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Recent Advances in Plant Growth Promoting Bacteria Enhancing Food Production With Biological Solutions

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ABSTRACT

Conventional agriculture technology plays an important role to fulfill the food demands for the growing human population. But utilization of chemical fertilizers and pesticides is increasing very fast in recent time for enhancing production level. The extensive use of chemical fertilizers and pesticides is the main cause of air, soil and ground water pollution. Plant-associated microbes have marvelous potential to develop plant flexibility and production in farming systems. Therefore the aim of this chapter is to focus on importance and use of plant growth promoting bacteria for the sustainable agriculture. Using this approach the efforts have been made for the production of high quality nutrient rich food under the consideration of bio-safety. As per the previous research, some microbes or their metabolites can enhance production, diminish plant stress responses and also works as a bio control agent. In spite of this, their efficacy and stability under the broad range of conditions need to be improved. For the optimization of microbial bio pesticides and biofertilizers, lots of research still has to be done. Therefore these approaches can maximize benefits and can significantly improve crop production to address food security.

Key words: *PGPR, Biocontrol agent, Biofertilizer, Biopesticides, Crop improvement.*

Introduction

Conventional agricultural practices that rely on chemical fertilizers, pesticides and other chemicals to increase crop productivity to fulfill the food demand of growing population worldwide. The application of these chemicals poses severe effect on soil health by degradation of nutrients, loss of biodiversity, increased susceptibility towards pathogens and negative environmental impact and finally also have direct or indirect impact on human health due to intake of polluted water and food (Tilman *et al*., 2002; Sharma *et al*., 2018). In the present scenario, there is need to improve soil health and crop productivity. In this respect, the use of organic farming may act as an alternative strategy to ensure food security. This is an eco-friendly approach in which a wide range of microbes, known as plant growth promoting bacteria (PGPB) and some commonly available PGPBs present in soil are: *Pseudomonas, Azospirillum, Azotobacter, Bacillus, Burkholdaria, Enterobacter, Rhizobium, Erwinia, Mycobacterium, Mesorhizobium, Flavobacterium*, etc (Backer *et al*., 2018). These microbes can used as biofertilizer to improve plant growth, soil health, enhanced nutrient uptake and plant tolerance to abiotic and biotic stress. PGPB is an essential component of organic farming and play crucial role in maintaining long term soil fertility and sustainability and would be a viable alternative for farmers (Sharma *et al*., 2018). During plant-microbe interaction, microorganisms, act as an integral part of soil and plant rhizosphere that enhance soil physical and chemical properties, induced soil enzyme functions and also enhance the

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nutrient cycle to influence the crop productivity (Liu *et al*., 2019). Furthermore, this interaction also improves the plant health under abiotic stress (heavy metal, salinity, heat and drought)and biotic stress that include pathogenic microbes causing various diseases by modulating defense hormones, production of chelating compounds like siderophore, various signaling molecules, accumulation of osmolytes and reduced oxidative damage leading to enhanced plant growth (Choudhary *et al*., 2011; Backer *et al*., 2018). Bhattacharya and Jha (2012) reported the direct and indirect mechanisms during plant-PGPR interaction. Direct mechanisms include siderophore production, phosphate solubilization and 1-aminocyclopropane-1-carboxylate deaminase synthesis which enable the plant to withstand abiotic and biotic stress conditions by reducing ethylene levels, and enhances plant growth hormone production (Glick, 2012, Ahemad and Kibret, 2014; Gamalero and Glick, 2015). Whereas, the indirect mechanism of growth promotion includes the PGPR acting as biocontrol agents and detoxifying noxious substances such as heavy metals and pesticides (Choudhary *et al*., 2016). The PGPRs associated with the rhizosphere could be extracellular plant growth promoting rhizobacteria (ePGPR) or intracellular plant growth promoting rhizobacteria (iPGPR) depending on the level of interaction with the host plant root cells (Martínez *et al.*, 2010; Ramadan *et al*., 2016). Most bacterial genera are ePGPR including *Erwinia, Flavobacterium, Micrococcus, Pseudomonas, Serratia, Chromobacterium, Caulobacter, Azospirillium, Azotobacter and Agrobacterium* (Bhattacharyya and Jha, 2012). These PGPR produce various substances that enhance plant growth under abiotic stress. Therefore, PGPR plays important role in enhancing plant growth through these mechanisms to improve plant health. That in turn, also improves productivity and nutritional value of food by using it as biological solution. Therefore, this book chapter discuss about the different PGPRs traits and their role during abiotic and biotic stress to provide safer food for growing population.

