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Revitalization of plant growth promoting rhizobacteria for sustainable development in agriculture.

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ABSTRACT

PGPR are those bacteria occurring as natural colonizers of soil which had gained worldwide importance in the field of agricultural enhancement. They had been observed in essential requirements to increase the productivity of soil by regaining fertility. Advancement of life in all systems has been nowadays not only reliant on farming butdietsafetyplay a chief role in satisfying the growing population basic needs.The viability of soilenvironmentserve as a source of a non-stopmanifestation of soil bacteria. There are even other aspects of soil which play conservatory role in soil fertility; including of plants in synergistic co-evolution, soil microbes and bio-mineralization. The growth of population globally has put pressure on farming thus demanding chemical fertilizer's high yield. Meanwhile with the application of peats and insect killer in the farming area have ruined the soil worth and richness, resulting incontraction of farmingacreage havingproductive soil, therefore the consideration of scientists and researchers has moved towards harmless and fruitful sources of farmingcarry out. (PGPR) Plant growth promoting rhizobacteria has been effective by co-evolution between plants and microbes. Bacteriologicalrevival had been attained byplant growth promoters activatedby direct and indirect tacticssuch as disease resistance, rhizoremediation, bio-fertilization, invigorating root growth, etc. The sort of unpredictability existed in the working of PGPR because of several ecological influences that effect their progression and propagation in plants. Due to existent limitations playing its role in agronomy PGPR applications were not improving. Theserestrictions could be overcome byusage of presentmethodologies and practices such asMicro-encapsulation and Nano-encapsulation.Theintroduction of new coming and modern research techniques are supporting their applications with the help of fields such as chemical engineering, biotechnology, agro biotechnology, nanotechnology, and material science by bringing together different environmental and practicalliving approaches to arrange new designs and prospects of hugeprospective.

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INTRODUCTION

Farming remained the biggest economic cause standingfrom the time ofbeginning of advancement. Around 7.41billionpeople dwelling around globe, occupy 6.38 billion hectares of world area, out of which 1.3 billion people are almostreliant on cultivation. With the increasing urge for food, soil viability is primarily significant for conservatory aspect ofcultivation (Paustian *et al.*, 2016; Tscharntke*etal*., 2012). Crop growingAssociation of the United Nations termed as (FAO) provided Food Balance Sheet 2004 which lead to conclusion that 99.7% of foodstuff for the population globally originated from terrestrial locationonly. A food fact suggested that 79 million people are newly added to the global population annually,there is no doubt; aconstant rise in foodplea which resulted in a concurrentunavailability in resources (Alexandratos and Bruinsma, 2003). In India, 60.6% of land is used for cultivationwhich serve as a driving force from half of its population to raise varieties of pulses vegetables and cereals. Three chief factors like Farmingoutputs, water class, and climate variability aremost prominently effectedby the exchange of atmosphere, the aquatic ecosystem, energy, the soil environment and carbon resources within soil organic materials(Lehmann and Kleber, 2015).Various constituents of soil which marks the wealthy nature vital for soil richness includeabiotic andbiotic factors, organic carbon content, nutrients, moisture, nitrogen, potassium and phosphorous. Yet, the major issue which brings negativity isunselective use of composts, mainly phosphorus and nitrogen, which lead toextensive soil effluencethrough exchangeable bases and reducing pH. Consequently, these are the phenomenon’s responsible for nutrients unreachable to crops causing productivity loss which could increase if not controlled (Gupta *et al*., 2015). Agreeing by FAO, 38.47% of the globalacreagespace is enclosed by cultivated area, of which 28.43% accounts for arable land necessary for cultivation. In accordance with record of world food and agriculture authority;lone 3.13% is always required for cultivation. Furthermore, the conditions are worsened when; 20–25% of land globally is continuallyruined every year and extra 5–10 Mha, is unavoidably ruined each year which is nowhere getting controlled (Abhilash*et al*., 2016). Sincedevelopingfarming area need proper management, becauseextraordinary demand putsgraveburden upon terrestrial environment for extraordinary yield. Therefore, anextra advancedand scientific agriculturalpracticeisneededforsatisfyingtherisingloadsthat are usefulconserving the soil productiveness. Nearly some of the modern techniques participating in effectivefarming termed aspracticalrunningcarry out (Ubertino *et al*., 2016), agricultural intensification (Shrestha, 2016), bio fertilizers usage (Suhag, 2016; Kamkar, 2016), use of microbes or genetically engineered microbes to support growth of plant (Perez *et al*., 2016; Kumar, 2016), genetically engineered crops to form nitrogen-fixing symbioses, and fixing nitrogen in the absence of microbial symbionts (Mus *et al*., 2016; Passari *et al*., 2016). Moreover, there are severalnew scientific and socioeconomic practices which participate inviableagricultural improvement include salt tolerance, drought tolerance, disease resistance, better nutritional value, and heavy metal stress tolerance.

