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REVIEW

Rhizobacteria mediated improvement of soil and plant health

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Rhizobacteria are root-associated bacteria, which have different type of relation with the plants like either cause disease or to improve their health. They play an important contribution in biodegradation of pesticides, phytoremediation of polluted soil by heavy metals, provide nutrients by producing siderophores, ammonia, nitrogen fixation, phosphate and potassium solubilization, acidification and redox changes to the plants. Rhizobacteria have ability to produce different types of bioactive compounds like antibiotics, volatile and growth promoting substances, which help plants to cope up with biotic and abiotic stresses.. Various antagonistic rhizobacteria are applied in the field to control the different diseases of crops. The ability of bacteria to bioremidate these pesticides mainly based on their biodegradation activity. The result indicates massive potential of species of *Bacillis, Pseudomonas, Panteao* and many more to degrade pesticides used in agriculture. Hence it is necessary to select the potential rhizobacteria to obtain benefit of them to have it well-characterized. However, further research on plant growth promoting, antagonistic and biodegradation activities through these bacteria is utmost require if these strategies are to be implemented for betterment of plant and soil health.

Key words: Antagonistic, PGPR, plant health, rhizobacteria, soil health,

INTRODUCTION

Rhizosphere is a zone of plant root system surrounded by soil with maximum activity of microbes. The “rhizobacteria” term is commonly used for those useful bacteria present in the rhizosphere and has ability to colonize the root environment. The rhizosphere is divided in to three different parts such as (i) the rhizospheric soil, (ii) the rhizoplane, and (iii) the root itself. The rhizospheric soil zone is regulated by roots which release various substrates and that directly affect the activities of microbes. The rhizoplane is the root surface that strongly binds soil particles where microbes colonize approximately 10–1000 times higher than in bulk soil. The function of plant root is to provide mechanical support, facilitate nutrient and water uptake, the roots synthesize, accumulate, and secrete a diverse group of root exudates.

The plant growth promoting rhizobacteria (PGPR) poses three peculiar characteristics such as (a) they must have ability to to colonize the root or any other parts of the plant (b) when applied as probiotic, they must have ability to multiply, survive, and compete with other native microflora at least for the time needed to express their plant promotion activities and (c) they must have ability to promote growth of the plant.

Presently, agricultural production is dependent on the large-scale use of chemical fertilizers and they play major role in modern agriculture, because they are main source of essential plant nutrients like nitrogen, phosphorus, and potassium. But the excess use of these fertilizers for increasing production of the crop leads to harmful effect on the environment and the the soil (Adesemoye *et al.,* 2009). Hence, to maintain soil & plant health and save environment, an alternative approach like using efficient PGPR inoculants is an important strategy to achieve maximum benefits in terms of fertilizer and pesticides (Hungria *et al.,* 2013).

Diversity of rhizobacteria

PGPR may be divided into two main groups depend on their inhabitant *viz.,* ePGPR (extracellular plant growth promoting rhizobacteria) and iPGPR

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Table 1. Application of plant growth promoting bacteria to improve soil and plant health

