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Plant growth-Promoting Rhizobacterial Biofertilizers for Quality Crop Production and Soil Health Sustenance

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ABSTRACT

Recent decades have witnessed increased agricultural production to match the global demand for food fueled by population increase. Conventional agricultural practices are heavily reliant on artificial fertilizers that have numerous environmental and human health effects. Cognizant of this, sustainability researchers and environmentalists have increased their focus on other crop fertilization mechanisms. The exploitation of plant microbiomes has particularly gathered surmountable interest in this regard. Among the most interesting plant microbiomes are the plant growth-promoting rhizobacteria (PGPR). Biofertilizers are microbial formulations of Plant growth promoting rhizobacteria (PGPR) which shows an important role in the sustainable agriculture industry. Biofertilizers are constituted of indigenous plant growth-promoting rhizobacteria that directly or indirectly promotes plant growth and soil fertility through the solubilization of soil nutrients, nitrogen (N2) fixation, suppression of plant diseases and the production of plant growth-stimulating hormones such as 1-aminocyclopropane-1-carboxylate (ACC) deaminase activity, gibberellic acid, Indole 3-acetic acid (IAA) and siderophores. Moreover, PGPR not only help in plant growth but also help in soil health sustenance. Over the past centuries, technological revolutions have brought about new sources of soil and (ground)water pollution . The clean-up costs by conventional remediation methods are often exorbitantly high, retarding soil remediation if performed at all. Against these drawbacks, rhizoremediation which is an inexpensive and sustainable technology, based on the actions of biodegradative microorganisms in the rhizosphere and the plant phytoremediation capacity, has gained increased attention.

INTRODUCTION

Agricultural sustainability, food security and energy renewability depend on a healthy and fertile soil. Imbalance in nitrogen cycling, nutritional status, physical and biological properties of soil, incidence of pests and diseases, fluctuating climatic factors and abiotic stresses are the interlinked contributing factors for reduced agricultural productivity. The existing approaches to agriculture include the use of chemical fertilizers, herbicides, fungicides and insecticides. However, the overuse of fertilizers can cause unanticipated environmental impacts and encounter problems such as, development of resistance by pathogen to fungicides and rapid degradation of the chemicals. Plant growth-promoting rhizobacteria (PGPR) are naturally occurring soil bacteria that colonize plant roots, which is an important environment for plant microbe interactions. PGPR have attracted special attention for their ability to enhance productivity, sustainability and profitability when food security and rural livelihood are a key priority. PGPR affect plant growth and development directly or indirectly, either by releasing plant growth regulators or other biologically active substances, and uptake of nutrients through fixation and mobilization, reducing harmful effects of pathogenic microorganisms on plants and by employing multiple mechanisms of action. During the symbiotic interactions in the rhizosphere, ectomycorrhizal fungi extended the belowground surface area of plant where billion of root- associated bacteria help to take up mineral and pollutant, produce vitamins and plant hormones and degrade organic compound or sequestrate metals.

Direct mechanism of PGPR

8Nitrogen fixation- PGPR follow two mechanism of nitrogen fixation. In symbiotic nitrogen fixation, legume crops undergo biological nitrogen fixation through symbiotic association with bacteria and meet their own requirements without depending external sources. Symbiotic bacteria which act as PGPR are *Rhizobium, Bradyrhizobium, Sinorhizobium*, and *Mesorhizobium* with leguminous plants, *Frankia* with non-leguminous trees and shrubs. Free living nitrogen fixers, which are non-symbiotic types survive close to root without penetration, fixed nitrogen that are acquired through uptake contribute to the nitrogen account of the plants. Non-symbiotic nitrogen fixing rhizospheric bacteria belongs to genera including Azotobacter, *Acetobacter, Azospirillum, Enterobacter, Cyanobacteria, Pseudomonas, Anabaena* and *Nostoc.*