Nowadays as the modern world is advancing, it brings new hopes for overcoming these negativities. The latest technique implies the usage of soil microbes, for example bacteria, fungi, and algae, which are quitepromising mode to satisfy these idealobjectives (Vejan *et al*., 2016). Microorganisms and leguminous plants having holobiant relationships by synergistic co-evolution and bio-mineralization have remarkable capacity for refining fertility and

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quality of soil (Paredes and Lebeis, 2016; Rosenberg and Rosenberg, 2016; Agler*et al*., 2016). soil microbes having Co-evolution with plants is important technology to counterlife-threatening abiotic environments, leading toenhancedenvironmental sustainability, economic viability, and soil fecundity (Khan *et al*., 2016; Compant *et al*., 2016). plant growth promoting rhizobacteria (PGPR) has no doubt truely illuminated the relationship betweenmicrobes and plants, which is an indicator of synergistic andantagonistic relations causing upgrading of plant growth (Rout and Callaway, 2012; Bhardwaj *et al*., 2014). PGPR soil physiognomies are hugely effected by PGPR which proves animportantrole in transformingpoor quality, unfertile area into fertileacreage. Regeneration of growth of plant and quality of soil through PGPR had been a field vigorouslymisused for improved agricultural yield in many areas globally (Gabriela *et al*., 2015). This task is commonly accomplished through indirect or direct grounds. This is directly achieved by direct provision of plants compounds that enhance growth of plant. This availability is reachable through methods for example plant stress control, bio-fertilization, and rhizo-remediation (Goswami *et al*., 2016). Suckingnutrients and water from the soil is generally the most fundamental ecologicalelementlimiting development of terrestrial plant species. PGPR like bio-fertilization enhances growth of plant through increase in the availability or suction of nutrients from a restricted soil nutrient land. Counteracting stress of plant is additionalvitalPGPR affect and is applicable equally to abiotic and biotic stress. It has been proved that biotic stress is a livingdanger (disease, insects), however abiotic stress which could be physical (temperature, light etc.) or chemical stress that the surroundings put upon plants (Gabriela *et al*., 2015) are equally harmful for the adequate growth of plant. PGPR also indirectly participate in improvement of plant growth bysubsiding or stopping the toxic effects of one or more phyto-pathogenic organisms. In the present instance, growth of plant is enhanced through mechanisms like competitive exclusion, antibiosis and induction of systemic resistance (ISR) (Tripathi*et al*., 2012).

Since results need an improvement in the field of plant growth by PGPR, due tolack of information amongstits present uses and the possible PGPR applications for ecological growth. The field of applications of PGPR is moreover extremelyrestricted because ofunpredictability and irregularity in resultsperceived inresearch laboratory, field trails and green house. Although these problems can be solvedby means ofpresent nanobiotechnological methodologies and use of procedures for example micro-encapsulation and nano-encapsulation.These outcomes signifies only fewmethodologies which can be

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revised for PGPR implementation as an instrument to fight plant infections and boost agricultural yield.

PLANT GROWTH ENHANCING RHIZOBACTERIA

Plants in their phase of progression and growth involve symbiotic relationship with soil microorganisms (fungus and bacteria). The free-living microbes of soilliving in rhizosphere of various species of plant; have considerablyvaried useful results on the host plant (Raza *et al*., 2016a,b) by implementation of dissimilar mechanisms considered as (PGPR) Plant Growth Promoting Rhizobacteriafor instance nodulation and nitrogen fixation. They are helpful in guarding plant's vigour in an environmentally friendly way (Akhtar *et al*., 2012). PGPR and their plant interactionsare implied in scientific practices but nowadays in this modern era they are constantlymisused for the support of commercial andagriculturalpurposes (Gonzalez *et al*., 2015). These interactions include applications examined oncucumber, radicchio, wheat, barley, lentil, oat, peas, tomato, maize, canola, potato, and soy (Gray and Smith, 2005). PGPR isinvolved in countless viableapproaches in the soil environment to make it vigorous for the profitable purposeand they are no doubt justified for crop yield (Gupta *et al*., 2015). Their compatibility toinhabit roots system of plants and improve growth of plant is accomplished through varied techniques, including degradation of environmental pollutants, hydrogen cyanate (Liu *et al*., 2016); siderophores (Jahanian *et al*., 2012), 1-amino-cyclopropane-1-carboxylate (ACC) deaminase, production ofindole-3-acetic acid (IAA), antibiotics or lytic enzymes (Xie *et al*., 2016), production of hormones, phosphate solubilization (Ahemad and Khan, 2012) nitrogen fixation (Glick, 2012). Moreover, Since PGPR is famous promoter for qualitative plant growth, therefore they are necessary and thusapplicable on insects, biological control of phytopathogens, salinity tolerance and heavy metal detoxifying activities (Egamberdieva and Lugtenberg, 2014).

2.1. Rhizosphere

Rhizosphere are referred as microorganismstore room colonizing soil areaneighbouring to roots of plantsand thus helpful in maintaining soilbiotic and chemical characteristics. Bacteria resident in rhizosphere can be symbiotic or non-symbiotic, consolidated through determining their useful and harmful modes of action (Kundan *et al*., 2015). The function of root system is anchorage and sucking of nutrients and water from soil, which isa considered fact implied in chemical factory wherever phenolic compounds are generated and instantaneouslyreleased to mediateseveral undergroundinteractions.Theplantroot's compounds are constantly released

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servingas chemical attractants for enormous butdivergedmicroscopicgroups. These compounds include composition influenced by the physicalposition andplant's species microbes(Kang *et al.*, 2010). Three dissimilarconstituents' form the rhizosphere are: the root, the rhizoplane, and therhizosphere itself. Among them, the rhizosphere is present in area of soil controlled by plant's root withthe help of substrate secretion and generalizedinfectiousaction. The function of rhizoplane present on the root surface is topowerfullyfix with particles of soil, where root has been occupied with microbes (Barea *et al.*, 2005). The bacterial concentration dwelling in rhizosphere is almost 10–1000 times higher as comparatively tosoil greater part, but lesser as compared to research laboratory medium. In order toconserve their useful outcomeswithin the root environs, there is a demand of compatibility with more rhizosphere microorganisms for the purpose of food released specifically by the root. The interactions between the rhizosphere and plant are vital to suck nutrients and waterfromsoilandtheseinteractionsare fruitful toboth the soil-borne microbes and plants.