Name of Microbe	Source/Host plant	Uses	References
Azotobacter aceae	*Fagopyrum esculentum*	Nitrogen fixation	Bhattacharyya and Jha, 2012
A. chroococcum	*Triticuma estivum*	P - solubilization	Damir *et al.,* 2011; Bhattacharyya and Jha, 2012
Bacillus amyloliquefaciens	*Solanum lycopersicum*	P- solubilization	Singh *et al.,* 2016
B. megaterium CY5, *B. mycoides* CA1	*Saccharum officinarum*	Nitrogen fixation	Singh *et al.,* 2020
B. megaterium	*Camellia sinensis*	P- solubilization	Stefanescu, 2015
B. megaterium var. *phosphaticum*	*Cucumis sativus*	P- solubilization	Stefanescu, 2015
B. subtilis DTBS-5	*S.lycopersicum*	P- solubilization	Singh *et al.,* 2012
Bradyrhizobium japonicum	*Glycine max*	Promote plant growth	Orlandini *et al.,* 2014
B. japonicum, Pseudomonas putida, P. chlororaphis,	*G. max*	P- solubilization	Rathore, 2015
Rhizobium leguminosarum	*Phaseolus vulgaris*	P- solubilization	Ahemad and Kibret, 2014
Achromobacter xylosoxidans	*Vigna radiata*	Influence plant homeostasis	Ma *et al.* 2009
Azospirillum brasilence , B. japonicum, B. subtilis	*Zea mays, G. max, S. officinarum*	Synthesize IAA and promote growth	Orlandini *et al.,* 2014; Singh *et al.,* 2012
A. chroococcum	*Brassica juncia*	Stimulate plant growth	Orlandini *et al.,* 2014
Azospirillium lipoferum	*T. aestivum*	Promote development of root system	Belimov *et al.,*2004
B. mucilaginosus	*Piper nigrum, C. sativus*	Improve potassium intake capacity	Liu *et al.,* 2012
P. aeruginosa	*Cicer arietinum*	Positively stimulate potassium and phosphorus uptake	Ahemad and Kibret, 2014
Pantoea agglomerans, Rahnella aquatilis, P. orientalis	*Oryza sativa*	Potassium solubilization	Khanghahi *et al.,* 2018
Burkholderia sp.	*Mikania micrantha*	Improve K- solubilization and uptake	Sun *et al.,* 2020
B. subtilis	*Brassica juncia*	Facilitate Nickel accumulation	Prathap and Ranjitha, 2015
B. megaterium	*Capsicum annuum*	Enhance plant growth, and yield	Bhatt and Maheshwari, 2020
P. fluorescens	*Medicago sativa*	Increase metabolism, sequester cadmium and degrade trichloroethylene	Ramadan *et al.,* 2016
Methylobacterium mesophilicum	*O.sativa, Eucalyptus globulus*	Influenc N-Acyl-homoserine lactone	Sanders *et al.,* 2000
P. putida	*Arabidopsis thaliana*	Improve utilization of plant secondary metabolites	Ahemad and Khan, 2012

(intracellular plant growth promoting rhizobacteria) (Martinez- Viveros *et al.,* 2010). ePGPR such as *Azotobacter, Serratia, Azospirillum, Bacillus, Caulobacter, Chromobacterium, Agrobacterium, Erwinia, Flavobacterium, Arthrobacter, Micrococcous, Pseudomonas, and Burkholderia* are present in rhizosphere or in the spaces between the cells of the root cortex. iPGPR such as *Allorhizobium, Bradyrhizobium, Mesorhizobium, Rhizobium*, and *Frankia* species are found inside the specialized nodular structures of the root cells and fix atmospheric nitrogen specifically for higher plants (Bhattacharyya and Jha, 2012). The rhizobacteria belong to diverse group of bacterial genera *viz., Acetobacter, Acinetobacter, Arthrobacter*, *Agrobacterium*, *Alcaligenes, Arthrobacter*, *Azoarcus*, *Azospirillum*, *Azotobacter*, *Azospirillum*, *Bacillus*, *Beijerinckia*, *Burkholderia*, *Cellulomonas, Caulobacter*, *Chromobacterium*, *Derxia*, *Erwinia*, *Enterobacter, Exiguobacterium, Flavigena, Flavobacterium*, *Gluconacetobacter, Herbaspirillum, Klebsiella, Methylobacterium, Micrococcous*, *Ochrobactrum, Paenibacillus*, *Pantoea, Pseudomonas*, *Rhodococcus*,

Serratia, *Stenotrophomonas*, and *Zoogloea* (Babalola, 2010; Singh *et al.,* 2016, 2020a; Singh *et al.,* 2017; Olanrewaju *et al.,* 2017; Yadav *et al.,* 2019) and enhance plant growth (Table 1) and biological control activity to suppress many plant diseases caused by fungi, bacteria, viruses and nematodes (Table 2). Besides these genera, Actinomycete genera such as *Streptomyces*, *Streptosporangium*, *Thermobifida* and *Micromonospora* are also responsible to promote growth of the plant and control many diseases plants.

Table 2. Rhzobacteria used for control various diseases of crops.

