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REVIEW PAPER

Plant growth promoting rhizobacteria in promoting sustainable agriculture

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ABSTRACT

Rapid human population growth and its consequences of food shortage become a significant concern in recent decades across the world. The untold reasons behind this food shortage were industrialization, urbanization, modern civilization, etc., where the agricultural land has been deployed. With the decreasing farmland and its cultivation, food productivity declined drastically and failed to serve the world's vast human population. The present challenge is to increase productivity with the least agricultural land. Thus, excessive chemical fertilizer has been used to quickly turn out more outstanding food production, leading to more significant damages to soil ecosystem and human health. Henceforth, bio-fertilizers find the best alternatives to chemical fertilizers. This study focuses on complete nature of plant growth Promoting rhizobacteria, which is used in bio fertilizers for sustainable agricultural productivity and everlasting soil fertility. The characteristics of plant growth promoting rhizobacteria and its role in plant growth and formulation of plant growth promoting rhizobacteria biofertilizers have been revealed through intensive literature. The consortium information collected from various literatures brings the unique findings that plant growth promoting rhizobacteria is the natural boon to the global agriculturist. This study discusses plant growth promoting rhizobacteria bacterial strains' role in protecting the soil from various biotic and abiotic stresses, regulating plant growth and its role in producing biofertilizers. Besides, it is transformed into commercial products. Eventually, the future trends and research in plant growth promoting rhizobacteria bio inoculants that promote sustainable agriculture have been elucidated. The microorganism is the bio fertilizer's main ingredients, promoting the soil nutrients for efficient plant growth and increasing food productivity. Although many microorganisms efficiently contribute to the soil nutrients, this review narrows down to the plant growth promoting rhizobacteria study. Beneficial bacterium plays a vital role in nutrient mineralization and productivity among the various microorganisms. Bio fertilizers containing beneficial bacteria were economically viable and readily available in nature. This review reveals the complete essence of plant growth promoting rhizobacteria and its part in bio fertilizers.

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INTRODUCTION

One of the foremost goals of human life is the consistent and adequate food supply. Due to the increasing rate in population across the world, consistent food supply becomes a challenging phenomenon in current scenario. There are many factors in offering food supply for the rapid population growth, such as production rate, cost, climate, land utilization, adequate water supply, technology, consistency in crop productions and etc. Besides, soil fertility is the crucial element which determines the crop production quantitatively and qualitatively. Soil fertility is in the great need of continuous and consistent monitoring because of its intangible activities like nutrient cycling, structural arrangements, biotic regulation, transformation of harmful elements, holding capacity of nutrients, transferring water and nutrients to plants and etc., Shortage of soil fertility is one of the indispensable limitations in achieving expansive crop production (Franzluebbers *et al.,* 2013). In order to fulfill the world food security, excessive usage of inorganic fertilizers were practiced that in turn became one of the vital reasons for declining in soil fertility (Kumar *et al.,* 2019). The utilization of inorganic fertilizers increases the crop production; however it causes long term degradation of soil fertility over the years (Shambhavi *et al.,* 2017). Massive utilization of organic fertilizers is very essential to regain the soil fertility. The hybrid combo of inorganic with organic fertilizers retains the soil fertility that triggers off crop production rate (Emmerson *et al.,* 2016). Hybridization of fertilizers completely depends on physical, chemical and biological characteristics of soil (Walsh *et al.,* 2012).Utilization of fertilizers greatly concern with biological characteristic changes which in turn indicate the soil fertility rate (Bargaz *et al.,* 2018). Biological components of soil are more pertinent to long term crop productivity and for sustainable agricultural practices (Lima *et al.,* 2015). Improvising the soil biological composition evokes amelioration of crop productivity by means of biofertlizers. Biofertlizers is eco-friendly, which aid in sustainable agricultural practices (Santhosh *et al.,* 2018). It holds alive microorganism, which induces the soil nutrients by means of organic matter decomposition (Mazid *et al.,* 2011). Intake of mineral nutrients by plants with the help of biofertlizers brings a better outcome in terms of long term crop productivity (Malusa *et al.,* 2012). All bacterial biofertlizers has significant part in Nitrogen (N) fixing, Phosphorus (P), Potassium (K), zinc and silica solublization (Narendra *et al.,* 2017) which helps in fixing all kinds of micro and macro nutrients to the soil. In addition biofertilizers enhance the plant growth through enriching the soil fertility by release of plant growth harmones, antibiotic production and organic matter biodegradations (Sinha *et al.,* 2014). Biofertilizers involves and accumulates the nutrients in the soil and prevents the nutrient loss during intake by plants, thus helping in enhanced plant growth (Singh *et al.,* 2011). PGPR, the main ingredients of bacterial biofertlizers has hefty relationship with different species relevant to host plants. Rhizospheric and Endophytic, the two prime classes of relationship which are found in the intercellular (Imran *et al.,* 2019) and apoplastic space of the host plant respectively (Qiu *et al.,* 2016). Some of the notable Rhizospheric bacteria are Bacillus, Azospirillum, Azotobacter, Burkholderia, Enterobacter, Klebsiella, Variovorax, Comamonadaceae, Pseudomonas, Gemmatimonadetes, Streptomyces filamentosus and Bacillales. Markable endophytic bacteria are Azoarcus spp, Herbaspirillum, seropedicae and Gluconacetobacter diazotrophicus (Carvalho *et al.,* 2014). Aforementioned PGPR produces Indole-acetic acid (IAA), Cytokinins (CK), Gibberellins (GA) and inhibitors of ethylene which takes up the great responsibilities of nutrients and water uptake required for plant growth (Tsukanova *et al.,* 2017). In this study, PGPR's role in agriculture, various species and its corresponding plants, its mechanism, advantages and disadvantages, future trends were reviewed. The aim of study is to provide adequate knowledge about the characteristics and functionality of PGPR through consortium literature reviews so as to practice the same to attain sustainability in agriculture. The overall literature study and compilation were made at SRM Institute of Science and Technology, Chennai in the year of 2021.

Plant growth promoting rhizobacteria

A cluster of bacteria that colonizes the root of the plant (rizhosphere) is termed as Plant growth promoting rhizobacteria (Egamberdieva *et al.,* 2014). Rhizhosphere is considered as the maximum nutrient amalgamate zone, where active microbial activities will be carried out. Though rhizhosphere consists of various microbes such as bacteria, fungi, algae, protozoa and acticomycetes, the bacterial colonies were found abundant (Kaymak *et al.,* 2010). The sustainable plant growth has been made possible through these bacterial colonies and it has been proved under various circumstances (Saharan *et al.,* 2011; Bhattacharyya *et al.,* 2012). Apart from promoting the plant growth through its active mechanism, the bacterial colonies in the rhizosphere has a strong effect on controlling the phytopathogenic microbes (Son *et al.,* 2014).Those bacterial colonies were named as rhizobacteria and are heterogeneous in nature. The unique characteristic of rhizobacteria such as ability to produce plant growth regulators, fixation of nitrogen, siderophore production, nutrients and mineral solubilization shows the superior nature when compared to other microorganism in promoting the plant growth (Souza *et al.,* 2012). Moreover, it acts as the Biocontrol agent to the pathogenic microbes (Beneduzi *et al.,* 2012). These beneficial bacterial colonies were affected by various factors such as temperature, pH, moisture, soil mineralogy and light. Among which the composition and activities of plant associated microbes. Beneficiary microbes enhance the plant growth usually at high temperature (Stephane *et al.,* 2010). pH is the important factor in determining the sustainability of microbes in the soil. pH ranges from 6.0 to 6.5 is found advantageous for the beneficiary microbes sustainability so as to ensure healthy plant growth (Berger *et al.,* 2013). These beneficiary microbes also maintain moisture through active secretion of harmones and enzymes (Dębska *et al.,* 2016).

Role of plant growth promoting rhizobacteria

Biotic and abiotic stress tolerance

The various external factors are responsible for the unproductive growth of plants which are referred as stress in plants. These stress disturb the genetic characteristic, metabolic activities, yield of the crops etc. and it can be categorized as biotic and abiotic stresses (Verma *et al.,* 2013). The living organism especially pathogenic bacteria, virus, fungi etc are responsible for causing biotic stress in plants. This affects the host cell of the plant and modifies the genetic code of the plant which leads to mortality of the plant (Suzuki *et al.,* 2014). Abiotic factors such as soil salinity, drought, extreme high temperature, deficient or excessive water supply leads to great reduction in agricultural productivity (Nadeem *et al.,* 2010). Abiotic and biotic stress caused by pathogenic mechanism, brings pre and post-harvest troubles in crops (Nejat *et al.,* 2017). These stresses are major barriers in sustainable agricultural productivity (Srividya and Sasirekha, 2017). Stresses that cause severe damages to the crop production can be determined by the efficacious process of PGPR. The enzyme called 1-aminocyclopropane-1- carboxylate (ACC) deaminase and Hydroxyacetophenone monooxygenase produced by PGPR and Pseudomonas fluorescens respectively breaks the ethylene precursor ACC to a-ketobutyrate and ammonia, that in turn, protects plants from various destructive effects of abiotic stresses (Kumara *et al.,* 2019). The bio-inoculants, developed by acdS gene coding for enzyme ACC-deaminase against the abiotic stresses (Shaik *et al.,*2013). The salinity and drought are the most devastating stresses that lower the agricultural productivity (Hasanuzzaman *et al.,* 2013). In addition, higher levels of ethylene in the plant stimulate prematurefatuity symptoms such as leaf yellowing, abscission, or desiccation/necrosis (Elisa and Glick, 2015). PGPR plays a major role in lessening the ethylene concentrations in plants, thus deduce the stresses.Pseudomonas putida and Enterobacter cloacae improvise the plant resistance to salt stress (Zhenyu *et al.,* 2012). Azospirillum brasilense, Pseudomonas chlororaphis (Egamberdieva, 2012), Streptomyces sp. strain (Palaniyandi *et al.,*2014), Chryseobacterium (Radzki *et al.,* 2013) on tomato plants, Pseudomonas putida in soyabean plants (Sang *et al.,* 2014) tends to reduce the ethylene level in plants so as to tolerate the salinity stresses. Bacillus megaterium founds to be highest phosphate solublization under salinity stresses in the plants (Chookietwattana and Maneewan, 2012). Enterobacter sp in okra plant (Habib *et al.,* 2016), Phyllobacterium in strawberries plant (Flores *et al.,* 2015), Putida, Gigaspora rosea (Gamalero *et al.,* 2010), Promicromonospora sp and Burkholderia cepacia in cucumber plants (Sang *et al.,*2014), Bacillus licheniformis, Brevibacterium iodinum,Zhihengliuela alba in red pepper plants (Siddikee *et al.,* 2011), Bacillus in alfalfa plants (Sokolova *et al.,* 2011), Pseudomonas sp in eggplant (Fu *et al.,* 2010) were some of the PGPRs actively diminish the salinity stresses. The functionality of the plants gets affected severely by turgor pressure and water potential during drought conditions. This leads to drought stress, causing severe damages to agricultural productivity (Rahdari and Hoseini, 2012) and flow of nutrients such as sulfates, nitrates, Calcium, Silica, Magnesium (Selvakumar *et al.,* 2012) and photosynthesis process (Anjum *et al.,* 2011; Rahdari *et al.,* 2012)founds to be reducing. The bacterial colonies of rhizosphere and endorhizosphere induce the plant to overcome the drought stress in order to attain sustainable agricultural productivity (Grover *et al.,* 2011).The plant biomass enhanced through the inoculation of Pseudomonas putida under the drought stress condition (Sandhya *et al.,* 2010). It is found that lavandula dentata with bacillus thuringiensis induces the growth of plant under drought stress by increasing the concentration of proline in the shoot (Armada *et al.,* 2014). Bacillus polymyxa in tomato plant (Shintu and Jayaram, 2015), Pseudomonas jessenii, Pseudomonas synxantha, and Arthrobacter nitroguajacolicus strain in rice plants (Gusain *et al.,* 2015),lipoferum and Pseudomonas putida in maize plants (Sandhya *et al.,* 2010; Bano *et al.,* 2013), Bacillus isolates and Pseudomonas with mesorhizobium ciceri in green gram plants (Isha *et al.,* 2013), rhizobacterial strain bacillus subtilis in mustard plant (Zhang *et al.,* 2010) were the PGPRs that induce the growth of plants under drought stress. In case of biotic stresses the Bacillus subtilis found a better resistance to the cotton pathogen rhizoctonia solani (Flavio *et al.,* 2011). Therefore, PGPR actively overcome all the biotic and abiotic stresses and induce the plants growth for sustainable crop productivity as shown in the Fig. 1.