Phosphorus solubilization- Phosphorus plays a crucial role in the nutrition of plants. It can be found in both organic (bound) and inorganic (bound, fixed, or labile) forms. The accessibility of phosphorus to plants is impacted by pH, compaction, air circulation, dampness, temperature, texture and organic matter of soils, crop deposits, degree of plant underground root, root exudate discharges and available soil organisms. Phosphorus is engaged with metabolic cycles of plant, for example in photosynthesis, energy transfer, signal transduction, macromolecular biosynthesis and respiration. Phosphorus is made available to plants through the soil phosphorus cycle. PGPR's straightforwardly solubilise and mineralise inorganic phosphorus or work with the portability of natural phosphorus through microbial turnover as well as by increasing the underground root growth. These microbes emit various kinds of natural acids which bring down the pH in the rhizosphere and subsequently discharge the phosphorus accessible to plants. Microscopic organisms from genera such as *Achromobacter*, *Agrobacterium*, *Pseudomonas* and *Serratia* are exceptionally productive in solubilising inaccessible complexed phosphate into accessible inorganic phosphate particle.

Siderophore formation- In aerobic conditions, iron happens as insoluble hydroxides and oxyhydroxides which is not available neither to plants nor microorganisms. Being a transitional element, iron gets quickly oxidized from dissolvable ferrous (Fe2) to insoluble ferric (Fe3) state. Siderophores improves the iron bioavailability by impacting the low solvency of iron. Siderophores get fixed to the metallic surface and facilitate dissolution by coordinating the iron atom in a soluble complex. Under iron limiting circumstances microorganisms and plants depend on chelating specialists to solubilise and transport inorganic iron. The membrane receptor and the ferric siderophore carrier are the common transporter for high affinity microbial acquisition of iron. Microbes release siderophores to scavenge iron from these mineral phases by forming soluble Fe_3+ complexes that can be taken up by active transport mechanisms. Microorganisms discharge the siderophore to overcome iron limitation and furnish plants with Fe, improving their development directly by expanding the accessibility of iron in the soil encompassing the roots. When plants recognize the bacterial ferric-siderophore complex, they absorb iron. Siderophores, in addition to iron, also form stable complexes with radionuclides like uranium and other environmental-harmful heavy metals like cadmium, copper, lead, and zinc. Restricting of the siderophore to a metal expands the dissolvable metal fixation Thus, bacterial siderophores help to reduce the burdens forced on plants by high soil levels of heavy metals.

Phytohormone-

Indole-3-acetic acidic (IAA)- is the individual from the gathering of phytohormones and is by and large viewed as the main local auxin which is low-sub-atomic weight, natural substances. Indole-3-acetic acid was found to be the substance that was called auxin. This phytohormone auxin is a critical controller of numerous parts of plant development and improvement, including cell division and elongation, tropisms, apical predominance, senescence, abscission, and blossoming (Teale *et al*., 2006); Due to the abundance of root exudates, a high percentage of rhizosphere bacteria are likely to synthesize auxin as secondary metabolites. As a result, the level of auxin is typically higher in the rhizosphere. The development of auxin (IAA), has been perceived as a significant impact on direct plant-development capacities of rhizosphere microbes. For different PGPR, it has been exhibited that improved root expansion relates to bacterial IAA biosynthesis. Endless supply of plants with PGPR, led to change in root design, fundamentally as an expansion in root hairs and parallel roots and shortening of the root length. IAA biosynthesis is far and wide among plant-related microscopic organisms. Microbes can utilize this phytohormone to cooperate with plants as a component of their colonization procedure, including Phytostimulation and basal plant protection instruments. IAA can likewise be a flagging particle in microbes and consequently can straightforwardly affect bacterial physiology. IAA creation under in vitro condition has been accounted for by many explores *in Azospirillum sp., Azotobacter sp., Azotobacter chrococcum, Pseudomonas fluorescens.*