Bacteria	Disease and host	Causal organism	Effect	References
1. Fungal diseases				
Paenibacillus lentimorbus NRRL B-30488	Wilt of chickpea	*F. oxysporum* f. sp. *ciceri*	Reduced mortality of seedlings	Dasgupta *et al.,* 2006
B. subtilis	Powdery mildew of barley	*Erysiphe graminis* f. sp. *hordei*	Prevent powdery mildew	Prathap an d Ranjitha 2015
P. putida strain 30	Wilt of muskmelon	*F. oxysporum* f. sp. *melonis*	Control wilt disease	Bora *et al.,* 2004
Bacillus subtilis EU07	Wilt of tomato	*F. oxysporum* f. sp. *radicislycopersici*	Reduced the disease incidence	Baysal *et al.*, 2009
B. subtilis	Powdery mildew of Barley	*Erysipheg raminis* f. sp. *hordei*	Prevent disease	Oyedele *et al.,* 2014; Prathap and Ranjitha, 2015
P. fluorescens	root rot of green gram	*M. phaseolina*	Reduced the disease	Begum and Kumar, 2005
P. fluorescens 89B61, *B. pumilus* SE34	Late blight of tomato	*Phytophthora infestans*	Protected disease	Yan *et al.,* 2002
B. pumilus INR7	Green ear disease bajra	*Sclerospora graminicola*	Maximum vigor index	Niranjan Raj *et al.,* 2003
P. cepacia	Root rot of cucumber	*Pythium ultimum*	Prevented pathogen	Pérez-Montano *et al.*, 2014
P. cepacia	Sclerotium rot of French bean	*Sclerotium rolfsii*	Prevent *S. rolfsii*	Pérez-Montano *et al.*, 2014
P. cepacia	Root rot of cotton	*Rhizoctonia solani*	Helped fight the *R. solani*	Pérez-Montano *et al.*, 2014
P. fluorescens	Red rot of sugarcane	*Colletotrichum falcatum*	ISR against the disease	Viswanathan and Samiyappan, 2002
P. putida, Serratia marcescens	*Cucumis sativus*	*Colletotrichum* sp.	Prevent cucumber anthracnose	Ahemad and Khan, 2012; Rathore, 2015
P. fluorescens	Cotton	Fungal pathogen	Reduce damping off disease	Ramadan *et al.,* 2016; Santoro *et al.,* 2016
Paenibacillus polymyxa	*Sesamum indicum*	Fungal pathogen	Prevent fungal disease	Ngumbi and Kloepper, 2016
2. Bacterial diseases				
P. fluorescens	Leaf light of rice	*Xanthomonas oryzae* pv. *oryzae*	Induced resistance to bacterial blight	Vidhyasekaran *et al.,* 2001
Serratia J2, *Bacillus* BB11, *Pseudomonas*	Bacterial wilt of tomato	*R. solanacearum*	Suppressed wilt and increase yield of tomato	Guo *et al.,* 2004
B. cereus, B. pumilus, B. lentimorbus,	Black rot of cabbage	*X. compestris* pv. *compestris*	Reduced the disease	Massomo *et al.,* 2004
P. fluorescens	Wilt of brijnal	*R. solanacearum*	Reduced wilt incidence	Chakravarty and Kalita, 2011
P. putida	Wilt of potato	*R. solanacearum*	Reduced wilt incidence	Zeinab and Behrouz, 2015
Stenotrophomonas maltophilia	Wilt of potato	*R. solanacearum*	Reduced wilt incidence	Messiha *et al.,* 2007
B. amyloliquefaciens	Wilt of tomato	*R. solanacearum*	Reduced wilt disease	Singh *et al.,* 2016; Yadav *et al.,* 2019
B. subtilis	Wilt of tomato	*R. solanacearum*	Reduced wilt disease	Singh *et al.*, 2012
Paenibacillus elgii JCK-5075	Wilt of tomato	*R. solanacearum*	Reduced wilt disease	Le *et al.,* 2020
Enterobacter aerogenes	Wilt of tomato	*R. solanacearum*	Reduce wilt disease	Seleim *et al.,* 2011
3. Viral diseases				
B. amyloliquefaciens, B. subtilis, B. pumilus	Tomato Mottle	Tomato mottle virus	Reduce disease severity	Murphy *et al.,* 2000
B. subtilis, B. pumilus B.amyloliquefaciens	tomato mosaic	Cucumber mosaic cucumo virus	PGPR mediated ISR	Zehnder *et al.,* 2000
B. amyloliquefaciens	Tobacco mottle	Pepper mild mottle virus	Induced systemic resistance	Ahn *et al.,*2002
B. amyloliquefaciens	Tomato	Tomato motle virus	Prevent virus	Oteino *et al.,* 2015
4. Nematode diseases				
Pseudomonas fluorescens	Okra	*M. incognita*	Reduced the galling on okra.	Devi and Dutta, 2002
A. chroochoccum, Azospirillum sp.	Okra	*M. incognita*	Azotobacter reduced galling	Sharma and Mishra, 2003