Soil Nutrients accessibility for the plant growth

The overall concentration of soil nutrients in the rhizosphere get increased with the help of PGPR. It helps in fixing the atmospheric nitrogen by preventing the leaching of soil nutrients (Choudhary *et al.,* 2011). The species that comes under azotobacter genus such asarmeniacus, vinelandii, chroococcum, paspali, beijerinckii, nigricans and salinestri has strong potential to fix nitrogen nutrients in the soil (Gothandapani *et al.,* 2017). Azospirillum belonging to the spirillaceae family has strong association with the roots of C4 crops and plays a significant role in fixing 20-40kg of nitrogen under aerobic conditions (Trabelsi and Mhamdi, 2013). For legumnus plants rhizobium finds greater potential in fixing the atmospheric nitrogen at major concern (Jehangir *et al.,* 2017). Cyanobacteria (Blue Green Alga, BGA) such as Nostoc, Anabaena, Cylindrospermum, Gloetrichia Tolypothrix, Aulosira and Aphanotheca tremendously increases the rice crop productivity up to 38%, by fixing the nitrogen nutrients(Mishra *et al.,* 2013). Azolla proves to be vital nitrogen source for sustainable agricultural productivity and it has the potential of fixing about 50kg of nitrogen (Yao *et al.,* 2018). Gluconacetobacter diazotrophicus which colonize enormously in monocotyledon sugarcane plants actively fix the atmospheric nitrogen so as to provide sufficient amount of nitrogen nutrients for the crop growth (Santhosh *et al.,* 2018). Apart from these strains Bacillus aerius, Bacillus amyloliquefaciens, Bacillus licheniformis, Bacillus mucilaginous, Bacillus subtilis helps in nitrogen fixation in soil (Singh *et al.,* 2019; Pahari and Mishra, 2017).Addition to nitrogen fixation, phosphorous solublization is also biologically important. PGPR has strong role in solubilizing phosphorous for the consistent plant growth (Rifat *et al.,* 2010). Pseudomonaserwinia and P. chlororaphiswere has strong tendency to solubilizing the phosphorous and promote the plant growth through proper uptake of phosphorous nutrients (Diriba *et al.,* 2013). From the biochemical characteristics of bacterial isolates of Pseudomonas putida and Bacillus sp., it has been proven that these colonies have viability to solubilizing the phosphate for consistent supply of nutrients to the

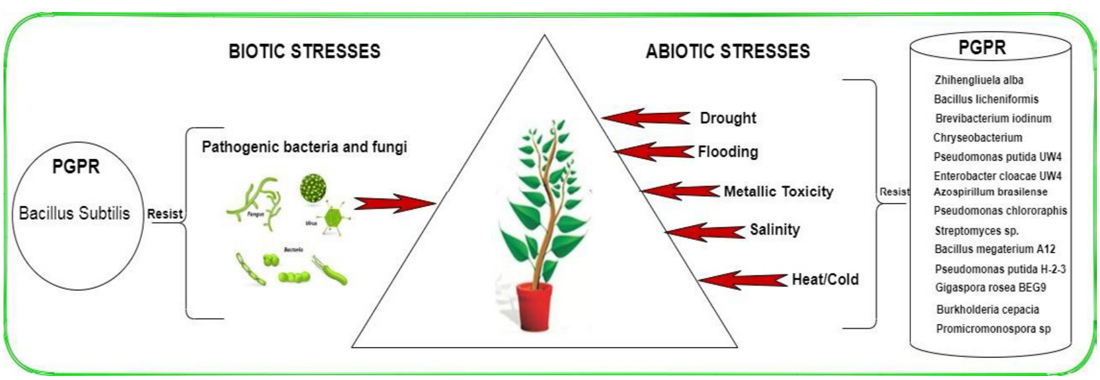

Fig. 1: PGPR in resisting biotic and abiotic stresses

plants (Grobelak *et al.,* 2015). PGPR bacterial strains such as Achromobacter xylosoxidans, Acinetobacter baumannii, Acinetobacter calcoaceticus, Aeromonas hydrophila, Arthroderma cuniculi, Aspergillus niger, Bacillus aerius, Bacillus altitudinis, Bacillus amyloliquefaciens, Bacillus licheniformis, Bacillus megaterium, Bacillus mucilaginous, Bacillus subtilis, Bacillus thuringenesis, Burkholderia cepacia, Burkholderia gladioli, Enterococcus casseliflavus, Enterococcus gallinarum, Fusarium proliferatum, Lecanicillium psalliotae, Paenibacillus favisporus, Paenibacillus taichungensis, Pseudomonas entomophila, Pseudomonas koreensis, Pseudomonas luteola, Pseudomonas simiae, Serratia marcescens, Serratia nematodiphila, Sphingomonas paucimobilis actively involves in solubilizing the phosphorous and tends to enhance the plant growth(Leite *etal.,*2018; Zhang *etal.,*2017; Martinez *et al.,* 2018; Karmakar *et al.,*2018; Gore and Navale, 2017; Kumaravel *et al.,* 2018; Vardharajula *et al.,*2011; Mussa *et al.,*2018; Kumari *et al.,* 2016; Sandhya *et al.,* 2010; Saikia *et al.,* 2018). Solublization of soil potassium is biologically an important factor and has equal importance, compared to the nitrogen and phosphorous in contributing sustainable crop production (Tri and Mutmainnah, 2016). Inorganic and organic acids, acidolysis, polysaccharides, complexolysis, chelation, polysaccharides, and exchange reactions produced by the bacteria aid to solubilizing the soil potassium (Archana *et al.,* 2013; Meena *et al.,* 2015). Bacillus licheniformis and Pseudomonas azotoformans in rice crops finds the best K solubilizing bacteria than others (Saha *et al.,* 2016). Potassium solubilizing capacity is found triggered by Enterobacter hormoecheiin cucumber crop fields (Prajapati and Modi, 2016).The species such as Burkholderia,Pseudomonas,Bacillus mucilaginosus, Bacillus edaphicus, Bacillus circulans, Acidithiobacillus ferrooxidans, and Paenibacillus spp. when inoculated with frateuria aurantiastrain shows about 39% increase in concentration of potassium in the crops (Subhashini, 2015), the aforementioned information are depicted in the Table 1.

Plant growth regulator

Plant producing organic substances in the name of harmones (also called as phytohormones) such as auxins, gibberellins (GA), abscisic acid (ABA), cytokinins (CK), salicylic acid (SA), ethylene (ET), jasmonates (JA), brassinosteroids (BR), and peptides were the key factors in developing the immune system against the pathogenic microbes and brings out tremendous agricultural outcomes (Dong *et al.,* 2013). These hormones act as the plant growth regulator for boosting up the crop productivity. Rhizobacterial traits make a major impact on the status of plant hormones by inducing the hormone secretion activities and increase the concentration of the hormones (Dodd *et al.,* 2010).Bacillus spp. producing auxin is proven as the deciding molecules which regulates the primary plant growth process (Ahmed and Hasnain, 2010).The most eminent auxin in the plant is indole-3-acetic acid. Lower the amount of IAA causes stimulation of elongation in primary roots, whereas higher concentration of IAA stimulates lateral root formation and root hair production. PGPR plays a vital role in synthesis of IAA which increases the both elongation of primary roots and lateral root formation (Vacheron *et al.,* 2013). Next to auxin, gibberellin is considered as most viable hormone responsible for seed germination, floral induction, flower, fruit, leaf and steam maturation. Sphingomonas produces gibberellins (GA) when inoculate with tomato plant, induces all the characteristics discussed above (Khan *et al.,* 2014). The plant organ size and stomata closure functionality is purely regulated by the plant hormone, namely abscisic acid (ABA) which is abundantly synthesized by the strains of Bacillus amyloliquefaciens (Raheem *et al.,* 2017). Bacillus subtilis strains synthesize the plant hormone called cytokinins which are responsible for plant cell division, inhibiting roots, stems, vascular differentiation and cambium sensitivity(Liu *et al.,* 2013).Reduction in antioxidant enzymes activity carried out by the salicylic acid (SA) were regulated majorly by the PGPR strains such as Mycobacterium spp., Pseudomonas spp., Azospirillum, lipoferum and Pseudomonas cepacia (Khan *et al.,*2020).Abscission of leaves and ripening of fruits were primarily regulated by ethylene plant hormones. 1-aminocyclopropane-1-carboxylate (ACC) is a plant, synthesized predecessor of ethylene hormone, which helps in exposing to environmental stress, pathogenic microbes and heavy metal presence (Glick *et al.,* 2012). Hence, PGPR plays a viable activity in decaying cycle of roots through degrading the ACC thus achieving the healthy root system(Glick *et al.,*2014). Jasmonates (JA) takes part in responding to the wounds in plant tissues and redirects the metabolism to repair the damages, which are mediated by PGPR. Bacillus subtilis in wheat

Table 1: Plant nutrients and its corresponding PGPR bacterial strains

Nutrients	PGPR	References
Nitrogen (N)	A. chroococcum	Gothandapani *et al.*,2017
	A. vinelandii	Gothandapani *et al.*, 2017
	A. beijerinckii	Gothandapani *et al.*, 2017
	A. paspali	Gothandapani *et al.*, 2017
	A. armeniacus	Gothandapani *et al.*, 2017
	A. nigricans	Gothandapani *et al.*, 2017
	A. salinestri	Gothandapani *et al.*, 2017
	Azospirillum	Trabelsi and Mhamdi, 2013
	Cyanobacteria	Mishra *et al.*, 2013
	Azolla	Yao *et al.*, 2018
	Gluconacetobacter diazotrophicus	Santhosh *et al.*, 2018
	Bacillus aerius	Singh *et al.*, 2019
	Bacillus amyloliquefaciens	Singh *et al.*, 2019
	Bacillus mucilaginous	Pahari and Mishra, 2017
	Bacillus subtilis	Pahari and Mishra, 2017
Phosphorous (P)	Pseudomonaserwinia	Diriba *et al.*, 2013
	P. chlororaphiswere	Diriba *et al.*, 2013
	P. putida	Grobelak *et al.*, 2015
	Bacillus sp	Grobelak *et al.*, 2015
	Achromobacter xylosoxidans	Leite *et al.*,2018
	Acinetobacter baumannii	Zhang *et al.*,2017
	Aeromonas hydrophila	Martinez *et al.*, 2018
	Arthroderma cuniculi	Karmakar *et al.*,2018
	Aspergillus niger	Gore and Navale, 2017
	Bacillus aerius	Singh *et al.*, 2019
	Bacillus altitudinis	Kumaravel *et al.*, 2018
	Bacillus thuringenesis	Vardharajula *et al.*, 2011
	Enterococcus casseliflavus	Mussa *et al.*, 2018
	Enterococcus gallinarum	Mussa *et al.*, 2018
	Lecanicillium psalliotae	Bilal *et al.*, 2018
	Paenibacillus taichungensis	Zhang *et al.*,2017
	Pseudomonas entomophila	Sandhya *et al., 2010*
	Pseudomonas koreensis	Kumari *et al.*, 2016
	Pseudomonas luteola	Martinez *et al.*, 2018
	Pseudomonas simiae	Kumari *et al.*, 2016
	Pseudomonas stutzeri	Sandhya *et al.*,2010
	Serratia nematodiphila	Saikia *et al.*, 2018
	Sphingomonas paucimobilis	Martinez *et al.*, 2018
Potassium (K)	Bacillus licheniformis	Saha *et al.*, 2016
	Pseudomonas azotoformans	Saha *et al.*, 2016
	Burkholderia	Subhashini, 2015
	Bacillus mucilaginosus	Subhashini, 2015
	B. edaphicus	Subhashini, 2015
	B. circulans	Subhashini, 2015
	Pseudomonas	Subhashini, 2015
	Acidithiobacillus ferrooxidans	Subhashini, 2015
	Paenibacillus sp	Subhashini, 2015
	Enterobacter hormoecheiin	Prajapati and Modi, 2016

seedling finds great response of synthesis of jasmonates harmones (Veselova *et al.*, 2014).PGPR has viable part in synthesizing harmones namely brassinosteroids (BR), and peptides which are responsible for various stress tolerance amelioration (Sharma *et al.*, 2017). Apart from aforementioned hormones PGPR Oozes out small, high-affinity iron-chelating compounds called Siderophores which is responsible for enhancing the plant growth through iron intensification (Flores *et al.,* 2015). Bacillus subtilis, Bacillus megaterium, Azotobacter vinelandii, Pantoeaallii and Rhizobium radiobacter were some of the PGPR strains that have strong ability to chelate iron in the form of Siderophores compounds (Ferreira *et al.,* 2019). In addition to iron magnification, PGPR produce volatile organic compounds (VOC) in order to manage plant pathogens, disease resistivity abatement and stunted plant growth (Hafiz *et al.,* 2017). Bacterial species such as Bacillus, Pseudomonas, Serratia, Arthrobacter, and Stenotrophomonas enhance the crop productivity through synthesizing the VOC (Yong *et al.,* 2015). Thus the various hormones and compounds synthesized by PGPR regulate the mechanism of plant growth and crop production as shown in the Fig. 2. Hence, PGPR is referred as plant growth regulator (Porcel et *al.,* 2014).