2.2. Different types of PGPR

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The classification of PGPR is recognized and divided into two chief types namely intracellular plant growth promoting rhizobacteria (iPGPR) and extracellular plant growth promoting rhizobacteria (ePGPR) (Viveros *et al.*, 2010). ePGPR live in the the gaps amongst cells of the root cortex or rhizosphere(ontherhizoplane), However iPGPR principallydwell withinparticular nodes of root cells. The genera of bacteria referred as ePGPR are Burkholderia, Pseudomonas, Micrococcous, Arthrobacter, Azotobacter, Erwinia, Agrobacterium, Serratia,Chromobacterium, Flavobacterium,Caulobacter, Azospirillum, and Bacillus. The iPGPR endophytic microorganisms areFrankia species, Rhizobium ,Mesorhizobium and Bradyrhizobium, that has the capacity to fix nitrogen in air particularly in higher plants (Bhattacharyya and Jha, 2012).

PGPR ROLE IN GROWTH AS PLANT PROMOTER

PGPR improve growth of plant through particularqualities(Gupta *et al.*, 2015). These qualities of PGPR includeincrease ingrowth of plant with the help ofindirect and direct procedures, likephytopathogens resistance and improvement in physiology of plants, byvariedactions and approaches (Zakry *et al.*, 2012). Actions are widespread approaches whichincludeenzymes for disease prevention, producing volatile organic compounds (VOCs), neutralizing abiotic and biotic stress and nutrient fixation. Though, the type of action by various PGPR types differs depending on plant host type (Garcia *et al*., 2015). They are also effected by a various biotic factors (climatic conditions, further microbial community members, plant defence mechanisms, plant developmental stages and plant genotypes) and abiotic factors (management and composition of soil) (Vacheron *et al*., 2013). Biotic and abiotic approaches are two important and vital foundations for PGPR applications in plant growth and nevertheless both are fundamental and necessary part of story

DIRECT TOOLS

PGPR is responsible for direct facilitation of the development and growth of plants with application of procedures likephytohormones production, solubilisation of mineral nutrients, mineralization of organic compounds, rise in nutrient obtainability by nitrogen fixation or uptake of nutrients (Bhardwaj *et al*., 2014).These mechanisms are very fruitful and thus responsible for direct plant growth which is entirely dependent on the plant species and type of microbial strain.Enhancement of mineral suction from the soil through root surface is directlydependent on singular ion flux and this is accomplished by the PGPR existance.

3.1.1. FIXING OF NUTRIENT

PGPR serve as direct growth promoters in plants, since they are linked with capacity whichincrease the concentration and availability of nutrients by lockingor fixing the plantgrowth supplyandyield(Kumar, 2016). Plants suck soil nitrogen in the form of ammonium (NH4+) and nitrate (NO3−), and thus referred as essential nutrients for development. Nitrateisknown asthepredominantformofnitrogen supplyin aerobic soils through plants where nitrificationprominently take place (Xu *et al*., 2012). Some PGPR have the capacity of phosphate solubility, causing abetteramount of phosphate ions accessible from the soil,which can be definitely absorbed by plants (Paredes and Lebeis, 2016). Kocuria Turkanensis 2M4 isolated from the soil rhizosphere serve as an IAA producer for various plant species. It is also act assiderophore producer, and phosphate solubilizer (Goswami et al., 2014). Additionally microbes such a Bacillus subtilis UPMB10, Acinetobacter sp. S3r2, Bacillus pumilus S1r1, Klebsiella pneumoniae Fr1, and Klebsiella sp. Br1have the area potential for fixing atmospheric N^2, and delay N^2 remobilization.

FIXING OF NITROGEN

Bioticway of nitrogen fixation is an astonishing process that explains for almost two-thirds of the nitrogen fixed universally. This organicmethod is executed either by symbiotic or non-symbiotic interactions amongst plants and microbes(Shridhar, 2012). Symbiotic PGPR, which are most commonly caused the fixation of atmospheric N^2 in soil, contain strains of K. pneumoniae,Pantoeaagglomerans., Beijerinckia sp., Azoarcus sp., and Rhizobium sp., (Ahemad and Kibret, 2014). Inoculation of several rhizobacterial species into soil enhances its quality and increases nodule formation.A particular gene called nif is involved in undertaking N^2 fixation, while additional structural gene is involved in switching on the iron protein, biosynthesizing the iron molybdenum cofactor, donating electrons and numerous other regulatory genes compulsory for the enzyme's activity and synthesis (Reed *et al*., 2011). BiologicalN^2-fixingthrough PGPR is an authenticated process perceived by inoculation on agricultural fields and cropsand thus fruitful in reviving activity by buildinggrowth enhancement. It is an extraordinary source that retains the level of nitrogen in crop soil and play role in disease management (Damam *et al*., 2016).