The genetic diversity of 49 rhizospheric/endophytic bacterial isolates from maize was studied by using amplified ribosomal DNA restriction analysis (ARDRA), four restriction enzymes and 16S rRNA-sequence analysis. The result showed that 89% of rhizobacteria belonged to phylum *Proteobacteria (Achromobacter*, *Agrobacterium*, *Bordetella*, *Cupriavidus, Ochrobactrum*, *Pseudoxanthomonas* and *Stenotrophomonas* genera) *and only* 11% were related to phylum *Bacteroidetes* (*Chryseobacterium* and *Flavobacterium* genera) (Youseif, 2018). Recently, several advanced technique like next generation sequencing (NGS) tools metagenomics, metatranscriptomics, metaproteomics, and metabolomics were used to analyse divisity microbial community in the rhizosphere which led to know the structure, abundance, spatial distribution (White *et al.,* 2017). Moreover, the multi-omics analysis can be carried out for better capture the structure and diversity of the bacteria in the rhizosphere.

ROLE OF RHIZOBACTERIA

Improvement of soil health and plant growth promotion

The rhizobacteria survive in the rhizosphere for longer period and their ability to colonize plant roots is depending on the soil conditions and the exudates produced by the plant root. Several soil characteristics like such as soil pH, soil texture, soil moisture, microbial diversity, availability of nutrients, toxic metal concentrations, and soil disturbances caused by management practices affect the efficiency and success of rhizobacteria. The efficiency of rhizobacteria to colonize the root is also closely depended on their competition and survival in the rhizosphere, related gene expression and cell to cell communication (Beauregard *et al.,* 2013). Plant roots secret different types of root exudates that interfers interaction between the plant and bacteria under different environmental conditions which is considered as major factor in the efficiency of the inoculated bacteria (Carvalhais *et al.,* 2013). The compositions of root exudates are changed due to the physiological status and species of the plants (Kang *et al.,* 2010). The vast range of chemical compounds such as sugars, flavonoids, amino acids, etc. of root exudates changes the chemical and physical properties of soil. Thus, it controls the structure of rhizobacterial communities in the rhizospheric soil. Besides these factors, variation in climatic conditions is also influenced the effectiveness of PGPR. Various traits *viz.,* nitrogen fixation, mineralization of organic compounds, solubilization nutrients, and phytohormone production for potential rhizobacteria are described in Table 1 which can directly facilitate the growth and development of plants through mechanisms such as nutrient uptake or increases nutrient availability to the plants (Bhardwaj *et al.,* 2014, Singh *et al.,* 2016). The major functions of rhizobacteria are described below-