Need for inhibiting PGPR as biofertilizers

Inspite of various beneficial characteristics of PGPR, it has natural inducing quality without any external agents (Klett *et al.,* 2011). However, it is a need of utilizing these PGPR as biofertilizers (Salme *et al.,* 2017) to overcome tangible and intangible soil infertility problems due to excessive utilization of chemical fertilizers.

Increased utilization of chemical fertilizers

In late 1970s the utilization of chemical fertilizers has been drastically increased, since the labor cost increased day by day, the practice of blending biofertlizers with soil get decreased (Yan *et al.,* 2010). Over the past few decades huge quantity of chemical fertilizers has been applied in the cultivable ground (Sun *et al.,* 2015; Savci, 2012). This leads to serious issues such as degradation and compaction of soil, lowering of soil organic matter and soil carbon. Over the years, due to the continuous usage of chemical fertilizers leads to decline crop productivity (Sun *et al.,* 2015; Nkoa, 2014). In the modern agriculture systems, a chemical fertilizer raises the acidity nature of soil, which forces the nitrogen cycle in the soil to being complete (Guo *et al.,* 2010). It shows the path to heavy metals mobility in the soil which could be taken up by the plants (Yang *et al.,* 2010). Although some of the microbes have strong tendency to absorb the heavy metals, the entire structure and biomass of microbes get affected (Carpio *et al.,* 2014). Soil contaminants bioaccumulation take place which results in overall deflation in crop productivity due to uncontrolled utilization of phosphate and superphosphate fertilizers (Carvalho, 2017). Accumulation of chemical fertilizer such as dithiothreitol (DDT), endosulfan, heptachlor, lindane in the soil leads to perishing soil organic content (Jayaraj *et al.,* 2016). Moreover, the chemical fertilizers block the process of photosynthesis which leads to stunted growth in plants (Pesce *et al.,*

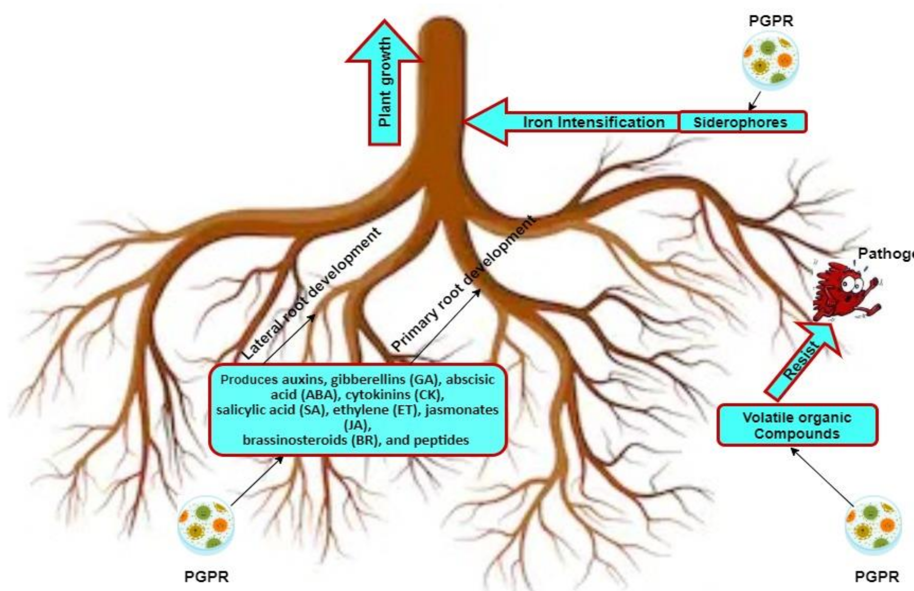

Fig. 2: Mechanism of PGPR in plant growth regulating

2011). Various evidential reports clears that chemical fertilizers volatilize and blend with the atmospheric air causes extreme atmospheric pollution (Chandrima *et al.,* 2020). The agricultural activities based on chemical fertilizers brings huge volume of crop productivity at short duration, however for the long term, it may not be suited for sustainable agricultural activities. It also have negative impacts on flora and fauna (Pimentel and Burgess, 2014; Goulson, 2014). To overcome these sort of problems and to achieve sustainable crop productivity, without any side effects, utilization the rhizosphere bacterial communities PGPR as a biofertilizers is essential (Wu *et* al.,2016).

Formulation of PGPR biofertilizers

The biofertilizers that comprises of live microbes needed to be formulated for its existence. Before formulation there is need to identify the beneficiary microbes which have to be cultivated and formulated for the further process. In identification of microbes, genotype and phenotype distinction were usually carried out. In genotype distinction of microbes rRNA functionalities were identified whereas in phenotype distinction microbial colonies, cell morphology, gram staining, metabolic and growth characteristics were identified in order to confirm the specific beneficiary bacteria. Confirmatory test is done usually for the precise identification of microbes (Lehner, 2013). After identifying the beneficiary bacterial culture it is isolated and cultured followed by formulation of biofertilizers (Rassem *et al.,* 2017). Formulation of biofertilizers includes a carrier that supports live microorganism existence, long term storage, and maintenance. It aids to supply the active live microbes to blend with the soil or plant so as to undergo aforementioned PGPR activities to improvise the crop yield and soil fertility (Sahu and Brahmaprakash, 2016).These formulations were prepared to strengthen both the crop yield and soil health (Arora *et al.,* 2010). Metabolically viable, adjustments in pH, non-toxic in nature and biodegradable are some of the basic characteristics for good formulation of bio fertilizers (Divjot *et al.,* 2020). Among the different types of commercial bio fertilizers, the liquid formulation found to be more convenient in handling compare to conventional solid base carrier inoculants(Herrmann and Lesueur, 2013; Brar *et al.,* 2012). A formulated bio fertilizer is demanding growth media for any selected bacteria. Although the cost of growth media for the microbes is high, still there are some natural media such as whey, water sludges, composts and etc., are can be used as source for the growth of microbes (Samer *et al.,* 2012). Rock phosphate along with agro based industrial residuals and bioflims can also be used as source for growth media (Allah *et al.,* 2017; Gamini *et al.,* 2010). Proper inoculation in formulation of bio fertilizers has equal importance for the plant growth (Indra *et al.,* 2014). Crop growth rate pattern increases through simultaneous inoculation with different PGPR rather than single inoculation mechanism (Martinez *et al.,* 2010). As per the literature, nitrogen and phosphorous content increases tremendously when A. brasilense is inoculated with maize(Shrivastava, 2015) and nodule-inducing rhizobia with AM fungi (Xiurong *et al.,* 2010). Mycorrhizal fungi were co-inoculated with PGPR to gain increased root colonization (Josef *et al.,* 2010). Thus co-inoculation resultant in formulation of biofertilizers is consistent for different PGPR microorganism consortium (Malusa *et al.,* 2012). Hence, effective commercial usage of biofertilizers, genuine inoculation of PGPR consortium under different species with different field condition is inevitable (Cristian *et al.,* 2017). The inoculants consist of carriers which helps the consortium PGPR microbes to be delivered at satisfactory physiological state (Jambhulkar *et al.,* 2016). Good moisture, absorptions, easy processing, sterilizing, pH buffering capacity, low cost and its availability are some of the most essential properties of carriers (Rawat *et al.,*2020).The physical form of biofertilizers is solely depends on the carriers used, such as peats, coal, clays, compost, soybean meal, wheat bran, saw dust, vermiculture, perlite and etc., (Herrmann and Lesueur, 2013). Solid type carriers are in different forms such as powders, granules and beads (John *et al.,* 2011). Alternative to carriers, freeze drying mechanism which is commonly known as lyophilization can be used where the bacterial survival rate is high (Fernanda *et al.,* 2014). In order to avoid dehydration, cryprotectant is added during the process. Henceforth, combination of growth media, inoculation and good carriers are helping to formulate strong PGPR biofertlizers. The above mentioned formulation processes of biofertlizers has been portrayed in Fig. 3.

Role of PGPR Bio fertilizers in plant growth

More than 90% of plant growth is purely depends on photosynthesis, since the plant biomass is derived from carbon dioxide assimilation. A photosynthetic process rate increases when rice gets inoculated with various rhizobia strains (Mia and Shamsuddin, 2010). Bacillus lentus, Pseudomonas sp., and Azospirillum brasilens increases the antioxidant and photosynthetic pigment that leads to rise in chlorophyll content in the plant (Heidari and Golpayegani, 2012).Bacillus sp., when inoculated with potato gives positive growth in photosynthetic performance (Gururani *et al.,* 2013). Thus PGPR biofertilizers induces photosynthesis mechanism for sustained growth of the plant even under various stress conditions. Amino acid plays an important role in plant growth by supporting the roots to intake water and nutrients from the soil (Berg *et al.,* 2014; Hildebrandt *et al.,* 2015).The active synthesis of amino acids is greatly relay on plant species and their associated microbes(Kang *et al.,* 2010). Thus PGPR biofertilizers increases the synthesis of amino acids for active performance of root system that nourishes the plant growth. Though there are certain factors that are responsible for sustainable plant growth, still few agents that causes the adverse hindrance to the plant growth. It can be perished with the help of PGPR biofertilizers. The major barrier to the plant growth is contamination in soil. The various factors contributing to the contamination in soil are accumulation of heavy metals in the soil, dumping of plastics, usage of chemical fertilizers etc. Heavy metal presence is mainly due to the rapid industrialization and population growth (Shinwari *et al.,* 2015).Heavy metals are non-biodegradable in nature and biodegradation is the only effective strategy to minimize the effects of heavy metals in the soil biosphere (Akhtar *et al.,* 2013; Lim *et al.,* 2014). In this connection, PGPR bacterial strains such as Azotobacter, Bacillus, Brevibacillus, Kluyvera, Mesorhizobium, Pseudomonas, Achromobacter, Psycrobacter, Bradyrhizobium, Rhizobium, Sinorhizobium, Ochrobactrum, Ralstonia, Variovox, and Xanthomonas were widely used for the purpose of biodegradation of heavy metals (Shinwari *et al.,* 2015). PGPR strains such as Azospirillum sp., Bacillus sp., Acinetobacter sp., Achromobacter sp., Cronobacter sakazakii, Agrobacterium sp., Alcaligenes sp., Mesorhizobium sp., Burkholderia sp., Klebsiella sp., Enterobacter, sp., Halomonas sp., Ralstonia sp., Methylobacterium fujisawaense, Pseudomonas sp., Rhizobium sp., Serratia sp., Variovorax paradoxus and Zhihengliuela alba(Chen *et al.,* 2013; Gontia *et al.,* 2017; Jha *et al.,* 2012; Siddikee *et al.,* 2011) were capable to synthesis ACC deaminase, that reduces the concentration of ethylene in plants which overcome the heavy metal stress. Thus, with the combination of these bacterial strains biofertlizers can be formulated that tends to degrade the heavy metal and reduce the contamination of the soil so as to enhance the plant growth. As it is discussed, the modern agriculture includes the practice of utilizing chemical pesticides for increasing the crop productivity which leads to adverse soil contamination and sustainability in agricultural practice (Kumar and Puri, 2012). Hence, there is a need of eco-friendly pesticides as alternatives to existing practice. The bacterial strains such as Azospirillum, Azotobacter, Bacillus, Enterobacter, Gordonia, Klebsiella, Paenibacillus, Pseudomonas and Serratia possess greater tendency to fight and degrades the harmful effects of pest, thus leading to reduce the soil contamination and provide pathway for sustained plant growth (Shaheen and Sundari, 2013). Microbial activity induce the plant growth through degradation of pesticides by synthesizing enzymes such as esterases, hydrolases and glutathione (Hernandez