3.1.3. SOLUBILIZATION OF PHOSPHATE

Phosphorus is the second most necessary nutrient compulsory for plants in suitableamounts for ideal growth. It serve askeypart in nearly all main metabolic processes, consist ofphotosynthesis, macromolecular biosynthesis, energy transfer, respiration and signal transduction (Anand *et al*., 2016). However, 95–99% of phosphorus existent inprecipitated, immobilized, or insolubleforms consequently, making its uptake difficult for plants. The uptake of phosphate in plants occur loneas dibasic (HPO4−2) and monobasic (H2PO4−) ions. Phosphate-solubilisation is the only process impliedby bacteria still involved in mineralization and Solubilisation of phosphorusand is attained chiefly through PGPR. The organic acids of low molecular weight are synthesized by countlessbacteria's of soil, responsible for inorganic phosphorus solubility which are no doubt miraculous approach effective in agriculture side (Sharma *et al*., 2013). Phosphate solubility in PGPR are provided by the bacterial genera ofSerratia,Rhodococcus, Enterobacter, Flavobacterium, Mesorhizobium, Rhizobium, Pseudomonas Arthrobacter, Erwinia,Microbacterium, Bacillus, Burkholderia, and Beijerinckia, that hasappealed to agriculturists thus confirming this fact that inoculation of soilincrease plant growth and production (Oteino *et al*., 2015). Amongst them, Mesorhizobium mediterraneum and Mesorhizobium ciceri isolated from nodules of chickpea, are worthy phosphate solubilizers (Parmar and Sindhu, 2013). No doubt nowadays these microorganismsare fruitful and definitely needed for phosphorus solubilitycausing an improvement in soil fertility. But we cannot deny this fact that still in spite of extensive research; resultsare inadequate regarding its application as a bio-fertilizers.

3.1.4. SOLUBILIZATION OF POTASSIUM

The thirdnecessary macronutrient for the growth of plants is Potassium. Since greater than 90% of potassium is available in the form of silicate minerals and insoluble rock but still concentration of soluble potassium is nevertheless very small in soil (Parmar and Sindhu, 2013). Aforemost limitation implying in grooming agriculturalyield is potassium deficiency. In the absence of sufficient potassium, proven poor growth of roots,lesser yield, ceased growth rate, and low seed yield has resulted. There is an inevitable demand required to search asubstantial endemic potassium source for keeping potassium wealth and for much betterabsorbing capacity for adequate crop yield (Kumar and Dubey, 2012). The PGPR capacity to solubilize potassium rock throughsynthesizing and releasing organic acids has beenbroadlyexplored. Potassium solubilizing PGPR, for example Burkholderia., Pseudomonas sp., Bacillus mucilaginosus., Paenibacillus sp., Ferrooxidans sp., Acidothiobacillus sp and Bacillus edaphicus sp., are employed in providing amazing results to secrete potassium in reachable form through potassium-bearing minerals existing in soil (Liu *et al*., 2012). Consequently, with the application of potassium-solubilizing PGPR serving as bio fertilizer for the fruitful farming can decrease the surge of agrochemicals needs and better in upkeep of agricultural yieldproven in environmental friendly way (Setiawati and Mutmainnah, 2016).

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3.1.5. PHYTOHORMONE RELEASE

Phytohormones or plant growth regulators are referred as biological substances, which are found at relatively low concentrations (<1 mM) modify,promote or inhibit plant's development and growth (Damam *et al*., 2016).luckily, yield of these phytohormones can even be induced through certainmicroorganisms, for example PGPR, in plants. Generally groups of phytohormones important and released from PGPR sourceconsist ofauxins, brassino steroids, gibberellins, ethylene, abscisic acid and cytokinins. With the arrival of phytohormones in the agricultural field, a considerable rise in water and food absorbancein root cell is observed which can even multiply by overproducing root hairs and lateral roots (Sureshbabuetal.,2016).Plantgrowthregulators are recently known which are referred as exogenous plant hormones, since they are applicable exogenouslyas synthetic analogues or extracted hormones onto plant tissues or whole plants. Phytohormones are classified by their dependence on area of action.

(A) INVIGORATION OF ROOT

Invigoration of root consist of various hormone-mediated pathways which coinside with pathways that are identified as exterior (Jung *et al*., 2013). These hormones involve production in a way that sometimes involvedefinite microorganisms, such as Rhizobium leguminosarum, Azotobacter chroococcum, Klebsiella oxytoca, Pseudomonas putida, Stenotrophomonas maltophilia, Pseudomonas aeruginosa, Mesorhizobium ciceriand, Enterobacter asburiae and Paenibacillus polymyxa, which are considered as PGPR. Hormones for exampleethylene, kinetin, gibberellins, and auxins are specifically formed by these microorganisms and serve a vital role in invigoration of root(Ahemad and Kibret, 2014).

(B) INVIGORATION OF SHOOT

The hormones such as auxins, gibberellins and Cytokinins, are important growth hormones that control all phases of growth in higher plants. Skoog and Miller, 1957 analysed that if we increase hormone availability; a positive relationship is built between cytokinins concentration and shoot development instead of root development. Fewforemost cytokinins includedihydrozeatin [6(4-hydroxy-3-methyl-butylamino) purine], cis-zeatin [6-(4hydroxy-3-methyl-cis-2-butenylamino) purine], trans-zeatin [6(4-hydroxy-3-methyl-trans-2-butenylamino) purine], and i6Ade [6-(3-methyl-2-butenylamino) purine] (Murai, 2014). The smooth making and assemblage of these hormones of plants through microorganisms could serve as an energetic attempt for positive changein agricultural yield and help in getting advancedand preferred traits. Microorganisms that serve as a resource in hormones assemblage, are even involved in application of shoot invigoration that is mostly observed in PGPR, likeAzotobactersp, Pseudomonas sp.,Paenibacillus polymyxa, Rhizobium leguminosarum, Bacillus subtilis,Pantoeaagglomerans, Pseudomonas fluorescens, andRhodospirillum rubrum (Prathap and Ranjitha, 2015).