PGP traits for improved plant growth

Plant growth promoting characters existing in rhizobacteria play vital role during abiotic and biotic stresses. which leads to accumulation of Osmoprotectant, production of superoxide radical as scavenging mechanisms, exclusion or compartmentation of ions by efficient transporter and symporters, production of specific enzymes involved in the regulation of plant hormones (Choudhary *et al*., 2011; García-Fraile *et al*., 2015). Here in this book chapter different PGP traits including phosphate solubilization, manufacturing of plant hormone and siderophore production has been discussed.

Phosphates Solubilization

As a plant macronutrient phosphorous (P) is a 2^{nd} major essential plant growth regulator because it involves biological functions like cell division, DNA replication, photosynthesis and respiration (Batool and Iqbal, 2019). Naturally, 100-1000g/ml phosphorous (P) present in soil either in organic or inorganic form but plants are unable to uptake this Phosphorus and finally affects the plant development and productivity (Awasthi *et al*., 2011). Thus, to improve phosphorus uptake in plants phosphate solubilizing bacteria can use biofertilizer and have important role in betteruptake of phosphate by acting as an alternative of chemical fertilizers. It has been reported that by implementation of P-solubilizing as inoculum increase growth and yield of many crops such as maize, wheat, and sweet potato (Zahid, 2015). The availability of soluble phosphorus to plants depends onsoil fertilityand pH for many beneficial bacterial strains reported that belongs to genera *Agrobacterium, Microccocus, Aerobacter, Pseudomonas, Bacillus, Rhizobium, Burkholderia, Achromobacter, Flavobacterium* and *Erwinia.* These bacterial strains have the capacityto solubilize insoluble inorganic phosphate (mineral phosphate) compounds likehydroxyl apatite tricalcium phosphate, dicalcium phosphate, and rock phosphate (Rodríguez *et al*., 2006).

Phosphate availability in soil and mechanism of solubilization

Commonly, soil phosphorus content is found to be low in most of natural soil because it is fixed as insoluble forms. The soil mineral phosphate is generallypresent as orthophosphate ions complexed with Al^{+++}, Mn^{++}, Ca^{++}, Fe^{++}, and Si^{++}. The insoluble soil phosphates remain present in the form of $Ca_3(PO_4)_2$, $[Ca_3(PO_4)_2CaO]$, $[Ca_3(PO_4)_2CaFe]$ in alkaline soils and hydroxyl-phosphates of Fe^{++} and Al^{+++} (strengite, varisite, dufrenite, etc.) in acidic soil (Sanyal and De Datta, 1991). The most important components of phosphorus cycle are mineralization, solubilization and immobilization. The processes of organic P mineralization and mineral P solubilization are of great importance for P nutrition of crop plants. As stated by Goldstein (1995) insoluble calcium phosphate can be dissolved and made available to plants by soil and rhizospheric microorganisms. The mechanism of solubiliztion of inorganic P by PGB involves the production of organic acid, siderophore production, protons, hydroxyl ions and CO_2 (Sharma *et al*., 2013). The organic acid that is producing in the form of carboxyl and hydroxyl ions, chelate cations that results decrease in pH and discharge of soluble phosphate (Alori *et al*., 2017). Additionally, some PSB produce phosphatase like phytase that hydrolyse organic phosphate compounds efficiently (Singh and Satyanarayana, 2011).

Phytohormones synthesis

Hormones work as chemical messengers that regulate plant cell process and metabolism. These are organic and chemical compounds that are effective at very low concentration; these are usually synthesized in one section of the plant and transported to other location. They interact with particular target tissues to cause physiological responses. Biologist recognized five main groups of hormones: auxins, ethylene, gibberellins, abscisic acid and cytokinin. As plants are immobile organisms with a advanced physiological plasticity, permitting endurance under a wide variety of environmental conditions. This happens because of the constantly active shoot and root meristems and their potential to generate new organs after embryogenesis (Wolter and Jurgens, 2009). Therefore, morphogenesis is tightly linked to hormonal homeostasis like cell elongation, cell division, re-orientation of growth and other processes such as stomatal movement (Davies, 2013). Therefore, hormone production is important for growth and survival of plants in normal and stressed condition.