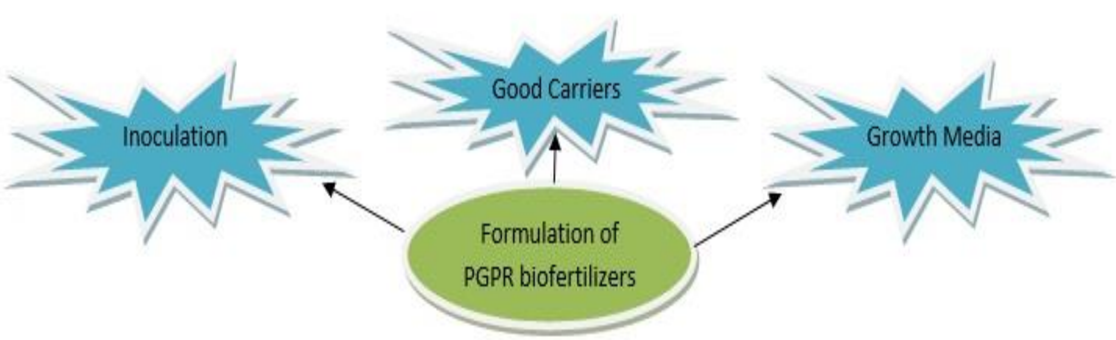

Fig. 3: Formulations of PGPR Bio-fertilizers

et al., 2013). Hence PGPR biofertilizers actively eradicate the harmful nature of pesticides that causes soil contamination so as to boost the plant growth. Moreover PGPR act as biocontrol for plant pathogens in which metabolites productions such as antibiotics and hydrogen cyanide were the primary biocontrol mechanism (Reddy, 2014). This mechanism involves wide variety of compounds having many antimicrobial activities which act as defence layer to pathogenic microbes. Phytopathogenic proliferation can be minimized or eradicated by antagonist mechanism. Antagonist mechanism includes production of siderophores, bacteriocins and antibiotics (Beneduzi *et al.,* 2012).In case of plastic waste, the bacteriological harmones such as IAA, GA and kinetins help to resist the effects causes by the plastic waste. Thus PGPR biofertilizers effectively resist the effects of plastic and reduces the soil contamination (Ikhwan and Nurcholis, 2020). It is reported that lack of micronutrients is basic problem of plant growth, specifically zinc (Zn) deficiency create a major barriers to the plant growth, especially to the cereals crops (Ashish *et al.,* 2012). PGPR bacterial strains increase the zinc and iron nutrients in the soil which is mandatory for the sustainable plant growth (Yadav *et al.,* 2017). Besides, bacterial colonies which includes Pseudomonas alcaligenes, Pseudomonas aurantiaca, Pseudomonas aureofaciens and Pseudomonas chlororaphis, Bacillus subtilis, Bacillus pumilus, Achromobacter xylosoxidans, Serratia marcescens, Pseudomonas extremorientalis, P. fluorescens, Serratia plymuthica, and Stenotrophomonas rhizophila, Phyllobacterium brassicacearum fight against biotic and abiotic stresses that are major barriers to the plant growth (Verma *et al.,* 2017; Yadav *et al.,* 2018; Liu *et al.,* 2013; Forchetti *et al.,* 2010; Lavania and Nautiyal, 2013; Egamberdieva, 2011;Timmusk *et al.,* 2014; Bresson *et al.,* 2014). In overview, it is revealed that PGPR bacterial inoculated biofertlizers has multi-disciplinary role in enhancing the sustainable plant growth. The roles of various PGPR strains utilized in biofertlizers are tabulated as shown in Table 2.

Commercialization of PGPR bio fertilizers

Around 24 countries were commercially engaged in producing PGPR biofertilizers both in large and small scales (Bharti *et al.,* 2017). Phosphorous solubilizing bacteria and atmospheric fixing nitrogen bacteria have been used for commercialization (Lesueur *et al.,* 2016). Non-rhizobial PGPR inoculants containing azospirillum were most frequently used commercial biofertilizers in global market (Herrmann *et al.,* 2013). The Non-rhizobial PGPR biofertilizers reached only 5% of global market and remaining were occupied by the chemical fertilizers because of its expensiveness (Wellesley, 2014). Later in developed countries legume and nitrogen fixing inoculants were dominated (GVR, 2020). In global biofertilizers market about 78% were occupied by rhizobial inoculants, whereas 15% and 7% has been occupied by Phosphorous solubilizers and other bioinoculants respectively (Owen *et al.,* 2015). Zinc and potassium based biofertilizers were the emerging commercial products that address the soil nutrient deficiencies (Shaikh *et al.,* 2017; Khatibi, 2011). Among this, potassium based biofertlizers has been increasing tremendously in most of the countries (Teotia *et al.,* 2016).In this regard, India stands in fourth whereas nations like USA, China and Brazil stands first in producing potassium solubilizing biofertilizers (Investing News Network, 2019). In PGPR biofertilizers commercialization, Asia-pacific nations started attaining maximum growth from 2014 and the global biofertlizers market expanded to increase the sustainable food productivity (Verma *et al.,* 2019).This shows the progress of potential nature of PGPR in the commercialization aspects.

Limitations and future trends in PGPR utilization in agriculture

In recent days the utilization of bio fertilizers became an integral part of sustainable agricultural practices and major developed countries achieved the sustainability (Weekley *et al.,* 2012). In developing countries, there is a minimum impact of PGPR bio fertilizers, due to the poor quality in inoculants and stringent regulatory legal frameworks (Berninger et *al.,* 2018). In addition, the bio fertilizer takes time to bring out the productivity in agriculture which makes the investors and scientist difficult to bring the PGPR inoculants to general farmers (Mahanty *et al.,* 2017). Large scale commercialization of PGPR inoculants requires large volume trials in understanding the bacteriological characteristics and their activities which is not an economically feasible for the farmers (Qiu *et al.,* 2019). In this connection, research in biofertilizers should be focused on cost effective, faster benefits, sustainable higher productivity under various environmental conditions (Ijaz *et al.,* 2019). Besides,

Table 2: PGPR bacterial strains utilized in bio-fertilizers and its role in plant growth

Role of PGPR Bio fertilizers in inducing:	PGPR	References
photosynthesis	Pseudomonas sp Bacillus lentus Azospirillum brasilens	Heidari and Golpayegani, 2012
	Bacillus sp	Gururani *et al*, 2013
Amino acid	B. subtilis P. putida Rhizobium sp	Luke *et al*, 2013
Biodegradation of heavy metal	Achromobacter Azotobacter Bacillus Bradyrhizobium Brevibacillus Kluyvera Mesorhizobium Ochrobactrum Pseudomonas Psycrobacter Ralstonia Rhizobium Sinorhizobium Variovox Xanthomonas	Shinwari *et al.,* 2015
Controlling pesticides	Azospirillum Azotobacter Bacillus Enterobacter Gordonia Klebsiella Paenibacillus Pseudomonas Serratia	Shaheen and Sundari, 2013

these researches promote the usage of bio inoculants and develop the confidence among the local farmers, based on their utilization and performance (Gupta *et al.,* 2015). Future world looking to bring novel biofertilizers which are very affordable, safe and best substitute to agrochemical fertilizers by the usage of consortium multi-tarit PGPR strains. It enhances the communication with the plant through quorum sensing (Ijaz *et al.,* 2019; Vassilev *et al.,* 2015; Khan *et al.,* 2017). Utilization of bioflims protects the bio inoculants from varying environments. It is expected to evolving in future that leads to increase in microbial population (Sahai *et al.,* 2017; El-Ghamry *et al.,* 2018). According to the literatures, future strategies could focus on biofertilizers which involves interactions of microbes with nano particle. It is mainly to improvise the micronutrients to bacteria and plants. It became the revolution in future agricultural practices by introducing nanofertilizers (Tarafdar *et al.,* 2013). The efficiency of nano fertilizers has been proven as best alternatives to all traditional ones because of its characteristics of reducing nitrogen loss, leeching, toxic effects, long term sustainability of microbes in the soil (Suman et al., 2010). Thus Nanoencapsulation technology will be a versatile tool to protect PGPR from various environmental changes and to extract its complete benefits so as to make sustainable crop productivity with maintained soil fertility.

A summary of present and forthcoming ideas

The present studies on PGPR in sustainable agriculture focus on formulation of biofertilizers. Moreover the PGPR bacterial strains are isolated and cultured for the formulation purpose. Followed with the formulation, the biofertilizers were commercialized so as to use in agricultural field. PGPR due to its unique characteristic such as nutrients intake, stress tolerance, wide hormonal secretion etc. finds wide range of scope in inducing the plant growth. Forthcoming challenges in agriculture can be faced with the help of genetically modified PGPR bacterial strains. Genetically modified PGPR bacterial strains can be produced without disturbing its beneficiary nature and tends to increase the efficiency. In terms of biofertilizers efficiency can be increased through these modified PGPR bacterial strains. Thus sustainable agricultural practice will tends to grow through continuous research in genome sequence analysis and characteristic of PGPR bacterial strains.

CONCLUSION

In the late 1960s, green revolution tremendously increases the crop productivity by triggering the utilization of chemical fertilizers along with other advances in agricultural practices. Thus more than billions of world population were protected from starvation and ensured the food security. But, due to the excessive population and civilization, the need of individuals were increased which leads to over utilization of chemical fertilizers in order to achieve the rapid crop productivity. Besides, the mono-cultivation strategy was widely followed because of easy handling and management resulting in complete dependency on chemical fertilizers. It leads to complete disturbance in soil ecosystem and challenge to attain sustainable crop production. Hence, it is mandatory to switch over from inorganic to organic agricultural practices for the welfare of future agricultural productivity. Organic agricultural practices needs frequent analysis of soil report for every cropping season which helps them to choosing proper organic manure and suitable crops. Although the manual soil testing gives effective information about the major soil parameters N, P and K, it is essential to identify the major minerals which supports for sustainable productivity. Though, there is a least chance to utilize the traditional agricultural practices in this modern era, the good natures of PGPR can be imported in agricultural practices. As it is discussed in this extensive literature review, PGPR plays major role in handling biotic and abiotic stress by utilizing the aforementioned bacterial strains. PGPR bacterial strains induce the plants for its effective uptake of soil macro, secondary and micro nutrients. PGPR bacterial secretion of different plants hormones such as auxins, gibberellins, abscisic acid, cytokinins, salicylic acid, ethylene, jasmonates, brassinosteroids, and peptides helps in nourishing plant growth. Adapting the PGPR in fields, makes viable impact in crop productions due to its unique features such as protecting against different environmental stresses, regulating the plant growth, influencing the crop productivity and soil ecosystem so on. In addition, PGPR utilization comes in reality and finds best alternative to various strategies in agricultural sustainability. Biofertilizers were formulated as liquid as well as solid fertilizers through proper usage of PGPR inoculation, carriers and growth medium. This formulated biofertlizers were commercialized and makes perfect alternatives to the chemical fertilizers in all means. Though the usage of these biofertlizers takes more time to show the productivity, the sustainability is rich enough. But the scientists and researchers target to bring back the organic farming and resolve the time consumption problems through major innovations such as consortium multi-trait PGPR strains, bioflims, Nanoencapsulation technology. It leads to practice multiple cropping in agricultural fields. In this modern agricultural era many farmers and policy makers aims to bring sustainable profit in agriculture through multi cropping. This makes to have more focus on PGPR biofertlizers and advanced nanotechnology intrusion in agriculture. Thus the plant growth promoting Rhizobacterial products and its corresponding technologies will be a boon to upcoming world agriculturist in ensuring the sustainable crop productivity and soil ecosystem.