Nitrogen fixation

Biological nitrogen is carried out either with the symbiotic or non-symbiotic association between bacteria and plants. Symbiotic rhizobacteria which fix atmospheric N_2 in the soil are *Rhizobium* sp., *Azoarcus* sp., *Beijerinckia* sp., *Pantoea agglomerans*, and *Klebsiella* (Ahemad and Kibret, 2014; Kuan *et al.,* 2016). Species of *Allorhizobium*, *Azorhizobium*, *Bradyrhizobium*, *Mesorhizobium,* and *Rhizobium* of the family Rhizobiaceae are nitrogen-fixing endophytic rhizobacterial genera that colonize internally in roots of legume plants to form nodules and ultimately increase plant growth directly or indirectly. A combination of rhizobacterial species into the increase nodule formation in the plant as well as improve soil health. (Damam *et al.,* 2016; Singh *et al.,* 2020b). The *nif* gene is responsible for N_2-fixation along with other structural genes to activate the iron protein, donating electrons, biosynthesizing the iron molybdenum cofactor, and many other regulatory genes which are responsible for the synthesis and activity of the enzymes. However, Biological nitrogen-fixation process is mainly confined to legume crops but there is a lot of scope to explore same types of symbiotic or non-symbiotic association in non-legume crops for sustainable production and improvement soil health.

Phosphorus is the 2nd major essential nutrient after nitrigen needed by the plants and contains about 0.2% (w/w) of dry weight of plant (Maharajan *et al.,* 2018). It has a vital role in almost metabolic processes of plants *viz.,* signal transduction, energy transfer, respiration, photosynthesis, and macromolecular biosynthesis (Anand *et al.,* 2016). Approximately 0.05% (w/w) of phosphorus content is found in the soil in the form of inorganic P (Pi) and organic P (Po). However, the plants utilize P only 0.1% phosphate as monobasic (H_2PO_4") and dibasic (HPO_4"2) ions and delivering available P is a prohibitive factor for plant growth (Lambers and Plaxton, 2018). The low molecular weight organic acids synthesized by various soil bacteria solubilize inorganic phosphorus (Sharma *et al.,* 2013). The phosphate solubilising rhizobacteria are species of *Arthrobacter, Bacillus, Beijerinckia*, *Burkholderia, Enterobacter, Microbacterium Pantoea, Pseudomonas*, *Erwinia, Rhizobium, Mesorhizobium, Flavobacterium, Rhodococcus*, and *Serratia* and they are inoculated in the the soil or through biopriming of seeds and significantly increased plant growth and yield (Singh *et al.,* 2016, Chen and Liu, 2019; Yadav *et al.,* 2019).

Potassium solubilization

Potassium is the 3rd main essential macronutrient required for plant growth. Deficiency of K in plants mainly affects meager development of roots, reduction in seed production, poor growth rate, and a lesser yield. Approximately, > 90% of potassium is found in the soil in the form of insoluble rock and silicate minerals. Usually very low concentration of soluble potassium is available in the soil (Parmar and Sindhu, 2013). The potassium-solubilizing bacteria like *Acidothiobacillus* sp., *Bacillus edaphicus*, *B. mucilaginosus, Ferrooxidans* sp., *Pseudomonas* sp., *Burkholderia* sp., and *Paenibacillus* sp. have ability to solubilize potassium rock by producing and secreting organic acids. These bacteria may be used as a biofertilizers to increase K availability in the soils (Liu and Lian, 2012). Khanghahi *et al.* (2018) reported that *Pantoea agglomerans, Rahnella aquatilis* and, *Pseudomonas orientalis* isolated from from paddy soil and *Enterobacter* sp. from rubber tree soil (Dong *et al.,* 2019) had potential to solubilize the potassium. Species of *Mesorhizobium*, *Paenibacillus* and *Arthrobacter* isolated from rape rhizospheric soil showed potassium solubilizing ability (Xiao *et al.,* 2017). Thus, applying potassium-solubilising rhizobacteria as biofertilizers can reduce the use of inorganic ferlizer and support organic crop production.

Zinc solubilization

The micronutrient used in agriculture, Zinc (Zn) is a pivotal micronutrient, needed by the plants for their growth. Zinc deficiency in plants shows symptoms such as slow shoot growth, chlorosis, and retarded leaf size, affects root development, grain yield, water uptake and transport and susceptibility to heat, light and fungal infections (Tavallali *et al.,* 2010). Several rhizobacterial strains were identified which are mainly belong to genera *Pseudomonas, Ochrobacterum, Bacillus, Azospirillum, Azotobacter, Rhizobium, Stenotrophomonas, Serratia*, and *Enterobacteria* (Maleki *et al.,* 2011). Rhizobacteria solubilise the metal forms by protons, chelated ligands, and oxidoreductive systems present on the cell surface and membranes. *Bacillus megatarium* CDK25 showed markedly higher solubilization of ZnO (20.33 ppm) (Bhatt and Maheshwari, 2020). Zn-Solubilizing bacteria secrete different organic acids which solubilize the fixed form of Zinc to available form and increase plant growth, yield, and soil health.