Auxin Production

Auxin hormones are a class of plant hormone that have important function in plant growth and behavior process and are necessary for plant development. The function of auxin in plant development involves the cell growth, cell division, root initiation, increased phototropism, growth rate, apical dominance, and geotropism (Paque *et al*., 2016). Eighty percent of microorganisms isolated from the rhizosphere of different crops have the ability to produce and discharge auxins as secondary metabolites (Ahmed and Hasnain, 2014). The auxin production pathway has been reported to present in many bacteria like *Azospirillum, Enterobacter cloacae, Paenibacillus, Bacillus, Bradyrhizobium, Pseudomonas* and *Rhizobium* (Spaepen and Vanderleyden, 2011). The microbial colonization modifies root architecture to produce auxin and play role in development of new organs in plants such as nodules and galls (Lindow and Brandl, 2003).

Siderophores production

Siderophores are low molecular weight metal chelating agents that are produced by microorganisms and plants, particularly under Fe-limiting conditions (Ahmed and Holmstrom, 2014). Iron is one of the necessary nutrients mandatory for plant metabolism but it is deficient in soil. Siderophores are iron binding protein compounds involve in the process of chelating ferric iron from the environment. When Fe^{+++} is in adequate in the soil, siderophores produced by microbes solubilize and remove Fe^{+++} from the soil and afterward supply to plants by promoting their growth (Vejan *et al*., 2016). In soil, siderophore production plays important role in determining the capability of several microorganisms to promote plant development. The microbial siderophores used for the enhancement of iron uptake by plants that are capable to identify the bacterial ferric-siderophore complex (Dimkpa *et al.*, 2009) and are also significant in the iron uptake by plants in the occurrence of other metals such as Cd++ and Ni^{++}(Dimkpa *et al.*, 2008). The examples of siderophore producing bacteria are *Escherichia coli, Salmonella, Klebsiella pneumonia, Vibrio cholerae, Aeromons* etc. (Kannahi and Senbagam, 2014).

Plant growth promoting bacteria as a bio-fertilizer for safer crop production

Because of higher application of chemical fertilizers in agriculture field, there is a big challenge to provide safer food for growing population because in present time chemical fertilizers to soil and water pollution and affected the population and diversity of beneficial microorganism in soil. Consequently, crops become more prone to attack of insect pest and extreme decline of the crop productivity (Dotaniya *et al.*, 2016). It is expected that by 2021, to achieve the targeted production of 280 MT of food grain, and the requirement of plant nutrients will be 28.8 MT, while their availability will be only 21.6 MT. Therefore, the use of biofertilizers as a substitute of chemical fertilizers is future strategy because it is cost-effective; environment-friendly. It will be easily accessible to small farmers (Mahajan *et al*., 2008). Biofertilizers are beneficial microbial isolates obtained from soil that can be used as soil inoculants to enhance crop yield and improve soil fertility.

Numerous groups of PGPB are known on the basis of their nature and function, such as nitrogen fixer, phosphate solubilizer and mobilizer, micronutrient fertilizer, and bio control agent (Glick, 2012; Calvo *et al.,* 2014; Setiawati *et al.*, 2019; Gouda *et al*., 2018). Nitrogen-fixing bacteria belonging to PGPB can fix atmospheric nitrogen and supply it to plants. Bio inoculants composed of nitrogen fixing bacteria are currently being used as an alternative to nitrogen fertilizers (Welbaum *et al.,* 2004, Ashrafuzzaman *et al.,* 2009; Adesemoye *et al.,* 2009). The enhanced gene expression of various antioxidant enzymes such as manganese-dependent superoxide dismutase (MnSOD), peroxidase (POD), glutathione reductase (GR), ascorbate peroxidase (APX), glutathione peroxidase (GPX) and catalase (CAT, and high amount of proline content in PGPR treated wheat plants contributed to increased tolerance to salinity stress (Bharti *et al*., 2016). In a study, rice plants treated with entophytic strains were shown a significant up regulation of the nitrogenase activity.