AUTHOR CONTRIBUTIONS

V. Dhayalan performed the literature review, experimental design, analyzed and interpreted the data; K. Sudalaimuthu prepared the manuscript text, and manuscript edition.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVATIONS

ABA	Abscisic Acid
ACC	1-aminocyclopropane-1-carboxylate
acdS	ACC deaminase structural gene
a-ketobutyrate	alpha-ketobutyrate
AM fungi	Arbuscular Mycorrhiza fungi
BGA	Blue Green Alga
BR	Brassinosteroids
CK	Cytokinins
DDT	Dithiothreitol
ET	Ethylene
etc	Et cetera
Fig.	Figure
GA	Gibberellins
IAA	Indole-3-acetic acid
JA	Jasmonates
K	Potassium
Kg	Kilogram
N	Nitrogen
PGPR	Plant growth promoting rhizobacters
P	Phosphorous
pH	Potential of Hydrogen
SA	Salicylic acid
Sp.	Single bacterial type
Spp.	Number of bacteria with different names belong to one genus
USA	United States of America

REFERENCES

Ahmed, A.; Hasnain, S., (2010). Auxin producing Bacillus sp.: Auxin quantification and effect on the growth Solanum tuberosum. Pure Appl. Chem., 82: 313-319 **(7 pages).**

Akhtar, M.S.; Chali, B.; Azam, T., (2013). Bioremediation of arsenic and lead by plants and microbes from contaminated soil. Res. Plant Sci., 1: 68–73 **(6 pages).**

Allah, D.; Muhammad, J.; Imtiaz, M.; Sajid, M.; Zheng, Q.; Shuxin, Tu., (2017). Application of rock phosphate enriched composts increases nodulation, growth and yield of chickpea. Int. J. Recycl. Organic Waste Agric.,7: 33-40 **(8 pages).**

Anjum, S.A.; Xie, X.Y.; Wang, L.C.; Saleem, M.F.; Man, C.; Lei, W., (2011). Morphological, physiological and biochemical responses of plants to drought stress. Afr. J. Agric. Res., 6(9): 2026–2032 **(7 pages).**

Archana, D.; Nandish, M.; Savalagi, V.; Alagawadi, A., (2013). Characterization of potassium solubilizing bacteria (KSB) from rhizosphere soil. Q. J. Life Sci., 10: 248-257 **(10 pages).**

Armada, E.; Roldán, A.; Azcon, R., (2014). Differential activity of autochthonous bacteria in controlling drought stress in native Lavandula and Salvia plants species under drought conditions in natural arid soil. Microb. Ecol., 67(2): 410–420 **(11 pages).**

Ashish, S.; Babita, P.; Deepti, S.; Shankhdhar, S.C., (2013). Zinc-an indispensable micronutrient. Physiol. Mol. Biol. Plants., 19(1): 11–20 **(10 pages).**

Bano, Q.U.; Ilyas, N.; Bano, A.; Zafar, Z.A.; Akram, A.B.; Hassan, F., (2013). Effect of azospirillum inoculation on maize (Zea mays L.) under drought stress. Pak. J. Bot., 45(S1): 13–20 **(8 pages).**

Bargaz, A.; Lyamlouli, K.; Chtouki, M.; Zeroual, Y.; Dhiba, D., (2018). Soil microbial resources for improving fertilizers efficiency in an integrated plant nutrient management System. Front. Microbiol., 9(1606): 1-25 **(25 pages).**

Beneduzi, A.; Ambrosini, A.; Passaglia, M.P.L., (2012). Plant growth-promoting rhizobacteria (PGPR): Their potential as antagonists and biocontrol agents. Genet. Mol. Biol., 35(4): 1044-1051 **(8 pages).**

Berg, G.; Grube, M.; Schloter, M.; Smalla, K., (2014).Unraveling the plant microbiome: looking back and future perspectives. Front. Microbiol., 5(148): 1-7**(7 pages).**

Berger, L.R.; Stamford, N.P.; Santos, C.E.R.S.; Freitas, A.D.S.; Franco, L.O.; Stamford, T.C.M., (2013). Plant and soil characteristics affected by biofertilizers from rocks and organic matter inoculated with diazotrophic bacteria and fungi that produce chitosan. J. Soil Sci. Plant Nutr.,13(3): 592-603 **(12 pages).**

Berninger, T.; González, L.O.; Bejarano, A.; Preininger, C.; Sessitsch, A., (2018). Maintenance and assessment of cell viability in formulation of non-sporulating bacterial inoculants. Microbiol. Biotechnol.,11: 277–301 **(25 pages).**

Bharti, N.; Sharma, S.K.; Saini, S.; Verma, A.; Nimonkar, V.; Prakash, O., (2017). Microbial plant probiotics: problems in application and formulation. Ed. Springer. Probiotics and Plant Health. Singapore. 317–335 **(19 pages).**

Bhattacharyya, P.N.; Jha, D.K., (2012). Plant growth-promoting rhizobacteria (PGPR): Emergence in agriculture. Wood J. Microb. Biotechnol.,28: 1327–1350 **(24 pages).**

Bilal, L.; Asaf, S.; Hamayun, M.; Gul, H.; Iqbal, A.; Ullah, I.; Lee, J.; Hussain, A., (2018). Plant growth promoting endophytic fungi asprgillus fumigatus TS1 and fusarium proliferatum BRL1 produce gibberellins and regulates plant endogenous hormones.,76: 117-127 **(11 pages).**

Brar, S.; Sarma, S.; Chaabouni, E., (2012). Shelf-life of biofertlizers: an accord between formulations and genetics. J. Biofert. Biopestic., 3: 1–2 **(2 pages).**

Bresson, J.; Vasseur, F.; Dauzat, M.; Labadie, M.; Varoquaux, F.; Touraine, B.; Vile, D., (2014). Interact to survive: Phyllobacterium brassicacearum improves arabidopsis tolerance to severe water deficit and growth recovery. PLoS One., 9(e107607): 1-12 **(12 pages).**

Carlos, M.H.; Ângela, V.; Cátia, A.S.; Helena, M.V.; Eduardo, V.S., (2019). Comparison of five bacterial strains producing siderophores with ability to chelate iron under alkaline conditions. AMB.Expr., 9: 1-12 **(12 pages).**

Carpio, I.E.M.; Mangadlao, J.D.; Nguyen, H.N.; Advincula, R.C.; Rodrigues, D.F., (2014). Graphene oxide functionalized with ethylenediamine triacetic acid for heavy metal adsorption and anti-microbial applications. Carbon., 77: 289–301 **(13 pages).**

Carvalho, T.L.G.; Balsemão, P. E.; Saraiva, R.M.; Ferreira, P.C.G.; Hemerly, A.S., (2014). Nitrogen signalling in plant interactions with associative and endophytic diazotrophic bacteria. J. Exp. Bot., 65: 5631–5642 **(11 pages).**

Carvalho, F.P., (2017). Pesticides, environment, and food safety. Food Energy Secur., 6: 48-60 **(13 pages).**

Chandrima, B.; Rupsa, R.; Prosun, T.; Anupama, G.; Abhrajyoti, G., (2020). Biofertlizers as substitute to commercial agrochemicals. Pesticides and Chemical Fertilizers., 11: 263-290 **(28 pages).**

Chen, L.; Dodd, I.C.; Theobald, J.C.; Belimov, A.A.; Davies, W.J., (2013). The rhizobacterium variovorax paradoxus 5C-2, containing ACC deaminase, promotes growth and development of Arabidopsis thaliana via an ethylene-dependent pathway. J. Exp. Bot., 64: 1565-1573 **(9 pages).**

Chookietwattana, K.; Maneewan, K., (2012). Screening of efficient halo tolerant phosphate solubilizing bacterium and its effect on promoting plant growth under saline conditions. World Appl. Sci. J., 16: 1110–1117 **(8 pages).**

Choudhary, D.K.; Sharma, K.P.; Gaur, R.K., (2011).Biotechnological perspectives of microbes in agro-ecosystems. Biotechnol. Lett.,33: 1905–1910 **(6 pages).**

Cristian, D.C.; Giuseppe, B.; Giovanna, V.; Monica, M.; Giuliano, M.; Teofilo, V., (2017).Increased root growth and nitrogen accumulation in common wheat following PGPR inoculation: Assessment of plant-microbe interactions by ESEM. Agric. Ecosyst. Environ., 247: 396–408 **(13 pages).**

Dębska, B.; Długosz, J.; Długosz A.P.; Szott M.B., (2016). The impact of a bio-fertilizer on the soil organic matter status and carbon sequestration—results from a field-scale study. J. Soils Sediments. 16: 2335–2343 **(9 pages).**

Dodd, I.C.; Zinovkina, N.Y.; Safronova, V.I.; Belimov, A.A., (2010). Rhizobacterial mediation of plant hormone status. Ann. Appl. Biol., 157: 361-379 **(19 pages).**

Dong, Y.; Yinong, Y.; Zuhua, H., (2013). Roles of plant hormones and their interplay in rice immunity. Molecular Plant.6: 675–685 **(11 pages).**

Diriba, M.; Fassil, A.; Elisabet, B.; Ulf G., (2013). Phosphate-solubilising rhizobacteria associated with Coffea arabica L. in natural coffee forests of southwestern Ethiopia. J. Saudi Soc. Agric. Sci., 12: 73-84 **(12 pages).**

Divjot, K.; Kusam, L.R.; Ajar, N.Y.; Neelam, Y.; Manish, K.; Vinod, K.; Pritesh, V.; Harcharan, S.D.; Anil K.S., (2020). Microbial biofertlizers: bioresources and eco-friendly technologies for agricultural and environmental sustainability. Biocatalysis Agric. Biotechnol., 23(101487): 1-11 **(11 pages).**

Egamberdieva, D., (2011).Survival of pseudomonas extremorientalis TSAU20 and P. chlororaphis TSAU13 in the rhizosphere of common bean (Phaseolus vulgaris) under saline conditions. Plant Soil Environ., 57: 122–127 **(6 pages).**

Egamberdieva, D.; Jabborova, D., (2013). Biocontrol of cotton damping-off caused by rhizoctonia solani in salinated soil with rhizosphere bacteria. Asian Australas J. Plant Sci. Biotechnol., 7(2): 31–38 **(8 pages).**

Egamberdieva, D.; Lugtenberg, B., (2014).Use of plant growth-promoting rhizobacteria to alleviate salinity stress in plants. In use of microbes for the alleviation of soil stresses., 1: 73–96 **(24 pages).**

Elisa, G.; Bernard, R.G., (2015). Bacterial modulation of plant ethylene levels. Plant physiol., 169: 13–22 **(10 pages).**

El-Ghamry, A.; Mosa, A.A.; Alshaal, T.; El-Ramady, H., (2018). Nanofertilizers vs. Biofertilizers: new insights. Environ. Biodivers. Soil Sec., 2: 51–72 **(22 pages).**

Emmerson, M.; Morales, M.B.; Oñate, J.J.; Batáry, P.; Berendse, F.; Liira, J.; Aavik, T.; Guerrero, I.; Bommarco, R.; Eggers, S.; P€art, T.; Tscharntke, T.; Weisser, W.; Clement, L.; Bengtsson, J., (2016). How agricultural intensification affects biodiversity and ecosystem Services. Adv. Ecol. Res., 55: 43-97 **(55 pages).**

Fernanda, F.; Stéphanie, C.; Stéphanie, P., (2019). Freeze-drying of lactic acid bacteria: A stepwise approach for developing a freeze-drying protocol based on physical properties. Methods Mol. Biol., 2180: 703-719 **(17 pages).**

Flavio, H.V.; Ricardo, M.S.; Fernanda, C.L.M.; Huiming, Z.; Terry, W.; Paxton, P.; Henrique, M.F.; Paul W.P., (2011).Transcriptional profiling in cotton associated with Bacillus subtilis (UFLA285) induced biotic-stress tolerance. Plant Soil. 347: 327–337 **(11 pages).**

Flores, J.D.; Silva, L.R.; Rivera, L.P., (2015). Plants probiotics as a tool to produce highly functional fruits: the case of Phyllobacterium and vitamin C in strawberries. PLoS One 10., e012228: 1-10 **(10 pages).**