Cytokinin-known to encourage the division of cells, expansion of cells, and tissue growth in some plant parts (Werner et al., 2003). Cytokinin assume a significant role throughout development, from seed germination to leaf and establish senescence and tweak physiological phenomena significant over the lifetime of the plant, including photosynthesis and respiration. It has been viewed that as numerous as 90% of microorganisms found in the rhizosphere are equipped for delivering cytokinin. *Azotobacter sp., Rhizobium sp., Rhodospirillum rubrum, Pseudomonas fluorescens, Bacillus subtilis,* and *Paenibacillus polymyxa* are some of the plant-growth-promoting rhizobacteria that can produce cytokinin and other growth-promoting substances.

Gibberellin- are a class of phytohormones generally concerned with changing plant morphology by the expansion of plant tissue, especially stem tissue (Ross CW, 1994). These are produced by higher plants, organisms, and microorganisms. They are engaged with a few plant formative cycles, including cell division and elongation, seed germination, stem lengthening, blooming, natural fruit setting, and delay of senescence. The capacity of microorganisms to combine gibberellins-like substances was first depicted in *Azospirillum brasilense* and *Rhizobium*. Creation of gibberellins had been discovered in various bacterial genera that occupy the plant underground root growth including *Azotobacter, Arthrobacter, Azospirillum, Pseudomonas, Bacillus., Acinetobacter, Flavobacterium, Micrococcus, Agrobacterium.*

Abscisic acid- (ABA) plays a primary role in water-stressed environment, such as found in arid and semiarid climates where it helps in combating the stress through stomatal closure of leaves. Therefore, its uptake by and transport in plant and its presence in the rhizosphere could be extremely important for plant growth under water stress conditions (Frankenberger and Arshad, 1995)

Indirect Mechanisms

Antibiotics-One of the most effective mechanisms by which PGPR employ to prevent proliferation of phytopathogens is the synthesis of antibiotics. Antibiotics include a heterogeneous group of organic, low-molecular-weight compounds that are deleterious to the growth or metabolic activities of other microorganisms. There are six classes of antibiotic compounds linked to the biocontrol of root diseases are, phenazines, phloroglucinols, pyoluteorin, pyrrolnitrin, cyclic lipopeptides (all of which are diffusible) and hydrogen cyanide (HCN which is volatile) (Haas and Defago, 2005). The mechanism of action is to inhibit synthesis of pathogen cell walls, influence membrane structures of cells and inhibit the formation of initiation complexes on the small subunit of the ribosome.

Lytic enzymes-The growth and activities of pathogens can be suppressed by the secretion of lytic enzymes. These are cell wall degrading enzymes such as glucanases, proteases, chitinases, and lipases etc, secreted by biocontrol strains of PGPR involved in the lysis of fungal cell wall (Neeraja et al., 2010). These enzymes either digest the enzymes or deform components of cell wall of fungal pathogens. Hydrolytic enzymes directly contribute in the parasitisation of phytopathogens and rescue plant from biotic stresses.

Induced systemic resistance-The uses of plant growth promoting strains are reported to trigger the resistance of plants against pathogens (Ramamoorthy et al., 2001). Induced resistance (ISR) is a state of enhanced defensive capacity developed by a plant when appropriately stimulated. Systemic acquired resistance (SAR) and induced systemic resistance (ISR) are two forms of induced resistance which can be differentiated on the basis of the nature of the elicitor and the regulatory pathways involved. SAR can be triggered by exposing the plant to virulent, avirulent, and non-pathogenic microbes and involves accumulation of pathogenesis-related proteins (chitinase and glucanase), and salicylic acid. ISR does not involve the accumulation of pathogenesis-related proteins or salicylic acid, but instead, relies on pathways regulated by jasmonate and ethylene and these hormones stimulate the host plant's defence responses against a variety of plant pathogens. Bacterial components to induce induced systemic resistance such as lipopolysaccharides, flagella, siderophores, etc.