Role of PGPRs in biotic stress

Infectious diseases are developed due to physiological disorder in the plant which has been considered as major negative factor to food security for the ever

Table 1. Plant growth promoting bacteria (PGPB) as bio-fertilizer and plant growth promotion (PGP) traits

PGP strains	PGP activity	Plant	References
B. subtilis, CT-1, *A. tumefaciens* CT-2 *Bacillus sp.,* CT-3, *P. putida* CT-4, *Pseudomonas sp.,* CT-5	P. Solubilization, I AA, Ammonia,	*Cassia tora* L.	Kumar *et al*. (2015a)
Brevundim onasdiminuta EGEB-1 *Agrobacterium tumefaciens* EGE-B-5 *Stenotrophom onasrhizophilia* EGE-B-6	P. Solubilization, I AA	Peach	Liaqat and Eltem (2016)
Stenotrophom onasmaltophilia R551-3	ACC deaminase, IAA synthesis,	Poplar	Taghavi *et al*. (2009)
Paenibacillus durus BR 30	N_2 fixation, IAA, P. solubilization	*Asphodelus sp.*	Navarro-Noyaa *et al.* (2012)
Paenibacillus borealis BR 32 *Paenibacillus graminis* BR 35 *Azospirillum lipoferum* KYR F6	N_2 fixation, IAA, P. solubilization	*Juniperus sp.* *Aster gymnocephalus* *Haplopappus sp.*	Navarro-Noyaa *et al.* (2012)
Arthrobacter sp. SMR3, *B. subtilis* SMR15	ACC deaminase, IAA,	*Papaversomniferum*	Pandey *et al.*(2016)
Bacillus velezensis strain CR-502	I AA, P-Solubilization,	*Gnetumgnemon L.*	Agarwal *et al.* (2020)
Bacillus sp, Pseudomonas putida (ECL5)	Siderophore, IAA, P-Solubilization	*Curcuma longa* L.	Kumar *et al.* (2016)
Clavibacterm ichiganensis	IAA	*Curcuma longa* L.	Kumar *et al.* (2016)
Azotobacter chroococcum CL13	P-Solubilization, Ammonium production, IAA, HCN	*Curcuma longa* L.	Kumar *et al.* (2016)
Pseudomonas aeruginosa FTR, *Enterobacter asburiae* MRC12, *Acitenobacter brumalii* MZ30V92	HCN, Ammonia, P. Solubilization, Siderophore	Maize	Sandhya *et al.* (2017)
Pseudomonas monteilii FMZR2, *Sinorhizobium meliloti* MRC31	HCN, Ammonia, P-Solubilization,	Maize	Sandhya *et al.* (2017)
Acinetobacter sp. ALEB16	Salicylic acid (SA), Abscisic acid (ABA),	*Atractylodeslancea*	Wang *et al.* (2015)
Serratia sp. Rh269	P. Solubilization, IAA, Siderophore	Rice	Yasmin *et al.* (2016)

growing world population (Carvalho, 2006). Henceforth, analysis of sufficient amounts of balanced and secure foods that are produced in an environmentally sustainable way is crucial (Carvalho, 2006). The indiscriminate and extensive use of pesticides upset the soil environment by affecting soil microflora and also the physico-chemical properties of the soil like pH, alkalinity, salinity, leading to infertility of soil (Sarnaik *et al.,* 2006). So, the biological control considered as a best alternatives which is eco-friendly and efficient for the management of plant disease. Biological control is process in which pathogenic strain is maintained at low inoculums density either through one or more organisms' occurred naturally or by influencing the environment, host, or by introduction of one or more antagonists in mass (Saraf *et al*., 2014).