Forchetti, G.; Masciarelli, O.; Izaguirre, M.J.; Alemano, S.; Alvarez, D.; Abdala, G., (2010). Endophytic bacteria improve seedling growth of sunflower under water stress, produce salicylic acid, and inhibit growth of pathogenic fungi. Curr. Microbiol., 61: 485–493 **(9 pages).**

Franzluebbers, J.; Jorge, S.; Miguel, A., (2013). Agronomic and environmental impacts of pasture–crop rotations in temperate North and South America. Agric. Ecosyst. Environ., 190:18-26 **(9 pages).**

FreyKlett, P.; Burlinson, P.; Deveau, A.; Barret, M.; Tarkka, M.; Sarniguet, A., (2011). Bacterial-fungal interactions: hyphens between agricultural, clinical, environmental, and food microbiologists. Microbiol. Mol. Biol. Rev., 75(4): 583–609 **(27 pages).**

Fu, Q.; Liu, C.; Ding, N.; Guo, B., (2010).Ameliorative effects of inoculation with the plant growth promoting rhizobacterium pseudomonas sp. DW1 on growth of eggplant (Solanum melongena L.) seedlings under salt stress. Agric. Water Manage., 97: 1994–2000 **(7 pages).**

Gamalero, E.; Berta, G.; Massa, N.; Glick, B.R.; Lingua, G., (2010). Interactions between pseudomonas putida UW4 and gigaspora rosea BEG9 and their consequences for the growth of cucumber under salt-stress conditions. J. Appl. Microbiol., 108: 236–245 **(19 pages).**

Gamini, S.M.L.; Weerasekara, K.A.; Seneviratne, J.S.; Zavahir, M.L.; Kecske; Kennedy, I.R., (2010). Importance of biofilm formation in plant growth promoting rhizobacterial Action: Maheshwari, D.K.(Eds.), Plant growth and health promoting bacteria. Microbiol. Monographs. 18: 81-95 **(15 pages).**

GVR, (2020). Grand View Research Biofertlizers market analysis by product (nitrogen fixing, phosphate solubilizing), by application (seed treatment, soil treatment) and segment forecasts to 2022 2015. 1-11 (**11 pages).**

Glick, B.R., (2012).Plant growth promoting bacteria: Mechanisms and applications.Scientifica.,1-15 **(15 pages).**

Glick, B.R., (2014). Bacteria with ACC deaminase can promote plant growth and help to feed the world. Microbiol. Res., 169:30–39 **(10 pages).**

Gontia, I.; Sapre, S.; Kachare, S.; Tiwari, S., (2017).Molecular diversity of 1-aminocyclopropane-1-carboxylate (ACC) deaminase producing PGPR from wheat (Triticum aestivum L.) rhizosphere. Plant Soil. 414: 213–227 **(15 pages).**

Gore, N.S.; Navale, A.M., (2017). In vitro screening of rhizospheric Aspergillus strains for potassium solubilization from Maharashtra, India. South Asian J. Exp. Biol., 6: 228–233 **(6 pages).**

Gothandapani, S.; Soundarapandian, S.; Jasdeep, C.P., (2017). Azotobacter chroococcum: Utilization and potential use for agricultural crop production: An overview. Int. J. Adv. Res. Biol. Sci., 4: 35-42 **(8 pages).**

Goulson, D., (2014). Ecology: Pesticides linked to bird declines. Nature. 511 (7509): 295-296 **(2pages).**

Grobelak, A.; Napora, A.; Kacprzak, M., (2015). Using plant growth-promoting rhizobacteria (PGPR) to improve plant growth. Ecol. Eng., 84: 22–28 **(7 pages).**

Grover, M.; Ali, S.K.Z.; Sandhya, V.; Rasul, A.; Venkateswarlu, B., (2011). Role of microorganisms in adaptation of agriculture crops to abiotic stresses. World J. Microbiol. Biotechnol., 27: 1231–1240 **(10 pages).**

Gupta, G.; Parihar, S.S.; Ahirwar, N.K.; Sneni, S.K.; Singh, V., (2015). Plant growth promoting Rhizobacteria (PGPR): Current and future prospects for development of sustainable agriculture. J. Microbiol. Biochem., 7: 96–102 **(7 pages).**

Gururani, M.A.; Upadhyaya, C.P.; Baskar, V.; Venkatesh, J.; Nookaraju, A.; Park, S.W., (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. J. Plant Growth Regulation. 32: 245–258 **(14 pages).**

Gusain, Y.S.; Singh, U.S.; Sharma, A.K., (2015). Bacterial mediated amelioration of drought stress in drought tolerant and susceptible cultivars of rice (Oryza sativa L.). Afr. J. Biotechnol., 14(9): 764–773 **(10 pages).**

GVR, (2020). Grand View Research Biofertlizers market analysis by product (nitrogen fixing, phosphate solubilizing), by application (seed treatment, soil treatment) and segment forecasts to 2022 2015. 1-11 **(11 pages).**

Habib, S.H.; Kausar H.; Saud H.M., (2016). Plant growth-promoting rhizobacteria enhance salinity stress tolerance in okra through ROS-scavenging enzymes. Biomed. Res. Int., 2016: 1-11 **(11 pages).**

Hafiz, A.S.; Tahir, Q.G.; Huijun, W.; Waseem, R.; Alwina, H.; Liming, W.; Massawe, V.C.; Xuewen, G., (2017). Plant Growth Promotion by Volatile Organic Compounds Produced by Bacillus subtilis SYST2, Front. Microbiol., 8: 1-11 **(11 pages).**

Heidari, M.; Golpayegani, A., (2012). Effects of water stress and inoculation with plant growth promoting rhizobacteria (PGPR) on antioxidant status and photosynthetic pigments in basil (Ocimum basilicum L.). J. Saudi Soc. Agric. Sci., 11: 57–61 **(5 pages).**

Herrmann, L.; Lesueur, D., (2013). Challenges of formulation and quality of biofertlizers for successful inoculation. Appl. Microbiol. Biotechnol., 97: 8859–8873 **(15 pages).**

Hildebrandt, T.M.; Nesi, A.N.; Araújo, W.L.; Braun, H.P.,(2015). Amino acid catabolism in plants. Mol. Plant., 8: 1563–1579 **(17 pages).**

Ijaz, M.; Ali, Q.; Ashraf, S.; Kamran, M.; Rehman, A., (2019). Development of future bioformulations for sustainable agriculture: Kumar, V.; Prasad, R.; Kumar, M.; Choudhary, D.K.(Eds.), In microbiome in plant health and disease: challenges and opportunities, Springer., Singapore. 421–446 **(26 pages).**

Ikhwan, A.; Nurcholis, M., (2020). Bacteria analysis as plastic biodegradation agent and biofertilizers. Earth and Environmental Science., 458: 1-8 **(8 pages).**

Imran, A.; Zabta, K.; Shinwaria; Shomaila, S.; Shaheen, S., (2019). Plant beneficial endophytic bacteria: mechanisms, diversity, host range and genetic determinants. Microbiol. Res., 221: 36–49**(14 pages).**

Indra, B.; Vijay, S.; Meena; Sanjay, K., (2014). Importance and application of potassic biofertilizer in Indian agriculture. Int. Res. J. Biol. Sci., 3(12): 80-85 **(6 pages).**

Isha, S.; Navdeep, K.; Pratap, K.P., (2017). Brassinosteroids: A promising option in deciphering remedial strategies for abiotic stress tolerance in rice .J. Front. Plant Sci., 8: 1-17**(17 pages).**

Jayaraj, R.; Megha, P.; Sreedev, P., (2016). Organochlorine pesticides, their toxic effects on living organisms and their fate in the environment. Interdiscip. Toxicol., 9: 90-100 **(11 pages).**

Jehangir, I.A.; Mir, M.A.; Bhat, M.A.; Ahangar, M.A., (2017). Biofertlizers an approach to sustainability in agriculture: A Review. Int. J Pure App. Biol. Sci., 5: 327-334 **(8 pages).**

Jha, B.; Gontia, I.; Hartmann, A., (2012). The roots of the halophyte salicornia brachiata are a source of new halotolerant diazotrophic bacteria with plant growth-promoting potential. Plant Soil., 356: 265–277 **(13 pages).**

Josef, K.; Fuensanta, C.; Antonio, R., (2010). An AM fungus and a PGPR intensify the adverse effects of salinity on the stability of rhizosphere soil aggregates of lactuca sativa. Soil Biol. Biochem., 42: 429-434 **(6 pages).**

Jyoti, R.; Nirmal, Y.; Veena, P.,(2020). Role of rhizospheric microbial diversity in plant growth promotion in maintaining the sustainable agrosystem at high altitude regions. Recent Adv. Microbial Divers., 7: 147-196 **(50 pages).**

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 Biotechnol., 4: 179–183 **(5 pages).**

Karmakar, P.; Sharma, D.; Das, P.; Saha, A.K., (2018). Phosphate solubilizing capacity and siderophore production by arthroderma cuniculi dawson 1963 isolated from rhizospheric soil. Res. J. Life Sci., 4(3): 330-336 **(7 pages).**

Kaymak, D.C., (2010). Potential of PGPR in agricultural innovations, in: Maheshwari, D.K. (Ed.), Plant Growth and Health Promoting Bacteria. Springer-Verlag., Germany. 3: 45-79 **(35 pages).**

Khan, A.L.; Waqas, M.; Kang, S.M., (2014). Bacterial endophyte Sphingomonas sp. LK11 produces gibberellins and IAA and promotes tomato plant growth. J. Microbiol., 52: 689–695 **(7 pages).**

Khan, W.U.; Ahmad, S.R.; Yasin, N.A.; Ali, A.; Ahmad, A.; Akram, W., (2017). Application of bacillusmegaterium MCR-8 improved phytoextraction and stress alleviation of nickel in Vinca rosea. Int. J. Phytoremed., 19: 813–824 **(12 pages).**

Khatibi, R., (2011).Using sulfur oxidizing bacteria and P solubilizing for enhancing phosphorous availability to raphanus sativus. Afr. J. Plant Sci., 5: 430–435 **(6 pages).**

Kumar, M.; Puri, A., (2012). A review of permissible limits of drinking water. Indian J. Occup. Environ. Med., 16: 40-44 **(5 pages).**

Kumar, R.; Prakash, O., (2019). The impact of chemical fertilizers on our environment and ecosystem. Res. Trends Environ. Sci., 5: 69-86 **(18 pages).**

Kumara, A.;Patelc, J.S.;Meenad, V.S.;Ramtekee, P.W., (2019). Plant growth-promoting rhizobacteria: strategies to improve abiotic stresses under sustainable agriculture.J. Plant Nutrition., 42:1402–1415**(14 pages).**

Kumaravel, S.;Thankappan, S.;Raghupathi, S.;Uthandi, S., (2018). Draft genome sequence of plant growth-promoting and drought-tolerant bacillus altitudinis FD48, isolated from rice phylloplane. Genome Announc., 6: e00019-00018**(2 pages).**

Kumari, S.;Vaishnav, A.;Jain, S.;Choudhary, D.K.; Sharma, K.P.,(2016). In vitro screening for salinity and drought stress tolerance in plant growth promoting bacterial strains. Int. J. Agric. Life Sci., 2:60–66 **(7 pages).**

Laetitia, H.; Didier, L.,(2013). Challenges of formulation and quality of biofertlizers for successful inoculation. Appl. Microbiol. Biotechnol.,97: 8859–8873 **(15 pages).**

Lavania, M.; Nautiyal, C., (2013). Solubilization of tricalcium phosphate by temperature and salt tolerant Serratia marcescens NBRI1213 isolated from alkaline soils. Afr. J. Microbiol. Res., 7: 4403–4413 **(11 pages).**

Leite, M.C.; Pereira, A.P.; Souza, A.J.D.; Andreote, F.D.; Freire, F.J.; Sobral, J. K., (2018). Bioprospection and genetic diversity of endophytic bacteria associated with cassava plant. Rev. Caatinga., 31: 315–325 **(11 pages).**

Lim, S.P.; Pandikumar, A.; Huang, N.M.; Lim, H.N.; Gu, G.; Ma, T.L., (2014). Promotional effect of silver nanoparticles on the performance of N-doped TiO2 photoanode-based dye-sensitized solar cells. RSC Adv., 4: 48236–48244 **(9 pages).**