3.1.6. SIDEROPHORE RELEASE

Siderophores are referred as small biological molecules obtained by microbes in iron-limiting conditions which support and improve iron absorbing potential. The results of Research on siderophores has concluded that during recent decadethe iron metal ion absorbance capacity has developed (Saha *et al*., 2016). The plant microbe such as Pseudomonas sp., which serve as PGPR, consumes the siderophores takenby rhizosphere microorganisms for satisfying their demand of iron. Particularly, the microbe such as Pseudomonas putida consumes heterologous siderophores justified from other microbes in

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order to improve the iron availability level within the ecosystem (Rathore, 2015). An effective siderophore, for example the complex of ferric-siderophore, serves a vital part in plant's iron absorbancein the presence of metals, like cadmium and nickel (Beneduzi et al., 2012). Since PGPR is known for production of siderophores, thus serving as a foremost part in satisfying iron demand. The research conducted on siderophores potential aboutrise in iron absorbance is till now very restricted, therefore further research is demanded in this field.

3.1.7. EXOPOLYSACCHARIDE RELEASE

Exopolysaccharides (EPSs) are included in a group regarding biodegradable polymers having high molecular weight involvingderivatives and monosaccharide residues from various plants, algae and bacteria (Sanlibaba and Cakmak, 2016). EPSs play a pivotal rolenda chief part in survival of host in stress conditions like (water logging, saline soil, or dry weather) or pathogenesis and therefore are suggested for good agricultural yield through obligate interactionamongst rhizobacteria and plant roots, soil particle's aggregation and maintenance of water potential (Pawar *et al*., 2016). EPS results confirmed the production of PGPR, for instance fromRhizobium sp., Xanthomonas sp., Agrobacterium sp., Enterobacter cloacae, Bacillus drentensis, Rhizobium leguminosarum and Azotobactervinelandii,are very important to capacitate a rise in fertility of soil by supporting agricultural yield (Mahmood *et al*., 2016).

3.1.8. BIOLOGICAL-fiXATION OF ATMOSPHERIC NITROGEN

Atmospheric nitrogen fixation is referred asnon-mutualisticor mutualistic association between plants providing a fixed carbon and and suitable habitat by microorganisms through fixed nitrogen exchange(Kuan*et al*., 2016). The mentioned associationamongst plants and PGPR is observed in the genera Pseudomonas, Bacillus,Azospirillum,Burkholderia, and Klebsiellawhich hasbeen extensively studied(Islametal.2016).But, still these practices are limitedmostly to legumes in agrariansciences because of lack ofsubstantialcuriosityexisting in the field of discovery of either symbioticor non-symbioticrelationship betweennon-legumes.

3.1.9. RHIZOREMEDIATION

Contamination of water and soil has been a critical issue emerging globally these days. The major type of problems arising nowadays is a lethal sources of pollution in ecosystem. Pollution can be lessened through bioremediation, referred as a method or system in which living entities ortheirgoodsareusedartificially or naturallytoimmobilize, destroy/or remediate

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pollutants in the ecosystem (Uqab *et al*., 2016).Since bioremediation is known to be an economical and time taking resource harboured for tackling pollution of water and soil. The several bioremediation methods are existent, including bioventing, bio-slurry, bio-pile, phytoremediation and landfarming. All these techniques has been applicable in polluted areas for to cut downwaste products. In spite of several advancements, yet; while applying these procedureswe need to execute a relationship which is applicable beyond restrictions (Hassan *et al*., 2016). One such trialtactic is rhizoremediation, which is practically done by the mixture of two techniques bio-augmentation and phytoremediation. The modern and latest method of mining metals from polluted soil through plant consumptionis (phytoextraction), and this can help in observing better yield through another procedure known as phytoremediation (Hamzah*et al*., 2016). The process of bio-augmentation include the addition of microbes to “support” biological waste treatment for effective reduction of pollution by converting the waste into less harmful compounds (Herrero and Stuckey, 2015). The symbiotic and non-symbiotic associationsamongst plants and microbes, which are truly done by PGPR, is one of the source of rhizoremediation. Nowadays, PGPR application throughrhizoremediation possesslimited research for few species of microbes, for instanceBacillus species, and Pseudomonas aeruginosa; genetically engineered as Pseudomonas fluorescens (Kuiper *et al*., 2004). Moreover, PGPR is applicable in bioremediators on which the world places a huge demand in eradicating pollution in the form of toxic waste and heavy metals from water and soil environment.

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3.2. INDIRECT TOOLS

Indirect mechanisms include the method by which PGPR annul or nullify the deadly effects of phytopathogens on plants by the suppressive substances production which has a potential to rise host’s natural resistance(SinghandJha,2015).Moreover, this method is referredas apassage which support active growth of plants in environmental stress (abiotic stress) or shield plants from contaminations such as biotic stress (Akhgar*et al*. 2014). The PGPR contribute in this method of releasing of hydrolytic enzymes like (proteases, cellulases, chitinases, etc.), VOCs, EPSs, production of siderophores various antibiotics in response to plant pathogen or disease resistance, induction of systematic resistance against various pathogen and pests, etc. (Nivya, 2015; Gupta *et al*., 2014).