Production of Volatile Organic Compound- Volatile organic compounds (VOCs) produced by plant growth promoting rhizobacteria (PGPR) are heavily involved in improving plant growth and induce systemic resistance (ISR) towards pathogens. Several bacterial species, from diverse genera including Bacillus, Pseudomonas, Serratia, Arthrobacter, and Stenotrophomonas, produce VOCs that influence plant growth. Acetoin and 2,3-butanediol synthesized by Bacillus are the best known of these compounds and are responsible for significant improvements in plant growth. Some other PGPR strains emit VOCs that can indirectly mediate increases in plant biomass, disease resistance, and abiotic stress tolerance. VOC emission is indeed a common property of a wide variety of soil microorganisms, although the identity and quantity of volatile compounds emitted vary among species.

Rhizoremediation

The plant-stimulated bioremediation of organic pollutants by rhizospheric microorganisms is termed rhizoremediation. It is also referred to as rhizodegradation, rhizosphere bioremediation and microbe assisted phytoremediation technology (MAPT). Rhizoremediation, a major mechanism for phytoremediation of petroleum-polluted soils, mainly focuses on stimulating the population of degrading microorganisms through the plant rhizospheric effects. The rhizosphere is the extremely active area around roots (1–2 mm) influenced by plant activity. In the rhizosphere, roots can provide a favourable microenvironment and a carbon source for hydrocarbon-degrading microbes. In return, microorganisms enhance plant growth by providing plant nutrients, protection against plant pathogens, and contaminant degradation. It is well established that rhizoremediation by grasses, trees and other annual species helps in dissipation of TPH from petroleum-polluted soils (Cook and Hesterberg, 2013). Rhizobacteria utilize organic contaminants as a carbon and energy source for their cell functioning and life cycle, whereas plants favour the survival of rhizobacteria by providing residency. Additionally, plants can change the rhizosphere area to favourable microenvironment by providing root exudates, organic acids, cations/anions and biogenic surfactants. Rhizobacteria capable of synthesizing bio-surfactants have been shown to enhance the bioavailability of organic pollutants by releasing the pollutant from soil particles, and thus their degradation. These bio-surfactants can be helpful for desorption of many organic xenobiotics from soil particles. When plant roots interact with microbes in TPH-impacted soils, roots provide microaerophilic conditions. Plant root exudates; low molecular weight organic acids (malic acid, succinate and ascorbate), provide substrate for microbial metabolism as well as adjust the pH of soils. Therefore, degradability and availability of hydrocarbons to microbes increases. There are four possible ways by which root exudates can enhance the biodegradation of petroleum-contaminated soils. These include direct degradation by plant enzymes, enhancement of pollutant bioavailability, co-metabolic process and stimulation by energy/nutrient flow (Martin et al., 2014). Addition of inorganic (nutrients, fertilizers, surfactant) and organic soil amendments (compost, biochar), soil or plant (seed) inoculation with endophytic or rhizospheric microbial strains, the application of transgenic microbes or plants, and integrated approaches are some of the approaches by which we can enhance the rhizoremediation process.

CONCLUSION

Plant growth promoting rhizobacteria in rhizosphere soil is highly dynamic, more versatile in transforming, mobilizing and solubilising the nutrients. Therefore, the rhizobacteria are the dominant deriving forces in recycling the soil nutrients and consequently, they are crucial for soil fertility. They may be extensively used in plant growth promotion as it acts as a plant nourishment and enrichment source which would replenish the nutrient cycle between the soil and plant roots, exhibits detoxifying potential, controls phytopathogen thereby exerts a positive influence on crop productivity and ecosystem functioning, hence can be implemented in agriculture. With better research and development, these microbial populations use would become a reality and instrumental and build stability and productivity of agro-ecosystems, thus leading us towards an ideal agricultural system with sustainability, improvement in human health, benefits environment and ecosystem and leads to the production of adequate food for the increasing world population.

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