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Review

Role of Microorganism in Agricultural Sustainability

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Abstract

Agriculture sustainability is the hot topic nowadays because of vigorous growing population of the world. In order to increase the yield of crops researcher work a lot on chemicals, to meet the nutrition demand of plants and cope the biotic stress, which exert pressure on economy and environmental health. Future food security need to be achieved without damaging environment, and this lead to the use of biological tools. Microbes play a vital role in achieving the food sustainability by increasing the yield of crops using their specific biochemical signaling and interaction with plants and increasing the overall yield of plants. Biological nitrogen fixation and nutrient solubilization and mobilization, phytohormone production are the most important functions of microorganism. The phytomicrobiome act as a biocontrol and save the plant from biotic stress, alter physiological and biochemical activity of plants in case of abiotic stress for its survival and growth. The holobiont that includes plants and its phytomicrobiome is taking part in agricultural sustainability and thriving to meet the demands of world in present environmental challenges using sustainable mechanisms in limited resources. The current review was therefore, carried out to document the current advances in the role of plant growth promoting rhizobacteria (PGPR) in biological nitrogen fixation, phytohormone production, solubilization of the insoluble nutrients and their role in mitigating the adverse effects of biotic and abioic stresses in plants.

Keywords: nitrogen fixation, phosphate solubilization, phytohormones, iron sequestration, potassium solubilization

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1 INTRODUCTION

Food security is one of the most important challenges nowadays because of vigorous growth of world population. Agricultural sustainability is necessary to overcome hunger and poverty among the 7 billion people of the world[1]. Climate change is also the major factor which negatively impacts the agricultural yield. To overcome the global shortage of food, "Green Revolution" of 20th century increased the food production using chemical inputs, breeding and genetic manipulation of plants. This innovative idea puts a huge burden on the economy and also results in environmental damage[2] At the end of this century the world's population will increase from 7 billion to 12 billion, so the agricultural yield must increase more than 50%[3]. Future food security is necessary but the environmental damages need to be avoided and pressure on the overall economy should need to be reduced. Climate changes cause the reduction in the yield of major crops (3.8% and 5.5% reduction in yield of maize and wheat), and the major climate changes include high temperature and other abiotic factors which are adversely affecting the agriculture system[4]. The idea of "Fresh Green

Revolution" emerge out with Bio-revolution that involves the use of phytomicrobiome (use of microbial inoculants, use of microbial compounds etc.) and improved the agricultural yield through manipulation of phytomicrobial community[5]. The soil near the roots (rhizosphere), the root surface (rhizoplane) and the space between plant cells (endosphere) have specialized community of microbes that affect the plant growth, crop yield, phytoremediation, carbon sequesterization, help to resist the biotic and abiotic stress. Beneficial microbes including plant growth promoting rhizobacteria (PGPR) enhance plant growth through nutrient absorbtion, produce phytohormone, produce antibiotics and mitigate biotic stress. Since several decades there has been a lot of research on signal compounds that trigger and control the association between plants and microbes[6]. The plant host and its associated phytomicrobiome is known as "holobiont"[7]. Several studies have been taken place since many decades in order to achieve the signaling between phytomicribiomes and host plants in order to deploy these microbes in place of chemical fertilizers to achieve the agricultural sustainability. For instance, plants releases the flavonoids in response to this microbial strains releases the lipo-chitooligosaccharides (LCOs) which consists of receptors that have kinase activity and result in variation in phytohormone profile of roots and help in root development; this use of microbial strains will eliminate the use of chemical fertilizers.

The present study aims to elaborate plant-microbe interaction and role of PGPR as beneficial microbes and their role in agricultural sustainability in the present era of climate change.

2 BENEFICIAL MICROBES ASSIST PLANT HOLOBIONT ACQUIRE NUTRIENTS

Plants always heavily rely on beneficial microbes to assist in fulfilling their nutrient requirements. The most important tasks performed by microbes in nutrient acquisition of plants are 1) biological nitrogen fixation, 2) solubilization of insoluble nutrients, 3) increase of root surface area.