3.2.1. STRESS CONTROL

The character which is a source of damaging influence on growth of plants is termed as stress (Foyer *et al*., 2016). Stress of any typecauses the rise in the construction of reactive oxygen species (ROS) for instanceOH^-, O^{-2}, and H_2O_2 radicals. Extra ROS assembly leads to oxidative stress, that create negative influence on plants withnucleic acids, proteins, membrane lipids and oxidizing photosynthetic pigments. Plants are normallyexposed to severalecological stresses and have produced particular response mechanisms (Ramegowda and Senthil-Kumarb, 2015). Within the recent ten years, a need for grasping the molecular mechanisms has arisen which has application on biotic and abiotic stresstolerance (Tripathi et al., 2015; Tripathi *et al*., 2016; Pontigo et al., 2017; Singh *et al*., 2017; Tripathi *et al*., 2017). Few of the factors which include PGPR induce stress controlling in plants are discoursed here.

(A) NON-BIOLOGICAL STRESS TOLERANCE

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Abiotic stress (floods, salinity, drought, extreme temperature and high wind etc.) have anextraordinary damaging effect upon biomass production, therefore a need for survival of essentialdiet crops specifically up to 70%, is needed which will annul the negative effect on food safety globally. Drought stress reported by dryness, high temperature and salinity, are termed as major abiotic stress which play role in restricting growth and yield of plants (Vejan *et al*., 2016). Tolerance which is positive response of stress is quantifiable and multigenic naturally, and involvesgathering of definite stress metabolites, for instance abscisic acid, glycine-betaine, proline, poly-sugars and include upregulation in the release of non-enzymatic and enzymatic antioxidants, like glutathione, αtocopherolglutathione reductase, ascorbic acid, superoxide dismutase(SOD), ascorbate peroxidase (APX), and catalase(CAT)(Agami *et al*., 2016). Besides these, there are various additionalapproaches whichlessen the intensity of cellular damage produced through water stress and is fruitful in inducing crop tolerance. It involveexogenous application of PGPR on potential osmolytes, for instancetrehalose, glycinebetaine, and proline, etc., that has attainedgreatresponsivenessfor decreasing the stress effect. The application of PGPR during abiotic stress controllingin plants has been widely analysed by bacterial strains ofPseudomonas fluorescens and Pseudomonas putida which is effective in annulling the lethal impactof cadmium pollution upon barley plants through their ability of scavenging soil cadmium ions (Baharlouei *et al*., 2011). Furthermore,enhanced leaf water station, specifically inabiotic stress and salinitysettings, are said to leave proven results relevant to PGPR effects (Ahmad et al., 2013; Naveed et al., 2014). The formation of a relationshipamongst drought resistance and PGPR has been testified in various crops, inclusivelywheat, chickpea and soybean (Ngumbi and Kloepper, 2016). Boosted stress tolerance by salinity in okra by ROS-scavenging enzymes and enhanced water-absorbing efficiency, known to be induced through PGPR, has likewise been proven by Habib *et al*., 2016.

(B) BIOLOGICAL STRESS TOLERANCE

Different pathogens, like viroids, insects, protists, nematodes, viruses, bacteria and fungi lead to definite decrease in crop production (Haggag *et al*., 2015). Worldwide agricultural yield is countering a substantialloss of nearly 15%primarily because of phytopathogens (Strange and Scott, 2005). Stress lead to decrease in food production and simultaneously supports resistant crops breeding because of great loss economically. Biotic stress impartshostile effects on plants, involvinghorticultural plant health, natural habitat ecology, ecosystem nutrient cycling, population dynamics and co-evolution (Gusain *et al*., 2015). Such difficulties could overcome by means of PGPR, for instance *B. subtilis* strain RMPB44,*P. Favisporus* strain BKB30,*Paenibacillus polymyxa* strains B2, B3, B4, Bacillus amyloliquefaciens strain HYD-B17, *B. thuringiensis* strain HYDGRFB19, and *B. licheniformis* strain HYTAPB18. Huge resistance to several types of biotic stress is achieved through inoculation of plants with PGPR cultures via seeds or roots soaked overnight (Ngumbi and Kloepper, 2016).

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3.2.2. RESISTANCE AGAINST DISEASE ANTIBIOSIS

Microbial antagonists deal with effect of plant pathogens on agrarianyieldswhich has been proposed a substantial substitute for chemical insecticides. PGPR, such asPseudomonas sp and Bacillus spserve a foremost partfor pathogenic microbial inhibition by the release of antibiotics. During the recent ten years; PGPR is a source of antibiotics release contrary to various plant pathogens which serve as a phenomenon for biological control(Ulloa-Ogaz *et al*., 2015). The Record showed that nearly maximum Pseudomonas species has the capacity to release antifungal antibiotics (pyocyanin, N-butylbenzene sulfonamide, , butyrolactones, viscosinamide, 2,4diacetylphloroglucinol, pyoluteorin, pyrrolnitrin, rhamnolipids, cepaciamide A, oomycin A, ecomycins, phenazine-1-carboxamide, phenazines, and phenazine-1-carboxylic acid), antiviral antibiotics (Karalicine), antitumor antibiotics (FR901463 and cepafungins), bacterial antibiotics (pseudomonic acid andazomycin), (Ramadan *et al*., 2016). Bacillus sp. even play a major role for the synthesis of antibacterial and antifungal antibiotics. The source of these antibiotics are both non-ribosomal and ribosomal. The ribosomal source of antibiotics cover sublancin A, subtilintas A, and subtilosin Aand the non-ribosomal sources cover bacillaene, difficidin, rhizocticins, mycobacillin and chlorotetain bacilysin, etc. Bacillus sp. also serve as a source of widespreaddiversity of lipopeptide antibiotics, for instance bacillomycin, iturins, and surfactin, etc. (Wang *et al.*, 2015). The antibiotics are furthermorecongregated into volatilenon-volatilecompounds. The volatile antibiotics consist ofhydrogen cyanide, sulfides, alcohols, ketones, and aldehydes, etc., and the antibiotics which are non-volatile are heterocyclic nitrogenous compounds, phenylpyrrole, polyketides,cyclic lipopeptides,aminopolyols, etc. (Fouzia *et al.*, 2015).