Plant growth promoting rhizobacteria in abiotic stress

All kinds of stresses such as abiotic and biotic affect crops in a negative manner. Drought is one of the major abiotic stress which limits the food production worldwide and is estimated to cause serious plant growth problems for crops on more than 50% of the earth's arable lands by 2050 (Fita *et al.,* 2015; Vinocur and Altman, 2005). In addition, the world populations about to reach nine billion by 2050, demanding continued increases in crop production to assure food security (Ngumbi and Kloepper, 2016). Therefore, it is new interest to find solutions related to water-related problems such as drought and its impacts on food security. It is estimated that plant growth promotingrhizobacteria in nature are about 2%-5% (Ahemad and Kibret, 2014). They promote plant growth either by moderating plant hormonal levels or helping in resource acquisition (phosphorus, nitrogen, and other essential minerals). Inoculation of seeds with PGPR could be done by drench application, seed bacterization, or via dual treatment. Bacteria belong to the genera *Azotobacter, Acetobacter, Azospirillum, Alcaligenes, Pseudomonas, Serratia, Arthrobacter, Azoarcus, Herbaspirillum, Beijerinckia, Bacillus, Derxia, Gluconacetobacter, Klebsiella, Ochrobactrum, Pantoae, Stenotrophomonas*, and *Zoogloea* have been subject of extensive studies fortheir followed mechanisms via which they improve plant growth andyield (Kumar *et al.,* 2016). PGPR provide support for the plant growth which get reduced by varioustypes of stresses (Babalola *et al.,* 2007) including, salt stress (Kaymak *et al.,* 2009), water logging (Barnawal *et al.,* 2012), drought stress (Zahir *et al*., 2008), heavy metals (Kumar *et al.,* 2009) and some other unfavorable environmental conditions. Another drought stress parameteris amount of reactive oxygen species (ROS) generated. Under drought stress, plant leaves generated enough antioxidant enzymes and metabolites, which can manage a large amount of reactive oxygen species (ROS) and lower oxidative damage (Zlatev and Lidon, 2012). There are number of low molecular weight antioxidants produced in plant tissues like ascorbic acids, glutathione, tocopherols and carotenoids which have specific character for reacting with all types of reactive oxygen species. The usual characteristic against stress is proline (for osmotic regulation), enhanced glutathione concentration (for oxygen free radical scavenging) and heat shock proteins (Gill and Tuteja, 2010 involved them as scavenging system to mediate drought tolerance. PGPR application showed enhancement in accumulation of antioxidant enzymes, such as POX, CAT and POX that minimize soxidative injury and contributes to the drought tolerance. Gururani *et al*., 2013 reported that potatoplants treated with PGPR strains including *Bacillus pumilus* as well as *Bacillus firmus*, induced an increase in the levels of ROS-scavengingenzymes including APX and CAT. The specific activity of catalase enzyme was observed up to 1.8 times higher under drought stress in PGPR treated plants in comparison of non-treated plants. The increased levels of ROS-scavenging enzymes could be the major reason for drought stress tolerance in PGPR-treated potato plants.

Plant growth promoting rhizobacteria in heavy metal tolerance

At present, due to increased anthropogenic activities and industrial effluents the concentration of heavy metal increased in ground water above permissible level. In addition to these, soil also gets contaminated due to irrigation with polluted water. Whereas, indirect mechanisms include the production of cell wall lytic enzymes and the production of plant defense mechanisms against various stresses (Weyens *et al*., 2009). Actively growing microbes are more colonized in rhizospheric soil of hyper accumulating plant as well as other crop plants. The microbes associated with plants produce various enzymes to detoxify and mineralize PAHs *viz*. dioxygenase, dehydrogenase, hydrolase, monooxygenase, peroxidases, and dehalogenase which have the ability to transform or degrade aromatic contaminants with respect to their concentration, bioavailability and environmental factors (Sreelal and Jayanthi, 2017)

Conclusion

Conventional agriculture is an urgent need of present era because it is a way to fulfilling the need of the food for growing population. Fast overexploitation of non-renewable natural resources can create food crisis in upcoming years. Agricultural crop production needs to be enhanced in new horizons without destroying natural resources as well as environmental quality. In this respect, low-cost, eco-friendly biofertilizer may play a crucial role for further enhancement of crop yield thereby reducing the use of chemical fertilizers and increased plant nutrient status by maintaining crop quality as well as environmental aspects. Manufacturing of biofertilizers should be inter linked and needs more attention for continuous research. Meanwhile, the screening, characterization and identification of new effective microbial strains with respect to type of crop and agro climatic conditions improve the soil and crop sustainability. It may be a best alternative to the chemical fertilizer applied by farmers to minimize issue related to soil health and promote the biofertilizers in agricultural field. This needs special attention and extensive market development efforts with the help of the government, non-government organizations (NGOs) and wide publicity through media to spread awareness among farmers. These efforts lead the application of microbes as a bio solution for crop cultivation and finally production of safer food for present and future population.

Conflict of Interest- None

References

Adesemoye, A.O. and Kloepper, J.W. 2009. Plant-microbes interactions in enhanced fertilizer-use efficiency. *Aplmicrobio and Biotech*. 85(1): 1-12.