3 BIOLOGICAL NITROGEN FIXATION

Biological nitrogen fixation in agriculture systems ranges from 40 to 70Tg N y^{-1} which is approximately 50% of global production of N fertilizers[8]. Nitrogen is one of the most important nutrients of plants and an integral part of important physiological processes including photosynthesis and protein synthesis. Nitrogen has low reactivity because of triple bond between its two atoms and exists as dinitrogen in nature, which is unavailable to plants directly[9]. The most of the members of phytomicrobiome has ability to fix atmospheric nitrogen in plants through legume rhizobium interactions or assist the nitrogen fixers by secreting various components[10]. Nitrogen fixers are categorized as symbionts and free living nitrogen fixers. To develop the symbiosis between plants (legumes) and rhizobia, cascades of signal are involved which lead to the formation of nodules. The initial signal is from plant sides that involve the root exudates which include flavonoids, amino acids and organic acids. The flavonoids from plants trigger the nod gene induction, result in production of lipochitin-oligosaccharides which binds to the plant receptor kinases, and contribute to calcium spiking in root hair and root hair start curling and trap rhizobia[11]. Plant forms the tubular structure known as infection threads which mature into nodule tissue. The plants take up the bacteria through endocytosis and are surrounded by peribacteriod membrane (PBM), fill the plant cell cytoplasm and mature into bacteriod and metabolize the atmospheric nitrogen to ammonia[12,13]. Nitrogenase enzyme is highly sensitive to oxygen, O_2 inhibit the activity of nitrogenase in aerobic conditions and prevent the fixation and assimilation of nitrogen[14]. For example, many diazotroph bacteria fix N_2 only in aerobic and microaerophilic conditions. They have specialized structures to achieve the nitrogen fixation by producing cyst for nitrogen fixation and prevent the entry of O_2 (Nostoc and Anabaena), while some have temporal separation between N_2 production and O_2 production (Non-hetrocyst cyanobacteria)[15]. The free living nitrogen fixers (Azospirillum, and Azotobacter) require the considerable amount of energy (16ATP) for reducing N_2 to NH_3, and this energy currency comes from the oxidation of photosynthetic sugars or non-photosynthetic bacteria that rely on other organism. To reduce the economy pressure and environmental damages, it is imperative to clarify the mechanism of nitrogen fixation through microorganism at commercial level and studies show that the deployment of nitrogen fixing bacteria plays a significant role in the future food security. BNF fixes 122 million tons of N per year among which 55 to 60 million tons is fixed in agricultural crops to achieve the sustainability[16].

4 PGPR PRODUCE PHYTOHORMONES

Plant hormones or phytohormones or PGR are chemical molecules produced by plants and have critical roles in regulating plant growth, serving as chemical messengers that modulate many cellular processes in plants[17]. Phytohormones develop root systems for better nutrient uptake, development of vascular tissue, shoot elongation and flowering. Microbe produces phytohormone auxins, and cytokinins regulate phytohormone levels of plants and promote the plant growth[18]. The plant respond to phytohormone produced by microorganism present in rhizosphere or supplement externally and affect the plant growth, cell enlargement, cell division and cell proliferation[19].

Indole acetic acid (IAA) controls many stages of plant growth including cell division, cell elongation, tissue differentiation and apical dominance[20]. IAA is produced by many plant growth-promoting microbes, develops the

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Table 1. PGPR Produces Phytohormones

Microbes	Phytohormone	Crop	Ref
Kocuria turfanensis	IAA	Suaeda fruticosa	[19]
Pseudomonas putida	IAA	Brassica nigra	[28]
Promicromonospora sp.	GA	Solanumlycopersicum	[29]
Azotobactersalinestris	GA	Sorghum	[30]
Bacillus subtilis	Cytokinin	Platycladus orientalis	[31]
Pseudomonas lini & Serratia plymuthica	Affect ABA level	Ziziphus jujuba	[32]
Glutamicibacter sp	Regulate ACC activity & ethylene production	Oryza sativa	[33]

roots of plants and helps to take plant nutrients easily and promotes its growth[21]. IAA produced by phytomicroboime helps the plants to develop its adventitious root system, increases root weight and increases the surface area of roots for better uptake of nutrients from pool[22]. Cytokinin is another class of phytohormones produced by microorganism, and stimulates the cell division, enhances root development and enhances root formation, shoot initiation and inhibits root elongation in plants[23,24].

Ethylene is a gaseous phytohormone produced with plants in extremely low concentration in plants in biotic and abiotic stresses, and increases tolerance in plants and causes senescence[25]. PGPR produces ACC deaminase which lowers the ethylene level and promotes plant growth. Abscisic acid (ABA) is a stress hormone that helps the plant to promote adaptation against stress and regulate plant growth[26]. Various PGPR produce phytohormones, as listed in Table 1. Under drought stress ABA acts as anti-transpirant and stomatal closure. Gibberellins play an important role in seed dormancy and stimulate plant growth under abiotic stress. Plants root are colonized by microrganisms and take nutrients from root exudates and in turn produce phytohormones (auxins, cytokinins, gibberellins, and ABA) and assist growth and development of plants[27].