3.2.3. TRIGGERING SYSTEMIC RESISTANCE

Induced systemic resistance (ISR) is termed as a biological condition of enhanced protective potential aroused as a reaction to a specificecological stimulus. PGPR causes systemic resistance in numerous plants with the effect of variousecological stressors (Prathap and Ranjitha, 2015). Signals are aroused as a protective mechanism stimulated by the vascular system throughout microbial attack that consequently lead to switching on of numerous defence enzymes, like APX, CAT, SOD, lipoxygenase, polyphenol oxidase, β-1, 3glucanase, chitinase, phenylalanine ammonia lyase, and peroxidase along with few proteinase inhibitor.ISRisnotspecifically applicableuponacertainmicrobehoweverit is supportive for plants in combatting various diseases (Kamal *et al.*, 2014). ISR includesignalling of ethylene hormone inside the plant and advantageous in causing host plant’s protective responses as an effect of attack of various pathogens of plants. The diverse forms exist in individual bacterial components which are responsible for triggering the release of volatiles, such as acetoin, and 2, 3butanediol, ISR; like lipopolysaccharides, homoserine lactones, 2, 4diacetylphloroglucinol, siderophores, cyclic lipopeptides (Berendsen *et al.*, 2015).While, widespread induction of ISR through PGPRwithinplants,andtheir application is regarded as an indispensable source tomodernisefarming, thereforeunpretentiousinvestigationis being carried out byconsumingPGPR which lead to a dire demand of modern fundamental tools and procedures usages forsustenance of plants from laboratory to actual field.

3.2.4. APPLICATION OF PROTECTIVE ENZYMES

PGPR plant growth is supported by PGPR by release of metabolites whichis a regulatorof phytopathogenic agents (Meena *et al.*, 2016).The enzymes likechitinase, ACC- deaminase, and β-1,3-glucanase, which are responsible for breakdown of cell walls and deactivating microbes (Goswami et al., 2016). Generallycell wall of fungi have components consisting of chitin, and β-1, 4-N-acetyl-glucoseamine and hencechitinase-producing bacteria and β-1,3glucanase-, have potential to control their absolute growth. *Sinorhizobium fredii* KCC5 and *Pseudomonas fluorescens* LPK2 release chitinase and beta-glucanases lead to withering of *Fusarium udum* and *Fusarium oxysporum* (Ramadan *et al.*2016).*Rhizoctonia solani* and *Phytophthora capsici* are completely inhibited through PGPR because they are considered as the bestdisastrous crop microbes renowned globally (Islam *et al*., 2016).

3.2.5. APPLICATION OF VOCs

VOCs which support plant growth since they are released by those strains which show biological control, cause inhibition of microbes such asnematodes, fungi and bacterias, and bring induction of systemic resistance within plants for phytopathogens (Raza *et al.,* 2016a,b). specific species of bacteria belonging from various genera, comprisingof Serratia, Stenotrophomonas, Arthrobacter, Bacillus, and Pseudomonas, have potential to produce VOCs which effect growth of plant. Bacillus sp are good producers of acetoin and 2, 3-Butanediol; termed as VOCs for support of growth of plant but cause inhibition of fungal growth (Santoro *et al.,* 2016). It has been testified that plant ISR are produced through bacterial VOCs (Sharifi and Ryu, 2016). The VOCs obtained through PGPRstrains indirectly or directly facilitateimproved resistance against diseases, improvement in plant biomass and abiotic stress tolerance. The microbes which are responsible for VOC releaseare 11-decyldocosane,dotriacontane,cyclohexane, 2,6,10-trimethyl, 2-(benzyloxy)ethanamine, tetradecane, benzene, methyl, 1-chlorooctadecane, decane, benzene(1-methylnonadecyl), dodecane, 1-(N-phenylcarbamyl)-2- morpholinocyclohexene. These VOCs are highly demanded in spite of variability existingbetween identity and quantity of the VOCs released from various species (Kanchiswamy *et al*., 2015).