Agarwal, H., Dowarah, B. and Baruah, P.M. 2020. Entophytes from *Gnetum gnemon* L can protect seedlings against infection of the phytopathogenic bacterium *R. solanacearum* as well as promote plant growth in tomato. *Elsevier, Microbiol Res.* 223: 126503.

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

Ahmed, A. and Hasnain, S. 2014. Auxins as one of the factors of plant growth improvement by plant growth promoting rhizobacteria. *Pol. J. Microbiol.* 63(3): 261-266.

Ahmed, E. and Holmström, S.J. 2014. Siderophores in environmental research: roles and applications. *Microbial Biotechnology*. *7*(3): 196-208.

Alori, E.T., Glick, B.R. and Babalola, O.O. 2017. Microbial phosphorus solubilization and its potential for use in sustainable agriculture. *Frontiers in Microbiology*. (8): 971.

Ashrafuzzaman, M., Hossen, F.A. and Ismail, M.R. 2009. Efficiency of plant growth-promoting rhizobacteria (PGPR) for the enhancement of rice growth. *African Journal of Biotechnology*. 8(7): 1247-1252

Awasthi, R., Tewari and Nayyar, H. 2011. Synergy between plants and P-solubilizing microbes in soils: effects on growth and physiology of crops. *International Research Journal of Microbiology*. 2(12): 484-503.

Backer, R., Rokem, J.S. and Ilangumaran, G. 2018. Plant growth-promoting rhizobacteria: context, mechanisms of action, and roadmap to commercialization of biostimulants for sustainable agriculture. *Frontiers in Plant Science*. (9): 1473.

Batool, S. and Iqbal, A. 2019. Phosphate solubilizing rhizobacteria as alternative of chemical fertilizer for growth and yield of *Triticum aestivum* (Var. Galaxy 2013). *Saudi Journal of Biological Sciences*. 26(7): 1400-1410.

Baysal, Ö. and Silme, R.S. 2018. The ecological role of biodiversity for crop protection. *Plant Competition in Cropping Systems*. DOI: 10.5772/intechopen.78228.

Bharti, N., Barnawal, D. and Shukla, S. 2016. Integrated application of *Exiguobacterium oxidotolerans*, *Glomusfasciculatum*, and vermicompost improves growth, yield and quality of Menthaarvensis in salt-stressed soils. *Industrial Crops and Products*. 83: 717-728.

Bhattacharyya, P.N. and Jha, D.K. 2012. Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. *WrdJr of Micro and Biot*. 28(4): 1327-1350.

Calvo, P., Nelson, L. and Kloepper, J.W. 2014. Agricultural uses of plant biostimulants. *Plant and Soil*. 383(1-2): 3-41.

Carvalho, F.P. 2006. Agriculture, pesticides, food security and food safety. *Environmental Science & Policy*. 9(7-8): 685-692.

Choudhary, D.K., Kasotia, A. and Jain, S. 2016. Bacterial-mediated tolerance and resistance to plants under abiotic and biotic stresses. *Journal of Plant Growth Regulation*. 35(1): 276-300.

Choudhary, O.P., Ghuman, B.S. and Thuy, N. 2011. Effects of long-term use of sodic water irrigation, amendments and crop residues on soil properties and crop yields in rice-wheat cropping system in a calcareous soil. *Field Crops Research*. 121(3): 363-372.

Davies, J. 2013. *Mechanisms of Morphogenesis*. Academic Press.

Dimkpa, C.O., Merten, D. and Svatoš, A. 2009. Siderophores mediate reduced and increased uptake of cadmium by Streptomyces tendae F4 and sunflower (*Helianthus annuus*), respectively. *Journal of Applied Microbiology*. 107(5): 1687-1696.

Dimkpa, C.O., Svatoš, A. and Dabrowska, P. 2008. Involvement of siderophores in the reduction of metal-induced inhibition of auxin synthesis in *Streptomyces* spp. *Chemosphere*. 74(1): 19-25

Dotaniya, M.L., Meena, V.D. and Basak, B.B. 2016. Potassium uptake by crops as well as microorganisms. In: *Potassium Solubilizing Microorganisms for Sustainable Agriculture*. Springer. New Delhi.

Gamalero, E. and Glick, B.R. 2015. Bacterial modulation of plant ethylene levels. *Plant Physiology*. 169(1): 13-22.