Phytohormone production

The plant growth regulators (Phytohormones) are organic substances which promote, inhibit, or modify growth and development of plants at low concentrations (< 1 mM) (Damam *et al.,* 2016). Gibberellins, cytokinins, abscisic acid, ethylene, brassino steroids, and auxins are common hormones stimulate proliferation of root cells by by over producing lateral roots and root hairs with a consecutive increase in nutrient and water uptake (Sureshbabu *et al.,* 2016). The hormones such as auxins, gibberellins, kinetin, and ethylene are also produced by *B. subtilis, P. fluorescens, P. putida, P. aeruginosa, P. agglomerans Enterobacter asburiae, P. polymyxa, Stenotrophomonas maltophilia, Mesorhizobium ciceri, Klebsiella oxytoca, A. chroococcum*, *Rhodospirillum rubrum* and *R. leguminosarum* and stimulated the shoot and root growth of the plants (Ahemad and Kibret, 2014; Prathap and Ranjitha, 2015). If plant hormones produced by rhizobacteria is regularised, it could be a vital step to revolutionize crop production and improve the quality of the produce.

Siderophore production

Siderophores synthesized by rhizobacteria such as *Pseudomonas, Azotobacter, Bacillus, Enterobacter, Serratia, Azospirillum* and *Rhizobium* are low molecular weight (< 10 KD) iron chelating compounds and they are a major asset providing the plant with the required amount of iron. The siderophores are classified as hydroxamate, catecholate and mixed ligand siderophores (Dimpka, 2016). The ferric-siderophore complex plays a vital role in iron uptake by plants in the presence of other metals, such as nickel and cadmium (Beneduzi *et al.,* 2012). *Pseudomonas* sp. fulfils their irons requirement by utilizing the siderophores produced by other microbes present in the rhizosphere. *P. putida* utilizes heterologous siderophores produced by other microbes to incease the iron level available in the natural habitat (Rathore, 2015; Singh *et al.,* 2020b).

Exopolysaccharide production

A vast majority of bacteria such as *Rhizobium leguminosarum, Azotobacter vinelandii, Bacillus drentensis, Enterobacter cloacae, Agrobacterium* sp., *Xanthomonas* sp., and *Rhizobium* sp. biosynthesize exopolysaccharides (EPSs), that is a high molecular weight and biodegradable polymer. They are formed of monosaccharide residues and their derivatives (Sanlibaba and Cakmak, 2016). The main function of EPSs is to maintain water potential, aggregate soil particles, ensure obligate contact between plant roots and rhizobacteria and sustain the host under stress conditions like saline soil, dry weather, or water logging) or disease. Thus, they are directly liable for increasing soil fertility, plant growth and its production (Mahmood *et al.,* 2016; Pawar *et al.,* 2016).

Rhizoremediation

The soil and water contamination is a major problem for production of crops worldwide. The effect of such type of pollution in the biosphere is basically depending on the nature of the pollution. Various types of bioremediation techniques such as biopile, land-farming, phytoremediation, bio-slurry, and bioventing are available, which can be applied to degrade pollutants at contaminated sites. Although application of these techniques is unidirectional but it is required further to associate with each other to over come such limitations (Hassan *et al.,* 2016). However, very less number of rhizobacteria like *P. aeruginosa,* genetically engineered *P. fluorescens*, and certain *Bacillus* species are used as tools for rhizoremediation.