4. Upcoming viewpoint

PGPR has been promoting the agricultural yield by means of various processes and mechanisms. Still, several environmental factors influence plant growth through inconsistence PGPR performance. The environmental factors consist ofsoil composition or activity of the native microorganism’s flora of soil, characteristics of soil, climate of soil, and weather conditions (Gupta *et al.,* 2015). Various types of factors such asabiotic and biotic comprising ofherbicides, microbes and weeds etc. whichconfines PGPR impact causing poor yield in plants. With the arrival of recent techniques and tools for instanceNano-fertilizers, Biosensors and Nanomaterialsin the areas of nanotechnology and biotechnology results in improvementin agricultural yield throughout the latest ten years. Soil serve as the richest constituent containing natural nanoparticles, both ofaggregates/agglomerates and primary particles. Nano agriculture is needed to introducebiotechnology, nanotechnology, and other areas of science against agricultural sciences for the purpose of replacement of old agricultural techniques to modern ones leading to food safety for rising population (Subramanian and Tarafdar, 2011). The development of latestNano devices like (enzyme encapsulation,biosensors,) and nanomaterials like (quantum dots, fullerene derivatives, nanotubes, and nanowires) by the arising of nanotechnology which declarepossible narrative use in the area of life sciences and agriculture (Dixshit *et al*., 2013).The superiority of these materialsshow reliance on its size in many areas supporting agriculture growth. Plant pathology dependant on nanoparticles is applicable on particular agricultural issues arising during pathogen-plant interactions and offer new techniques for agricultural safety. This consist of timely finding of biological stresses and their control, increasing input for good output like (fruits, flowers and vegetables etc.). Since, PGPR (Bacillus subtilis, Pseudomonas putida, and Pseudomonas fluorescens)treatedwithsilver, gold,and aluminiumcoated nanoparticles have been testified for the purpose ofrise in growth of plant, but also have application in inhibitionof the unsafe fungal parasite growthinside rhizosphere, thus performing as possible nano-biofertilizers. The nano bio-fertilizers can be encapsulated through micro-encapulation and have application in controlling the fertilizer release ontoaimed cell in the absence of unintentional loss. Improvedholding capacity of useful bacteria with the roots of oil seed rape which is vital for the safety of plants for infectionof fungal microbes by Titania nanoparticles was practically proven from Mishra and Kumar, (2009). Percentage of seed germination in various monocots and dicots have also be accepted to be enhanced through pretreatment by ZnO nanoparticles (Mishra and Kumar, 2009). In present situation, the application of nano bio-fertilizers serve a hugeprospect to cultivateenvironmentally friendly compounds which is used as a substitute instead of chemical pesticides (Caraglia *et al*., 2011). Microencapsulation and Nano encapsulation of nematicides, fungicides and insecticides, are supportive in generating a design which is influential while serving as a pest controller thusinhibiting soil residue. Encapsulated herbicide molecules for instance metal achlor and pentimethalin using polymers like poly alylamine hydrochloride (PAH), and poly styrene sulphonate (PSS) which show lysis in moist condition and thereforedefinitely be controlled. These encapsulated herbicides have constant production of active ingredients whichguarantee productive weed control (Kanimozhi and Chinnamuthu, 2012). Furthermore, these includehydro and thermalstrength.

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These encapsulated nematicides, fungicides, and insecticides mightare supportive in production of formulations implied for pests control. Arrival of smart biosensors for nutrient and contaminants discovery place anenormouseffect on precision agriculture that can definitely utilizeremote sensing devices, global positioning system (GPS), and computers, for measuringextremelylimitedecological conditions, using resources havingextreme efficiency and identifying the location and nature of difficulty. Precision farming has been a lengthy demandedobjective to decreaseinput (like herbicide, pesticides, fertilizer,etc.) and make best use of output (like agricultural production) bycheckingecological variables and application action directed. Nano scale Zeolites that is referred as naturally existing crystalline aluminum silicates, may even serve major part through enhancing the water retention potential of sandy soil and increase porosity of clay soils (Srilatha, 2011; Subramanian and Tarafdar, 2011; Vacheron *et al*., 2013; Trivedi and Hemantaranjan, 2014). Bioremediation even has arisen as a budding tool for removing contamination of metal polluted/ environment. The decrease inmetal contaminants bioavailability is observed inside rhizosphere (phytostabilization) which is helpful in enhancing plant health, growth and establishment, and can chiefly catalyse growth of plant and definitely its yield (Ma *et al*., 2011). Production of superior or new strains of PGPR by enhancingabove qualities is a probable result of genetic manipulations. These PGPR-biotechnologies can be misusedand considered as a low-input, supportable and eco-friendly technique for controlling plant stresses. In present situationNano based products and techniques have been observed for agronomic development. These techniques are followed in various developed countries such as India, South Korea, Switzerland, USA, Japan, Germany, France, and China wherebig scale application of such products are still restricted to certain biotechnological foodstuffs likeFlavr Savr tomatoes, seedless bananas, Golden rice, BT Brinjal, Cucumber, and BT cotton, etc. and thus main progress is demanded to please the requirements for the growing population.

5. CONCLUSION

Soil and agriculture are two vital components of globe which are necessary for human survival. Undiscriminating misuse of resources has put limitations on food yield which has led mankind to search for alternate for satisfying their requirements for living. PGPR shows an essential part in increasing growth of plant; overcoming the polluted earth consisting of sewage and eutrophied water bodies; and monitoring phosphorous runoff, nitrogen, and pesticide pollution. Yet, extraordinary reliance of mankind on compost and pests killers has increased the intensity of pollution and led to disturbance in ecosystem equilibrium.

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Furthermore, they have penetrated the food chain by different means. Thesedeviations can disturb microbe-plant interactions by changing biogeochemical cycles and microbial natural science. Still by implying new tools and practices for PGPR improvement play a vital part for the support of farming by increasing the fertility of soil, keeping a stable nutrient cycling having plant tolerance and rise in yield of agriculture. Advanced research has executed on choosingappropriate rhizosphere microorganisms and involve application upon microbial communities by unifying the research fields material science, chemical engineering, agro biotechnology and biotechnology, and to invent new techniques andtools for bringing revolution in agricultural processes.

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