García-Fraile, P., Menéndez, E. and Rivas, R. 2015. Role of bacterial biofertilizers in agriculture and forestry. *AIMS Bioengineering*. 2(3): 183.

Gill, S.S. and Tuteja, N. 2010. Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiology and Biochemistry*. 48(12): 909-930.

Glick, B.R. 2012. Plant growth-promoting bacteria: mechanisms and applications. *Scientifica.* 2012(1).

Goldstein, A.H. 1995. Recent progress in understanding the molecular genetics and biochemistry of calcium phosphate solubilization by gram negative bacteria. *Biological Agriculture & Horticulture*. 12(2): 185-193.

Gouda, S., Kerry, R.G. and Das, G. 2018. Revitalization of plant growth promoting rhizobacteria for sustainable development in agriculture. *Microbiological Research*. 206: 131-140.

Gururani, M.A., Upadhyaya, C.P. and Baskar, V. 2013. Plant growth-promoting rhizobacteria enhance abiotic stress tolerance in *Solanum tuberosum* through inducing changes in the expression of ROS-scavenging enzymes and improved photosynthetic performance. *Journal of Plant Growth Regulation.* 32(2): 245-258.

Kannahi, M. and Senbagam, N. 2014. Studies on siderophore production by microbial isolates obtained from rhizosphere soil and its antibacterial activity. *Journal of Chemical and Pharmaceutical Research*. 6(4): 1142-1145.

Kaymak, H.C., Guvenç, I. and Yarali, F. 2009. The effects of bio-priming with PGPR on germination of radish (*Raphanus sativus* L.) seeds under saline conditions. *Turkish Journal of Agriculture and Forestry*. 33(2): 173-179.

Kumar, A., Singh, R. and Yadav, A. 2016. Isolation and characterization of bacterial endophytes of Curcuma longa L. 3 *Biotech*. 6(1): 60.

Liaqat, F. and Eltem, R. 2016. Identification and characterization of endophytic bacteria isolated from in vitro cultures of peach and pear rootstocks. 3 *Biotech*. 6(2): 120.

Lindow, S.E. and Brandl, M. 2003. Microbiology of the phyllosphere. *Applied and Environmental Microbiology*. 69(4): 1875-1883.

Liu, J., Li, J. and Ma, Y. 2019. Crop productivity and nitrogen balance as influenced by nitrogen deposition and fertilizer application in North China. *Sustainability*. 11(5): 1347.

Mahajan, A., Bhagat, R.M. and Gupta, R.D. 2008. Integrated nutrient management in sustainable rice-wheat cropping system for food security in India. *SAARC Journal of Agriculture*. 6(2): 29-32.

Martinez-Viveros, O., Jorquera, M.A and Crowley, D.E. 2010. Mechanisms and practical considerations involved in plant growth promotion by rhizobacteria. *Journal of Soil Science and Plant Nutrition*. 10(3): 293-319.

Navarro-Noya, Y.E., Hernández-Mendoza, E. and Morales-Jiménez, J. 2012. Isolation and characterization of nitrogen fixing heterotrophic bacteria from the rhizosphere of pioneer plants growing on mine tailings. *Applied Soil Ecology*. 62: 52-60.

Ngumbi, E. and Kloepper, J. 2016. Bacterial-mediated drought tolerance: current and future prospects. *Applied Soil Ecology*. 105: 109-125.

Pandey, S.S., Singh, S. and Babu, C.V. 2016. Endophytes of opium poppy differentially modulate host plant productivity and genes for the biosynthetic pathway of benzylisoquinoline alkaloids. *Planta*. 243(5): 1097-1114.

Paque, S. and Weijers, D. 2016. Q &A: Auxin: the plant molecule that influences almost anything. *BMC Biology*. 14(1): 1-5.

Ramadan, E.M., Abdel Hafez, A.A. and Hassan, E.A. 2016. Plant growth promoting rhizobacteria and their potential for biocontrol of phytopathogens. *African Journal of Microbiology Research*. 10(15): 486-504.

Rodríguez, H., Fraga, R., Gonzalez, T. and Bashan, Y. 2006. Genetics of phosphate solubilization and its potential applications for improving plant growth-promoting bacteria. *Plant and Soil*. 287(1-2): 15-21.