5 SOLUBILIZATION OF INSOLUBLE NUTRIENTS

5.1 Phosphate Solubilization

Phosphorus is the most important macronutrient after nitrogen in plants, plays an important role in growth, development and metabolism of plants[34]. The phosphorus is abundant in soil but it is insoluble and not available to plants because it forms complexes with metal ions in soil[35]. The use of chemical fertilizer to meet the phosphorus demands are not eco-friendly and immobilizes shortly after its application. Plant growth promoting microorganisms (PGPM) play an important role in biofortification of phosphorus by secreting organic acids, enzymes and produces siderophores to chelate the phosphorus with metal ion and make it available to plant[36]. It is reported that *P. libanensis solubilize* the phosphate in water-deficit conditions and improve the growth of cereal crops, hence used to overcome the challenges of sustainable agriculture in stressed environmental conditions. *Pseudomonas stutzeri* and *Mesorhizobium* sp can solubilize the phosphate in alleviated salt stress and various PH conditions in cress land plants (acacia, sugar beet, and wheat) and can be used as efficient inoculants in nutrient management in sustainable agriculture[37] (Figure 1).

5.2 Sequestration of Iron

Iron is a micronutrient and essential for the important physiological process in plants including photosynthesis, DNA synthesis, phytohormone synthesis but its homeostasis is necessary because it can cause program cell death in organisms[38]. Iron is abundantly present on earth but it is unavailable to plants because it is present in insoluble form, and microbes use the different approaches to assist the absorption of Fe in plants by producing low molecular weight iron binding compounds known as siderophores that are water soluble[39]. These iron chelators are classified by the ligands and are categorized as catecholates, hydroxamates, and carboxylates. At a neutral PH to alkaline PH, iron is present in the form of Fe^{+3}[40,41]. Siderophores absorb the iron from the surrounding environment and make it unavailable to pathogens. Sideophore production for iron sequestrization binds with other heavy metals (Al, Cd, Cu, Ga, In, Cr, Pb, Zn and radionuclide U), in this way iron absorption and protection of plants from toxic effect of heavy metal is take place side by side[42] Microbes produce these siderophore and make the soluble form of Fe to plants as well protect the plants from phytopathogens and toxic effect of heavy metals. Iron is one the nutrient component in diet[43]. The co-inoculation of plant growth promoting microorganism *Serratia marcescens*, *Microbacterium arborescens*, and *Enterobacter sp* increases the iron content of wheat grains under pot, improves field condition, which benefits biofortifcation of wheat and control of iron deficiencies[44]. *Pseudomonas fluorescens* and *Pseudomonas putida* are siderophore producing microbes, facilitate the seed germination, root length of wheat and increase the iron content of grains[45]. *Pseudomonas sp.* produce siderophore and protect the plants from *Fusarium oxysporum* and increase biocontrol efficacy in oilseed crops and help to achieve the future food security[46].

5.3 Potassium Solubilization

Potassium is a macronutrient and plays an important role in primary metabolism of plants, stomatal opening,

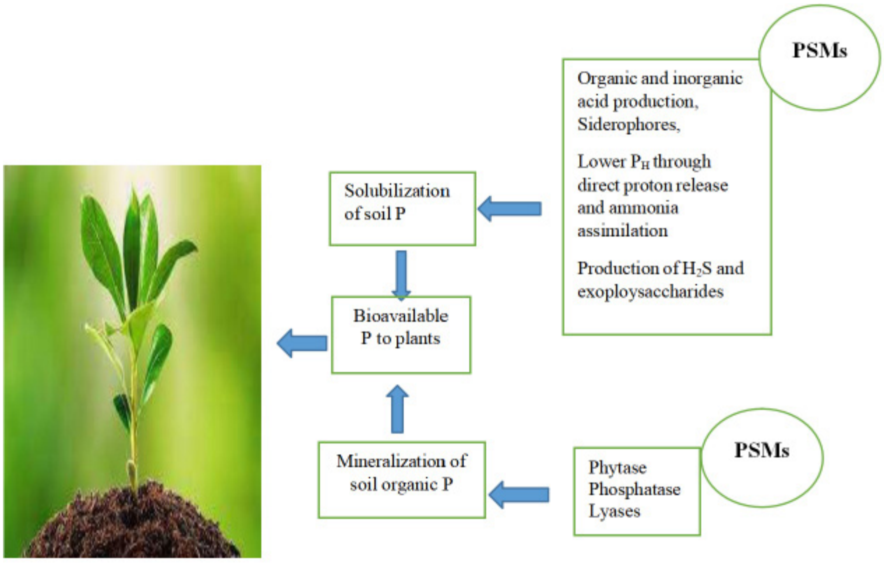

Figure 1. Presentation of mechanism phosphate solubilization by phosphate solubilizing microorganism (PSMs).