Lima, C.E.P.; Fontenelle, M.R.; Borba, L.R.; Soares, D.C.; Moita, A.W.; Daniel, B.Z.; Ronessa B.S.; Carlos A.L.,(2015). Short-term changes in fertility attributes and soil organic matter caused by the addition of EM Bokashis in Two Tropical Soils. Int. J. Agronomy., 2015: 1-10 **(10 pages).**

Liu, J.; Mehdi, S.; Topping, J.; Friml, J.; Lindsey, K., (2013). Interaction of PLS and PIN and hormonal crosstalk in arabidopsis root development. Front. Plant Sci., 4: 1-8 **(8 pages).**

Liu, F.; Xing, S.; Ma, H., (2013). Cytokinin-producing, plant growth-promoting rhizobacteria that confer resistance to drought stress in Platycladus orientalis container seedlings. Appl. Microbiol. Biotechnol.,97: 9155–9164**(10 pages).**

Luke, A.; Moe, (2013).Amino acids in the rhizosphere: from plants to microbes. Am. J. Botany., 100(9): 1692–1705 **(14 pages).**

Mahanty, T.; Bhattacharjee, S.; Goswami, M.; Bhattacharyya, P.N.; Das, B.; Gosh, A.; Tribedi, P., (2017). Biofertlizers: a potential approach for sustainable agriculture development. Environ. Sci. Pollut.Resa.,24: 3315–3335 **(21 pages).**

Malusa, E.; SasPaszt, L.; Ciesielska, J., (2012). Technologies for beneficial microorganisms inocula used as biofertlizers. Sci. World J., 2012: 1-13 **(13 pages).**

Martínez, G.V.; Bautista, C. A.; Martínez, L.; Soledad, P., (2018). First report of phosphate-solubilizing bacteria associated with agave angustifolia. Int. J. Agric. Biol., 20: 1298–1302 **(5 pages).**

Martínez, O.; Jorquera, M.A.; Crowley, D.E.; Gajardo, G.; Mora, M.L., (2010). Mechanisms and Practical Considerations Involved In Plant Growth Promotion by Rhizobacteria. J. Soil Sci. Plant Nutr., 10: 293-319 **(27 pages).**

Mazid, M.; Khan, T.A.; Mohammad, F., (2011). Potential of NO and H2O2 as signaling molecules in tolerance to abiotic stress in plants. J. Ind. Res. Technol., 1: 56-68 **(13 pages).**

Meena, V.S.; Maurya, B.R.; Verma, J.P.; Aeron, A.; Kumar, A.; Kim, K., (2015). Potassium solubilizing rhizobacteria (KSR): Isolation, identification, and K-release dynamics from waste mica. Ecol. Eng., 81: 340-347 **(8 pages).**

Mia, M.B.; Shamsuddin, Z., (2010). Nitrogen fixation and transportation by rhizobacteria: a scenario of rice and banana. Int. J. Bot., 6: 235–242 **(8 pages).**

Mishra, D.J.; Rajivir, S.; Mishrra, U.K.; Kumar, S.S., (2013). Role of biofertlizers in organic agriculture: a review. Res. J. Recent Sci., 2: 39-41 **(3 pages).**

Mussa, A.; Million, T.; Assefa, F., (2018). Rhizospheric bacterial isolates of grass pea (Lathyrus sativus L.) endowed with multiple plant growth promoting traits. J. Appl. Microbiol., 125: 1786-1801 **(16 pages).**

Naeem, K.; Asghari, B.; José, A.C.,(2020). Role of beneficial microorganisms and salicylic acid in improving rainfed agriculture and future food safety. Microorganisms., 8(1018): 1-22 **(22 pages).**

Nadeem, S.M.; Zahir, Z.A.; Naveed, M.; Ashraf, M., (2010). Microbial ACC-deaminase; prospects and applications for inducing salt tolerance in plants. Crit. Rev. Plant Sci., 29: 360–393 **(34 pages).**

Narendra, K.; Rakesh, K.; Sudhir, K.; Vijay, S.M.; Meena, V.S., (2017). Nutrient solubilizing microbes (NSMs): It's role in sustainable crop production. Agriculturally important microbes for sustainable agriculture., 25-61 **(37 pages).**

Nejat, N; Mantri, N., (2017). Plant immune system: crosstalk between responses to biotic and abiotic stresses the missing link in understanding plant defence. Mol. Biol., 23: 1-16 **(16 pages).**

Nkoa, R., (2014). Agricultural benefits and environmental risks of soil fertilization with anaerobic digestates: a review. Agronomy Sustain Dev., 34: 473–492 **(20 pages).**

Owen, D.; Williams, A.P.; Griffith, G.W.; Withers, P.J.A., (2015). Use of commercial bioinoculants to increase agricultural production through improved phosphorus acquisition. Appl. Soil Ecol., 86: 41–54 **(14 pages).**

Palaniyandi, S.A.; Damodharan, K.; Yang, S.H.; Suh, J.W., (2014). Streptomyces sp. strain PGPA39 alleviates salt stress and promotes growth of 'Micro Tom' tomato plants. J. Appl. Microbiol., 117: 766–773 **(8 pages).**

Pahari, A.; Mishra, B., (2017). Characterization of siderophore producing Rhizobacteria and its effect on growth performance of different vegetables Pepper. Int. J. Curr. Microbiol. App. Sci., 6: 1398–1405 **(8 pages).**

Pesce, S.; Bouchez, A.; Montuelle, B., (2011). Effects of organic herbicides on phototrophic microbial communities in freshwater ecosystems. Rev. Environ. Contam. Toxicol., 214: 87-124 **(38 pages).**

Pimentel, D.; Burgess, M., (2014). Environmental and economic costs of the application of pesticides primarily in the United States, in: Pimentel, D.; Peshin, R., (Eds.), Integrated Pest Manage., 47–71 **(25 pages).**

Porcel, R.; Zamarreño, Á.M.; García-Mina, J.M.; Aroca, R., (2014). Involvement of plant endogenous ABA in bacillus megaterium PGPR activity in tomato plants. BMC Plant Biol., 14(36): 1-12 **(12 pages).**

Prajapati, K.; Modi, H., (2016). Growth promoting effect of potassium solubilizing Enterobacter hormaechei (KSB-8) on cucumber (Cucumis sativus) under hydroponic conditions. Int. J Adv. Res. Biol. Sci., 3: 168-173 **(6 pages).**

Prashant, P.; Jambhulkar; Pratibha, S.; Rakesh, Y., (2016). Delivery systems for introduction of microbial inoculants, in: Singh, D.P., (Eds.), Microbial. Inoculants sustainable Agric. productivity., 2: 199-218 **(20 pages).**

Qiu, Z.; Egidi, E.; Liu, H.; Kaur, S.; Singh, B.K., (2019). New frontiers in agriculture productivity: Optimised microbial inoculants and in situ microbiome engineering. Biotechnology., 37(107371): 1-11 **(11 pages).**

Radzki, W.; Gutierrez, F.J.; Algar, E., (2013). Bacterial siderophores efficiently provide iron to iron-starved tomato plants in hydroponics culture. Antonie Van Leeuwenhoek., 104: 321–330 **(10 pages).**

Rahdari, P.; Tavakoli, S.; Hosseini, S.M., (2012). Studying of salinity stress effect on germination, proline, sugar, protein, lipid and chlorophyll content in purslane (Portulaca oleracea L.) leaves. J. Stress Physiol. Biochem., 8(1): 182–193 **(12 pages).**

Raheem, S.; Abdul, L.K.; Saqib, B.; Muhammad, C.; Sang, K.; Jung, L., (2017). Inoculation of abscisic acid-producing endophytic bacteria enhances salinity stress tolerance in Oryza sativa. Environ. Exp. Botany., 136: 68-77 **(10 pages).**

Rassem, A.M.;David, A.A., (2017). In-Vitroe evaluates antagonism strains of actinomycetes on growth strains of Rhizobium. World Journal of pharmacy and pharmaceutical sciences., 6(3): 894-903 **(10 pages).**

Reddy, P.P., (2014). Plant growth promoting rhizobacteria for horticultural crop protection. Pest Manage., 35-54 **(20 pages).**

Rifat, H.; Safdar, A.; Ummay, A.; Rabia, K.; Iftikhar, A., (2010). Soil beneficial bacteria and their role in plant growth promotion: a review.Ann.Microbiol.,60: 579–598 **(20 pages).**

Rojan, P.; John, R.D.; Tyagi, S.K.; Brar, R.Y.; Surampalli; Danielle, P., (2011).Bio-encapsulation of microbial cells for targeted agricultural delivery. Critical Rev. Biotechnol., 31(3): 211-226 **(16 pages).**

Saha, M.; Maurya, B.R.; Meena, V.S.; Bahadur, I.; Kumar, A., (2016). Identification and characterization of potassium solubilizing bacteria (KSB) from Indo-Gangetic Plains of India. Biocatal. Agric. Biotechnol., 7: 202-209 **(8 pages).**

Sahai, P.; Kumar, V., (2017). Carriers and their role in plant agrosystem, in: Kumar, V., Kumar, M., Sharma, S., Prasad, R., (Eds.), Probiotics and Plant Health. Springer., Singapore. 291–315 **(25 pages).**

Saharan, B.S.; Nehra, V., (2011). Plant growth promoting rhizobacteria: A critical review. Life Sci. Med. Res., 21: 1–30 **(30 pages).**

Sahu, P. K.; Brahmaprakash, G.P., (2016).Formulations of biofertlizers – approaches and advances, in: Singh, D.P., (Eds.), Microbial inoculants in sustainable agricultural productivity, Springer., India. 2: 179-198 **(20 pages).**

Saikia, J.; Sarma, R.K.; Dhandia, R.; Yadav, A.; Bharali, R.; Gupta, V.K.; Saikia, R., (2018). Alleviation of drought stress in pulse crops with

ACC deaminase producing rhizobacteria isolated from acidic soil of Northeast India. Sci. Rep., 8(3560): 1-16 **(16 pages).**

Salme, T.; Lawrence, B.; Julia, M.; Anthony, M.; Anne, C.; Aronsson, (2017). Perspectives and challenges of microbial application for crop Iimprovement. Front. Plant Sci., 8(49): 1-10 **(10 pages).**

Samer, S.; Lidia, F.; Hayet, D.; Samir, T.; Abdeltif, A., (2012). Bioaugmentation: possible solution in the treatment of bio-refractory organic compounds (Bio-ROCs). Biochem. Eng. J., 69: 75–86 **(12 pages).**

Sandhya, V.S.; Ali, S.Z.; Grover, M.; Reddy, G.; Venkateswarlu, B., (2010). Effect of plant growth promoting Pseudomonas spp. on compatible solutes, antioxidant status and plant growth of maize under drought stress. Plant Growth Regul., 62(1): 21–30 **(10 pages).**

Sang, K.; Radhakrishnan, R.; Latif, A.; Kim, M.J.; Jaeman, P.; BoRa, K.; Dong, S.; Jung, L., (2014). Gibberellin secreting rhizobacterium, pseudomonas putida H-2-3 modulates the hormonal and stress physiology of soybean to improve the plant growth under saline and drought conditions. Plant Physiol Biochem., 84: 115–124 **(10 pages).**

Santhosh, K.M.; Chandramohan, G.; Mamta, P.; Santosh, K., (2018). Role of bio-fertilizers towards sustainable agricultural development: A review. J. Pharmacognosy Phytochem., 7(6): 1915-1921 **(7 pages).**

Savci, S., (2012). An agricultural pollutant: chemical fertilizer. Int. J. Environ. Sci. Technol., 3: 77–80 **(4 pages).**

Selvakumar, G.; Panneerselvam, P.; Ganeshamurthy, A.N., (2012). Bacterial mediated alleviation of abiotic stress in crops, in: Dinesh, K.M. (Eds.), Bacteria in agrobiology: Stress Manage. Springer. Heidelberg. 205–224**(20 pages).**

Shaheen, S.; Sundari, K., (2013). Exploring the applicability of PGPR to remediate residual organophosphate and carbamate pesticides used in agriculture fields. Int. J. Agric. Food Sci. Technol., 4: 947–954 **(8 pages).**

