on however little research ought to be conceivable on potassium solubilization which is third noteworthy major macronutrient for plant advancement. This won't simply grow the field of the inoculants yet furthermore make sureness among the farmers for their usage. Besides, future exhibiting of bio inoculant things and landing of these transgenic into the earth as eco-obliging varieties to agrochemicals will depend upon the time of biosafety data required for the selection of plant advancement progressing rhizobacterial masters. A segment from that future research in upgrading improvement condition and extended self-presence of PGPR things, not phytotoxic to trim plants, persevere through disagreeable natural condition, higher yield and reasonable PGPR things for usage of green farmer will be similarly helpful.

Chapter IV

Conclusion

Around the world, impressive advance has been accomplished in the zone of PGPR biofertilizer innovation. It has been additionally shown and demonstrated that PGPR can be exceptionally powerful and are potential organisms for advancing the dirt fruitfulness and upgrading the farming yield. PGPR are amazing model frameworks which can give the biotechnologist novel hereditary constituents and bioactive chemicals having assorted uses in agribusiness and ecological manageability. Present and future advance in our comprehension of PGPR decent variety, colonization capacity, instruments of activity, definition, and application could encourage their improvement as dependable parts in the administration of maintainable rural frameworks.

References

Ahemad, M., & Khan, M. S. (2010). Plant growth promoting activities of phosphate-solubilizing Enterobacter asburiae as influenced by fungicides. EurAsian J BioSci, 4, 88-95.

Ahemad, M., & Kibret, M. (2014). Mechanisms and applications of plant growth promoting rhizobacteria: current perspective. Journal of King Saud University-Science, 26(1), 1-20.

Arora, N. K., & Mishra, J. (2016). Prospecting the roles of metabolites and additives in future bioformulations for sustainable agriculture. Applied Soil Ecology, 107, 405-407.

Avis, T. J., Gravel, V., Antoun, H., & Tweddell, R. J. (2008). Multifaceted beneficial effects of rhizosphere microorganisms on plant health and productivity. Soil Biology and Biochemistry, 40(7), 1733-1740.

Bhardwaj, D., Ansari, M. W., Sahoo, R. K., & Tuteja, N. (2014). Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. Microbial cell factories, 13(1), 66.

Bhattacharyya, P. N., & Jha, D. K. (2012). Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. World Journal of Microbiology and Biotechnology, 28(4), 1327-1350.

Bishnoi, U. (2015). PGPR interaction: an ecofriendly approach promoting the sustainable agriculture system. In Advances in Botanical Research (Vol. 75, pp. 81-113). Academic Press.

Damodaran, T., Sah, V., Rai, R. B., Sharma, D. K., Mishra, V. K., Jha, S. K., & Kannan, R. (2013). Isolation of salt tolerant endophytic and rhizospheric bacteria by natural selection and screening for promising plant growth-promoting rhizobacteria (PGPR) and growth vigour in tomato under sodic environment. African Journal of Microbiology Research, 7(44), 5082-5089.

Gupta, G., Parihar, S. S., Ahirwar, N. K., Snehi, S. K., & Singh, V. (2015). Plant growth promoting rhizobacteria (PGPR): current and future prospects for development of sustainable agriculture. J Microb Biochem Technol, 7(2), 096-102.

Hungria, M., Nogueira, M. A., & Araujo, R. S. (2015). Soybean seed co-inoculation with Bradyrhizobium spp. and Azospirillum brasilense: a new biotechnological tool to improve yield and sustainability. American Journal of Plant Sciences, 6(06), 811.

Illakkiam, D., Ponraj, P., Shankar, M., Muthusubramanian, S., Rajendhran, J., & Gunasekaran, P. (2013). Identification and structure elucidation of a novel antifungal compound produced by Pseudomonas aeruginosa PGPR2 against Macrophomina phaseolina. Applied biochemistry and biotechnology, 171(8), 2176-2185.

Kang, B. G., Kim, W. T., Yun, H. S., & Chang, S. C. (2010). Use of plant growth-promoting rhizobacteria to control stress responses of plant roots. Plant Biotechnology Reports, 4(3), 179-183.

Khan, M. S., Zaidi, A., Wani, P. A., Ahemad, M., & Oves, M. (2009). Functional diversity among plant growth-promoting rhizobacteria: current status. In Microbial strategies for crop improvement. Springer Berlin Heidelberg, (pp. 105-132).

Kumar, P., Dubey, R. C., & Maheshwari, D. K. (2012). Bacillus strains isolated from rhizosphere showed plant growth promoting and antagonistic activity against phytopathogens. Microbiological research, 167(8), 493-499.

Kundan, R., Pant, G., Jadon, N., & Agrawal, P. K. (2015). Plant growth promoting rhizobacteria: mechanism and current prospective. J Fertil Pestic, 6(2), 9.