Sandhya, V., Shrivastava, M., Ali, S.Z. and Prasad, V.S.S.K. 2017. Endophytes from maize with plant growth promotion and biocontrol activity under drought stress. *Russian Agricultural Sciences*. 43(1):22-34.

Saraf, M., Pandya, U. and Thakkar, A. 2014. Role of allelochemicals in plant growth promoting rhizobacteria for biocontrol of phytopathogens. *Microbiological Research*. 169(1): 18-29.

Sarnaik, S.S., Kanekar, P.P. and Raut, V.M. 2006. Effect of application of different pesticides to soybean on the soil microflora. *Journal of Environmental Biology*. 37(2): 423-426.

Setiawati, M.R., Aini H.F. and Suryatmana, P. 2019. Application of inorganic fertilizer and bio-fertilizer on chlorophyll content, pH, and leaves number of pakchoi (*Brassica rapa* l.) in hydroponics. *International Journal of Agriculture, Environment and Bioresearch*. 4: 269-278.

Sharma, A., Shankhdhar, D. and Shankhdhar, S.C. 2016. Potassium-solubilizing microorganisms: mechanism and their role in potassium solubilization and uptake. In: *Potassium Solubilizing Microorganisms for Sustainable Agriculture*. Springer. New Delhi. 203-219.

Sharma, P., Do-Park, S. and Park, K.T. 2013. Mesoporous cellular foams supported Fe2. 0SiW12O40: Synthesis, characterization and application to CO_2 sorption. *Powder Technology*. 233: 161-168.

Sharma, P., Singh, A. and Kahlon, C.S. 2018. The role of cover crops towards sustainable soil health and agriculture- A review paper. *American Journal of Plant Sciences*. 9(9): 1935-1951.

Singh, B. and Satyanarayana, T. 2011. Microbial phytases in phosphorus acquisition and plant growth promotion. *Physiology and Molecular Biology of Plants*. 17(2): 93-103.

Spaepen, S. and Vanderleyden, J. 2011. Auxin and plant-microbe interactions. Cold Spring *Harbor Perspectives in Biology*. 3(4): 001438.

Sreelal, G. and Jayanthi, R. 2017. Review on phytoremediation technology for removal of soil contaminant. *Indian J Sci Res*. 14(1): 127-130.

Taghavi, S., Garafola, C. and Monchy, S. 2009. Genome survey and characterization of endophytic bacteria exhibiting a beneficial effect on growth and development of poplar trees. *Applied and Environmental Microbiology*. 75(3): 748-757.

Tilman, D., Cassman, K.G. and Matson, P.A. 2002. Agricultural sustainability and intensive production practices. *Nature*. 418(6898): 671-677.

Vinocur, B. and Altman, A. 2005. Recent advances in engineering plant tolerance to abiotic stress: achievements and limitations. *Current Opinion in Biotechnology*. 16(2): 123-132.

Wang, X.M., Yang, B. and Ren, C.G. 2015. Involvement of abscisic acid and salicylic acid in signal cascade regulating bacterial endophyteinduced volatile oil biosynthesis in plantlets of Atractylodeslancea. *Physiologiaplantarum*. 153(1): 30-42.

Welbaum, G.E., Sturz, A.V. and Dong, Z. 2004. Managing soil microorganisms to improve productivity of agro-ecosystems. *Critical Reviews in Plant Sciences*. 23(2): 175-193.

Weyens, N., Van-der-Lelie, D. and Taghavi, S. 2009. Exploiting plant- microbe partnerships to improve biomass production and remediation. *Trends Biotechnol.* 27(10): 591-598.

Wolters, H. and Jurgens G. 2009. Survival of the flexible: hormonal growth control and adaptation in plant development. *Nature Reviews Genetics.* 10(5): 305-317.

Yasmin, S., Zaka, A. and Imran, A. 2016. Plant growth promotion and suppression of bacterial leaf blight in rice by inoculated bacteria. *PloS One*. 11(8): 0160688.

Zahid, M. 2015. Isolation and identification of indigenous plant growth promoting rhizobacteria from Himalayan region of Kashmir and their effect on improving growth and nutrient contents of maize (*Zea mays* L.). *Frontiers in Microbiology*. 6: 207.

Zlatev, Z. and Lidon, F.C. 2012. An overview on drought induced changes in plant growth, water relations and photosynthesis. *Emirates Journal of Food and Agriculture*. 23(1).