Table 2. PGPM Ameliorates Biotic and Abiotic Stress

PGPM	Mechanism of Action	Stress	Crop	Ref
P. fluorescens	Produce antibiotic 2, 4 Diacetylphloroglucinol	*Gaeumannomyc es graminis*	Wheat	[59]
Pseudomonas chlororaphis	Production of antifungal metabolite (Phenazine-1-carboxamide)	*Colletotrichum lindemuthianum*	Bean	[60]
Burkholderia cepacia	Gluconic acid, alpha, 2- ketogluconic acid, Benzoic acid, phenylacetic acid	*Phytopthora capsici*	Pepper	[61]
Paenibacillus polymyxa,Bacillus subtilis	Antibiosis, ISR, production of volatiles	*Colletotrichum acutatum*	Pepper	[62]
Bradyrhizobium japonicum	siderophore biogenesis	*Bacillus thuringiensis*	Soybean	[63]
Pseudomonas fluorescens	Lower the activity of cellulase, polygalacturonase	*Aspergillus niger*	Groundnut	[64]
Bacillus cereus+ Bacillus megaterium+ Trichoderma simmonsii	Act synergistically & increase seed germination & seedling growth by potassium uptake	Salt and drought	Soybean	[65]
Bacillus cereus	Maintain photosynthesis efficacy & peroxidase activities	Drought	Tomato	[66]
Pseudomonas psychrotolerans	Induced endogenous IAA, GA and improve growth	Cu, Zn Cd	Cucumber	[67]
Azospirillum Lipoferum and *Azotobacter chroococcum*	Increase the activity of K^+/Na^+ ratio, and the activity of CAT, POD	Salinity	Maize	[68]

cell volume growth and plant movement[47]. Potassium is abundantly present on earth surface and only 1-2% is available to plants, and the remaining is bound to other minerals[48]. The potassium is the part of the most abundant minerals (feldspar and mica) of earth, and microorganism helps in decomposing the minerals and extracting the potassium and enhancing the soil fertility[49]. Microrganisms release the organic acids (oxalic acid, tartaric acids, gluconic acid, 2- ketogluconic acid, oxalic acid, citric acid, malic acid and succinic acid) for dissolving potassium from rocks or use the chelated silicon ion to dissolve potassium[50,51]. Potassium solubilizing bacteria (PSB) *Enterobacter aerogenes*, *Pantoea agglomerans*, *Agrobacterium tumefaciens*, *Microbacterium foliorum*, *Myroides odoratimimus*, and *Burkholderia cepacia* are the potassium solubilizing bacteria and can be used in place of potash fertilizers in order to achieve agricultural sustainability[52].

5.4 PGPM Controls Biotic and Abiotic Stress

Phytopathogens are threats to sustainable agriculture and ecosystem. Plant growth promoting microorganism has biocontrol properties and exerts beneficial effects on crops[53]. PGPM produces siderophores, β-1, 3-glucanase, chitinases, antibiotics, fluorescent pigment or by cyanide production. Phytopathogenics are devastating 15-30% crops daily, PGPM are eco-friendly and can be used as biocontrol agents in place of chemicals[54]. PGPR combats stress, as listed in Table 2.

The adverse environmental factors hinder growth and development of plants and reduce the overall yield of plants. The stress conditions affect the metabolism of plants by affecting enzyme activity, substrate scarcity, excess demands of various compounds or combination of all these mechanism[55,56]. The abiotic stress including high level of salinity and drought is directly proportional to osmotic stress, oxidative and ionic stress[29]. The biochemical and physiological functions of plants are affected accordingly, and PGPR maintains the homeostasis in plants by producing the various solutes including sugars, polyamines, betaines, glycine, polyhydric alcohol, trehalose in order to maintain the turgor pressure to mitigating the effects of high salinity and drought[57,58].

6 CONCLUSION

Environmental challenges are the biggest hurdles of crop production. Deployment of microbes and their application can overcome this challenge without harming the health of the ecosystem. Using of microorganism as Biofertilizers/ Bioinoculants can help the plant to overcome the biotic and abiotic stress. PGPM are eco-friendly as well as cost-effective. Chemical fertilizers are proved to be detrimental to soil and environment health. Further research is needed for manipulation and usage of PGPM in increasing crop yield without greenhouse gas emission. This highlights the contribution of PGPM in the agricultural sector and environmental health. Microbial research based products need to be studied keenly to elicit robust results and gain the trust of the farmers, and the real stakeholders of agriculture. In addition, public awareness on use of biofertilizers and bioinoculants is needed for consumers and farmers for a better and greener future.

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Not applicable.

Conflicts of Interest

The author declared no conflict of interest.

Author Contribution

Tariq H planned for the idea, collected the data required for writing draft of review article, revised the language and adjusted the article according to journal formatting.

Abbreviation List

PGPM, Plant growth promoting microrganism CAT, Catalase
IAA, Indole acetic acid
GA, Gibberellic acid POD, Peroxidase
PSB, Potassium solubilizing bacteria
PSMs, Phosphate solubilizing microorganisms ABA, Abscisic acid

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