Biodegradation of pesticides

Excessive use of pesticides is probably hazardous to the environment by affecting soil fertility and may impart toxicity in living beings. Presently various methods such as physical, chemical, biological and enzymatic approaches are applied to reduce pesticides residues. The physical and chemical methods are inefficient to eradicate the pesticides. It has been reported that bacteria use pesticides as source of carbon, sulphur and electron donor under favourable conditions. The bacteria such as *Acinetobacter, Arthrobacter, Paracoccus, Aerobacter, Alkaligens Bacillus, Burkholderia, Pseudomonas, Flavobacterium, Moraxalla,* and *Sphingomonas* help remove or detoxify chlorinated pesticides; polychlorinated diphenyl, polycyclic aromatic hydrocarbons, organophosphorus (Anwar *et al.,* 2009). Actinomycetes the Streptomycetes have also been found to successfully detoxify pesticides. Persistent organic pollutants in the form of pesticides have also been reported to be taken care by The Various microbial enzymes such as dehydrogenase, ligninase, oxygenase, peroxidises, phosphotriesterase, hydrolases, dehalogenase, laccase and organophosphorus acid anhydrolase takes care of persistent organic pollutant in the form of pesticides. Jayashree and Vasudevan (2007) studied edosulfan remediation from the soil using synthetic surfactant Tween 80 and *P. aeruginosa* for degradation of endosulfan at neutral pH and at 8.5pH. Mixed application of *S. maltophilia* and *R. erythropolis* cultures degraded endosulfan (Kumar *et al.,* 2008). Another study, *Achromobacter xylosoxidans* CS5 was able to utilize edosulfan as the sole carbon, sulphur and energy source from the activated sludge of Jiangsu, China (Li *et al.,* 2009).

Rhizobacteria used for plant health management

Rhizobacteria play an important role in reducing the the deleterious effects of plant pathogens including fungi, bacteria, viruses and nematodes on plants through involving indirect mechanism by producing secondary metabolites and induced resistance in the host (Akhgar *et al.,* 2014; Singh and Jha, 2015, Singh *et al.,* 2016) as reported in the Table 2. The contribution of rhizobacteria in this mechanism includes production of hydrolytic enzymes, (chitinases, cellulases, proteases, etc.), various antibiotics to suppress growth of different pathogens or induction of systematic resistance in plants against the pathogens (Nivya, 2015; Gupta *et al.,* 2014). The mechanism involved by rhizobacteria to control plant diseases are described below-

Antibiosis

The rhizobacterial antagonists utilized against plant pathogens to manage the diseases of various crops has been reported as a substitute for chemical pesticides (Table 2). Rhizobacteria like species of *Bacillus* and *Pseudomonas* has been played a significant role to suppress growth of fungal and bacterial pathogens by producing different types of antibiotics. The antibiotics produced by rhizobacteria effective against several plant pathogens have become most studied biocontrol mechanisms over the past two decades . The *Pseudomonas* species are able to produce a vast group of antifungal and antibacterial antibiotics such as phenazines, phenazine-1-carboxylic acid, phenazine-1-car-boxamide, pyrrolnitrin, pyoluteorin, 2,4diacetylphloroglucinol, rham-nolipids, oomycin A, cepaciamide A, ecomycins, viscosinamide, butyrolactones, N-butylbenzene sulfonamide, pyocyanin pseudomonic acid andazomycin, antitumor antibiotics (FR901463 and cepafungins) and antiviral antibiotics (Karalicine) (Ramadan *et al.,* 2016). *Bacillus* sp. also produces different group of antifungal and antibacterial antibiotics such as subtilosin A, subtilintas A, sublancin, chlorotetain bacilysin, mycobacillin, rhizocticins, difficidin, and bacillaene, surfactin, iturins, and bacillomycin etc. (Singh *et al.,* 2013; Fouzia *et al.,* 2015; Wang *et al.,* 2015).