Loper, J. E., & Gross, H. (2007). Genomic analysis of antifungal metabolite production by Pseudomonas fluorescens Pf-5. European Journal of Plant Pathology, 119(3), 265-278.

Martínez-Viveros, O., Jorquera, M. A., Crowley, D. E., Gajardo, G. M. L. M., & Mora, M. L. (2010). Mechanisms and practical considerations involved in plant growth promotion by rhizobacteria. Journal of soil science and plant nutrition, 10(3), 293-319.

Miransari, M. (2014). Plant growth promoting rhizobacteria. Journal of Plant Nutrition, 37(14), 2227-2235.

Ongena, M., & Jacques, P. (2008). Bacillus lipopeptides: versatile weapons for plant disease biocontrol. Trends in microbiology, 16(3), 115-125.

Pandya, U., & Saraf, M. (2013). Integrated diseases management in groundnut for sustainable productivity. In Bacteria in Agrobiology: Crop Productivity. Springer, Berlin, Heidelberg, (pp. 351-377).

Pineda, A., Zheng, S. J., Van Loon, J. J., Pieterse, C. M., & Dicke, M. (2010). Helping plants to deal with insects: the role of beneficial soil-borne microbes. Trends in plant science, 15(9), 507-514.

Prashar, P., Kapoor, N., & Sachdeva, S. (2014). Rhizosphere: its structure, bacterial diversity and significance. Reviews in Environmental Science and Bio/Technology, 13(1), 63-77.

Saleem, M., Arshad, M., Hussain, S., & Bhatti, A. S. (2007). Perspective of plant growth promoting rhizobacteria (PGPR) containing ACC deaminase in stress agriculture. Journal of industrial microbiology & biotechnology, 34(10), 635-648.

Shilev, S. (2013). Soil rhizobacteria regulating the uptake of nutrients and undesirable elements by plants. In Plant Microbe Symbiosis: Fundamentals and Advances. Springer, New Delhi, (pp. 147-167).

Sindhu, S. S., Parmar, P., Phour, M., & Sehrawat, A. (2016). Potassium-solubilizing microorganisms (KSMs) and its effect on plant growth improvement. In Potassium solubilizing microorganisms for sustainable agriculture. Springer, New Delhi, (pp. 171-185).

Singh, J. S., & Singh, D. P. (2013). Plant Growth Promoting Rhizobacteria (PGPR): microbes in sustainable agriculture. In Management of Microbial Resources in the Environment. Springer, Dordrecht, (pp. 361-385).

Smith, R. S., Kosanke, J., Gygi, B., Reed, P., & Habib, A. (2011). LCO Applications provide improved responses with legumes and non-legumes. PLANT GROWTH-PROMOTING RHIZOBACTERIA (PGPR) FOR SUSTAINABLE AGRICULTURE, 54.

Spaepen, S., & Vanderleyden, J. (2011). Auxin and plant-microbe interactions. Cold Spring Harbor perspectives in biology, 3(4), 1438.

Stearns, J. C., Woody, O. Z., McConkey, B. J., & Glick, B. R. (2012). Effects of bacterial ACC deaminase on Brassica napus gene expression. Molecular plant-microbe interactions, 25(5), 668-676.

Sujatha, N., & Ammani, K. (2014). Phosphate solubilization by the isolates of fluorescent pseudomonads. International journal of advances in pharmacy, biology and chemistry, 3.

Tariq, M., Ali, Q., Khan, A., Khan, G. A., Rashid, B., Rahi, M. S., ... & Husnain, T. (2014). Yield potential study of Capsicum annuum L. under the application of PGPR. Advancements in Life Sciences, 1(4), 202-207.

Upadhyay, S. K., Singh, J. S., Saxena, A. K., & Singh, D. P. (2012). Impact of PGPR inoculation on growth and antioxidant status of wheat under saline conditions. Plant Biology, 14(4), 605-611.

Upadhyay, S., Singh, G., & Singh, D. (2016). Mechanism and Understanding of PGPR: An Approach for Sustainable Agriculture Under Abiotic Stresses. Journal of Plant Science, 134(2), 24-75

Walters, D., & Daniell, T. (2007). Microbial induction of resistance to pathogens. Induced Resistance for Plant Defence: A Sustainable Approach to Crop Protection, 143-156.

Wang, C., Guo, Y., Wang, C., Liu, H., Niu, D., Wang, Y., & Guo, J. (2012). Enhancement of tomato (Lycopersicon esculentum) tolerance to drought stress by plant-growth-promoting rhizobacterium (PGPR) Bacillus cereus AR156. Journal of Agricultural Biotechnology, 20(10), 1097-1105.

Yoshioka, Y., Ichikawa, H., Naznin, H. A., Kogure, A., & Hyakumachi, M. (2012). Systemic resistance induced in Arabidopsis thaliana by Trichoderma asperellum SKT-1, a microbial pesticide of seedborne diseases of rice. Pest management science, 68(1), 60-66.