Shambhavi, A.S.; Rakesh, K.; Sharma, S.P.; Gayatri, V.; Sharma, R.P.; Sanjay, K., (2017). Long-term effect of inorganic fertilizers and amendments on productivity and root dynamics under maize-wheat intensive cropping in an acid. J. Appl. Nat. Sci., 9 (4): 2004 -2012 **(9 pages).**

Shaik, Z.A.; Vardharajula, S.; Linga, V.R., (2013). Isolation and characterization of drought-tolerant ACC deaminase and exopolysaccharide-producing fluorescent Pseudomonas sp. Ann. Microbiol., 1-10 **(10 pages).**

Shaikh, S.; Saraf, M., (2017). Zinc biofortification: Strategy to conquer zinc malnutrition through zinc solubilizing PGPR's. Biomed. J. Sci. Tech. Res.,1: 224–226 **(3 pages).**

Sharma, P.; Khanna, V.; Kumari, P., (2013). Efficacy of aminocyclopropane-1-carboxylic acid (ACC) - deaminase-producing rhizobacteria in ameliorating water stress in chickpea under axenic conditions. Afr. J. Microbiol. Res., 7(50): 5749–5757 **(9 pages).**

Shintu, P.V.; Jayaram, K.M., (2015). Phosphate solubilising bacteria (Bacillus polymyxa)-an effective approach to mitigate drought in tomato (Lycopersicon esculentum Mill). Tropic Plant Res., 2:17–22 **(6 pages).**

Shinwari, K.I.; Shah, A.U.; Afridi, M.I.; Zeeshan, M.; Hussain, H.; Hussain, J.; Ahmad, O., (2015). Application of plant growth promoting rhizobacteria in bioremediation of heavy metal polluted soil. Asian J. Multidiscip. Stud., 3: 179–185 **(7 pages).**

Siddikee, M.A.; Glick, B.R.; Chauhan, P.S.; Jong, Y.W., (2011). Enhancement of growth and salt tolerance of red pepper seedlings (Capsicum annuum L.) by regulating stress ethylene synthesis with halotolerant bacteria containing 1-aminocyclopropane-1-carboxylic acid deaminase activity. Plant Physiol. Biochem., 49: 427–434 **(8 pages).**

Singh, J.S.; Pandey, V.C.; Singh, D.P., (2011). Efficient soil microorganisms: a new dimension for sustainable agriculture and environmental development. Agric. Ecosyst. Environ., 140: 339–353 **(15 pages).**

Singh, R.; Kumar, A.; Singh, M.; Pandey, K.D., (2019). Isolation and characterization of plant growth promoting rhizobacteria from Momordica charantia L, in: Singh, A.K., Kumar, A., Singh, P.K. (Eds.), PGPR Amelioration in Sustainable Agriculture. Woodhead Publishing., United Kingdom. 11: 217–238 **(22pages).**

Sinha, R.K.; Valani, D.; Chauhan, K.; Agarwal, S., (2014). Embarking on a second green revolution for sustainable agriculture by vermiculture biotechnology using earthworms: reviving the dreams of Sir Charles Darwin. Int. J. Agric. Health Saf., 1: 50–64**(15 pages).**

Sokolova, M.G.; Akimova, G.P.; Vaishlia, O.B., (2011). Effect of phytohormones synthesized by rhizosphere bacteria on plants. Prikl. Biokhim. Mikrobiol., 47: 302–307 **(6 pages).**

Son, J.S.; Sumayo, M.; Hwang, Y.J.; Kim, B.S.; Ghim, S.Y., (2014). Screening of plant growth promoting rhizobacteria as elicitor of systemic resistance against grey leaf spot dieses in pepper. Appl. Soil Ecol., 73: 1–8 **(8 pages).**

Srividya, S.; Sasirekha, B., (2017). Role of plant growth-promoting rhizobacteria (PGPR) in the improvement of vegetable crop production under Stress Conditions, in: Zaidi, A.; Khan, (Eds.), Microbial strategies for vegetable production. Springer international publishing., New York.81-97 **(17pages).**

Stephane, C.; Marcel, G.A.; Angela, S., (2010). Climate change effects on beneficial plant-microorganism interactions. FEMS. Microbiol. Ecol., 73: 197–214 **(18 pages).**

Subhashini, D.V., (2015). Growth promotion and increased potassium uptake of tobacco by potassium-mobilizing bacterium frateuria aurantia grown at different potassium levels in vertisol. Commun. Soil Sci. Plant Anal., 46(2): 210-220 **(11pages).**

Suman; Ram, P.; Jain, V.K.; Ajit, V., (2010). Role of nanomaterilas in symbiotic fungus growth enhancement. Curr. Sci., 99: 1189–1191 **(3 pages).**

Sun, R.; Zhang, X.X.; Guo, X.; Wang, D.; Chu, H., (2015). Bacterial diversity in soils subjected to long-term chemical fertilization can be more stably maintained with the addition of livestock manure than wheat straw. Soil Biol. Biochem., 88: 9–18 **(10 pages).**

Teotia, P.; Kumar, V.; Kumar, M.; Shrivastava, N.; Varma, A., (2016). Rhizosphere microbes: potassium solubilization and crop productivity-present and future aspects, in: Meena, V.; Maurya, B.; Verma, J.; Meena, R., (Eds.), Potassium Solubilizing microorganisms for sustainable agriculture. Springer., New Delhi. 2016: 315–325 **(11 pages).**

Timmusk, S.; Daim, I.A.A.; Copolovici, L.; Tanilas, T.; K€annaste, A.; Behers, L.; Nevo, E.; Seisenbaeva, G.; Stenstr€om, E.; Niinemets, Ü., (2014). Microbial biofilms: Functional annotation and potential applications in agriculture and allied sectors. Applications in biotechnology. Curr. Sci., 89:47–57**(11 pages).**Trabelsi, D; Mhamdi, R., (2013). Microbial inoculants and their impact in microbial soil microbial communities: a review. Biomed. Res. Int., 11: 81-97 **(17 pages).**

Tri, C.S.; Laily, M., (2016). Solubilization of Potassium Containing Mineral by Microorganisms from Sugarcane Rhizosphere. Agric. Agric. Sci. Procedia., 9: 108 – 117 **(10 pages).**

Umesh, P.S., (2015). Plant Microbe Interaction in Rhizosphere. Int. J. Graduate Res. Rev., 1: 110-124**(15 pages).**

Vacheron, J.; Desbrosses, G.; Bouffaud, M.L.; Touraine, B.; Moënne, L.Y.; Muller, D., (2013). Plant growth-promoting rhizobacteria and root system functioning. Front. Plant Sci.,4: 1-19 **(19 Pages).**

Vardharajula, S.; Zulfikar, A.S.; Grover, M.; Reddy, G.; Bandi, V., (2011). Drought-tolerant plant growth promoting bacillus spp. effect on growth, osmolytes, and antioxidant status of maize under drought stress. J. Plant Interact., 6: 1–14 **(14 pages).**

Vassilev, N.; Vassilev, M.; Lopez, A.; Martos, V.; Reyes, A.; Maksimovic, I.; EichlerLöbermann, B.; Malusá, E., (2015). Unexploited potential of some biotechnological techniques for biofertlizers production and formulation. Appl. Microb. Biotechnol.,99: 4983–4996 **(14 pages).**

Verma, P.; Yadav, A.N.; Kumar, V.; Singh, D.P.; Saxena, A.K., (2017). Beneficial plant-microbes interactions: biodiversity of microbes from diverse extreme environments and its impact for crop improvement. In: Singh, D.P.; Singh, H.B.; Prabha, R. (Eds.), Plant-Microbe Interactions in Agro-Ecological Perspectives. Springer. Singapore. 2: 543–580 **(38 pages).**

Verma, S.; Nizam, S.; Verma, P.K., (2013). Biotic and abiotic stress signalling in plants. Stress signaling in plants: Genomics and proteomics perspective., 1: 25-49 **(25 pages).**

Verma, M.; Mishra, J.; Arora, N.K., (2019). Plant growth-promoting rhizobacteria: Diversity and applications, in: Sobti, R.; Arora, N.K.; Kothari, R., (Eds.), Environmental biotechnology: For sustainable future. Springer. Singapore. 129–173 **(45 pages).**

Veselova, S.V.; Nuzhnaya, T.V.; Maksimov, I.V., (2015). Role of jasmonic acid in interaction of plants with plant growth Promoting rhizobacteria during fungal pathogenesis, in: Lucille, M., (Eds.), Jasmonic acid. Nova Sci., New York. 3: 33-66 **(34 pages).**

Walsh, E.; Donnell, K.P., (2012). The influence of added organic matter on soil physical, chemical, and biological properties: a small-scale and short-time experiment using straw. Archives agronomy soil Sci., 58(1): 201-205 **(5 pages).**

Wellesley, M.A., (2014). BCC research global market for biopesticides; Market Res. reports. 2014:1–137**(137 pages).**

Weekley, J.; Gabbard, J.; Nowak, J., (2012). Micro-level management of agricultural inputs: emerging approaches. Agronomy.,2: 321–357 **(37 pages).**

Wu, H.; Wu, L.; Wang, J.; Zhu, Q.; Lin, S.; Xu, J.; Zheng, C.; Chen, J.; Qin, X.; Fang, C.; Zhang, Z.; Azeem, S.; Lin, W., (2016). Mixed phenolic acids mediated proliferation of pathogens talaromyces helicus and kosakonia sacchari in continuously monocultured radix pseudostellariae rhizosphere soil. Front Microbiol., 7(335): 1-14 **(14 pages).**

Xiurong, W.; Qiang, P.; Fengxian, C.; Xiaolong, Y.; Hong, L., (2011). Effects of co-inoculation with arbuscular mycorrhizal fungi and rhizobia on soybean growth as related to root architecture and availability of N and P, Mycorrhiza. 21: 173–181 **(9 pages).**

Yadav, A.N.; Kumar, R.; Kumar, S.; Kumar, V.; Sugitha, T.; Singh, B.; Chauhan, V.S.; Dhaliwal, H.S.; Saxena, A.K., (2017). Beneficial microbiomes: biodiversity and potential biotechnological applications for sustainable agriculture and human health. J. Appl. Biol. Biotechnol., 5: 1–13 **(13 pages).**

Yadav, A.N.; Kumar, V.; Prasad, R.; Saxena, A.K.; Dhaliwal, H.S., (2018). Microbiome in Crops: diversity, distribution and potential role in crops improvements, in: Prasad, R.; Gill, S.S.; Tuteja, N., (Eds.), Crop improvement through microbial biotechnology. Elsevier, USA. 305–332 (**28 pages).**

Yan, X.; Gong, W., (2010). The role of chemical and organic fertilizers on yield, yield variability and carbon sequestration results of a 19-year experiment. Plant soil. 331: 471–480 **(10 pages).**

Yang, S.X.; Liao, B.; Li, J.T.; Guo, T.; Shu, W.S., (2010). Acidification, heavy metal mobility and nutrient accumulation in the soil–plant system of a revegetated acid mine wasteland. Chemosphere. 80: 852–859 **(8 pages).**

Yong, S.P.; Swarnalee, D.; Mina, A.; Jos, M.; Raaijmakers; Kyungseok P., (2015). Promotion of plant growth by Pseudomonas fluorescens strain SS101 Q4 via novel volatile organic compounds. Biochem. Biophys. Res. Commun., 461(2): 361-365 **(5 pages).**

Zhang, H.; Murzello, C.; Sun, Y.; Kim, M.S.; Xie, X.; Jeter, R.M.; Zak, J.C.; Dowd, S.E.; Paré, P.W., (2010). Choline and osmotic-stress tolerance induced in arabidopsis by the soil microbe bacillus subtilis (GB03). Mol. Plant-Microbe Interact., 23(8): 1097–1104 **(8 pages).**

Zhang, J.; Wang, P.; Fang, L.; Zhang, Q.A.; Yan, C.; Chen, J., (2017). Isolation and characterization of phosphate-solubilizing bacteria from mushroom residues and their effect on tomato plant growth promotion. Pol. J. Microbiol., 66: 57–65 **(9 pages).**

Zhenyu, C.; Owen, Z.; Woody, J.; Conkey, M.; Bernard, R., (2012). Combined effects of the plant growth-promoting bacterium pseudomonas putida UW4 and salinity stress on the Brassica napus proteome. Appl. Soil Ecol., 61: 255–263 **(9 pages).**

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