Induced systemic resistance

Rhizobacteria have ability to induce systemic resistance (ISR) in many plants against biotic stresses (Prathap and Ranjitha, 2015; Yadava *et al.,* 2017). The signals are produced and a defense mechanism is initiated via the vascular system during invasion of pathogen and a large number of defense enzymes, such as chitinase, â-1, 3-glucanase, phenylalanine ammonia lyase, polyphenol oxidase, peroxidase, lipoxygenase, SOD, CAT, and APX along with some proteinase inhibitors are produced by the plants. Although it is not specific against a particular pathogen but helps the plant to control various diseases (Kamal *et al.,* 2014). ISR involves ethylene hormone signaling within the plant and helps to induce the defense responses of a host plant against different group of plant pathogens. A variety of individual bacterial components induce ISR, such as lipopolysaccharides, cyclic lipopeptides, siderophores, 2, 4-diacetylphloroglucinol, homoserine lactones, and volatiles, like 2, 3-butanediol and acetoin (Berendsen *et al.,* 2015).

Production of protective enzymes

Rhizobacteria produce different enzymes (â-1,3-glucanase, ACC-deaminase, and chitinase), which are commonly associated with cell wall lysing and also neutralizing pathogens (Goswami *et al.,* 2016). Majority of cell wall of fungi consist of â-1,4-N-acetyl-glucoseamine and chitin and the bacteria produces â-1,3-glucanase- and chitinase are able to control fungal growth. *P. fluorescens* LPK2 and *Sinorhizobium fredii* KCC5 produced beta-glucanases and chitinase controlled fusarium wilt caused by *F. oxysporum* and *F. udum* (Ramadan *et al.,* 2016).

Production of volatile compounds

Many rhizobacteria have ability to produce volatile compounds (VOCs) and inhibited bacterial and fungal pathogens and nematodes, and also cause induce systemic resistance in plants against these pathogens (Raza *et al.,* 2016a, b**).** Species of *Pseudomonas, Bacillus, Arthrobacter, Stenotrophomonas*, and *Serratia* produce volatile compounds which affect plant growth. *Bacillus* spp. produced 2, 3-Butanediol and acetoin which are the most effective volatile compounds to inhibit growth of fungus and also increase plant growth (Santoro *et al.,* 2016). Sharifi and Ryu (2016) reported that bacterial volatile compounds are determinants for eliciting plant ISR. Volatile compounds such as cyclohexane, 2-(benzyloxy) ethanamine, benzene, methyl, decane, 1-(N-phenylcarbamyl)-2- morpholinocyclohexene, dodecane, benzene (1-methylnonadecyl), 1-chlorooctadecane, tetradecane, 2,6,10-trimethyl, dotriacontane and 11-decyldocosane emissions are a general characteristics of a major group of bacteria (Kanchiswamy *et al.,* 2015). The volatile compounds from rhizobacterial strains directly or indirectly mediate increased disease resistance, and plant biomass.

FUTURE RESEARCH

- Intergation of adavanced technologies like biotechnology, nanotechnology with other disciplines of science to transform traditional agriculture to precesion agariculture and ensure food security of growing populatiuon.

* The expansion of new nanodevices like biosensors, enzyme encapsulation and nanomaterials such as nanotubes, nanowires, fullerene derivatives and quantum dots with their application in the field of plant plant pathology for early detection and diagnosis of biotic and abiotics causes.
* Development of potentantial bio-fertilizers and biocontrol agent using smart delivery system like micro-encapulation to control the release into the target cell without any unintened loss.
* Improvement of bio-efficacy of beneficial bacteria on to the root and leaf surface by using surfactants and adhesions materials.
* Potential rhizobacteria should be screened for bioremediation and biodegradation of persistant pesticides for cleaning up the metal-contaminated/polluted environment.
* Development of superior or novel rhizobacterial strains by improving above traits through genetic manipulations.

CONCLUSION

Rhizobacteria play a major role for maintaining sustainable production of crops to ensure food seciruty to mankind on planet earth. These bacteria help to enhance plant growth, remediate and manage contaminated and degraded pesticide residues persist in the soil for longer period and manage diseases of crops due to biotic causal agents. Application of modern tools and techniques can enhance bioefficacy rhizobacteria to improve soil health and plant health. Further studies on selecting suitable rhizosphere microbes and producing microbial communities by combine applications of biotechnology, nanotechnology and different disciplies of science, and integrate them under various ecological and functional biological approaches. It is requirement of hour to develope smart formulations and their delivery system of rhizobacterial products for better soil and plant health.

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