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Full Length Review Paper

Beneficial effects of plant-growth-promoting rhizobacteria they improve soil productivity and crop production: A study of benefits

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Bacteria in soil are essential for biogeochemical cycles and have been utilized for decades for crop production. The effects of bacterial interactions on plant health and soil fertility are determined in the rhizosphere. Plant growth-promoting rhizobacteria (Gray, Smith and biochemistry) are free-living bacteria that can promote plant growth by colonizing the plant root. PGPR is also referred to as Plant Health-Promoting Rhizobacteria (PHPR). They are associated with the rhizosphere, which is one of the most important soil ecological environments for plant microbes. Cyanobacteria that fix nitrogen symbiotically include *Rhizobium, Bradyrhizobium, Azorhizobium, Allorhizobium, Sinorhizobium*, and *Mesorhizobium*. Plant growth promoters that attach and colonize the root surfaces are free-living nitrogen-fixing bacteria, or association nitrogen fixer's bacteria. These bacteria have the potential to contribute to the sustainability of plant growth. There are three main ways that the PGPR works: synthesizing specific compounds for the plants, facilitating the uptake of certain nutrients from the soil, and reducing or preventing disease. Plant growth promotion there are both direct and indirect ways to promote plant growth and development. Indirect plant growth promotion includes preventing phytopathogenic organisms from causing damage. In addition to producing siderophores, several bacterial species have also been found to synthesize antibiotics and control soil-borne pathogens. Hydrogen Cyanide (HCN) and/or enzymes capable of degrading fungal cell walls are another mechanism by which PGPR inhibits phytopathogens. There are two types of direct Plant Growth Promotion (PGPR): Symbiotic and non-symbiotic. Symbiotic PGPR generates plant hormones such as auxins, cytokines, gibberellins, ethylene and abscisic acid. Additionally, PGPR improves soil structure and organic matter content, enhances resistance to stress, stabilizes soil aggregates and helps solubilize mineral phosphates and other nutrients. By retaining more soil organic nitrogen and other nutrients in the plant-soil system, PGPR reduces the need for fertilizer N and P and enhances their release.

Key words: PGPR, Symbiotic, Non-Symbiotic, Plant hormones, P-solubilization.

INTRODUCTION

Soil bacteria have been used to enhance crop production (Davison, 1988) with their primary function being the supply of nutrients to crops and the stimulation of plant growth, e.g., by producing plant hormones to control or inhibit plant pathogen activity, thereby improving soil structure, bioaccum lation and leaching of inorganics through microbial activity. Recently, bacteria have been used in soil for mineralizing organic pollutants, *i.e.* bioremediation [1].

A critical component of sustainable crop production is plant microbe interactions in the rhizosphere, which transform, mobilize, solubilize, etc., nutrients from a limited pool of nutrients, and allow plants to capture essential nutrients in order to achieve their full genetic potential [2]. At present, the use of biological approaches is becoming more popular as an additive to chemical fertilizers for improving crop yield in an integrated plant nutrient management system. In this regard, the use of PGPR has found a potential role in developing sustainable systems in crop production.

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There are now many symbiotic (*Rhizobium* sp.) and non-symbiotic bacteria being used in agriculture throughout the world to enhance plant productivity. Free-living soil bacteria that support plant growth are known as Plant Growth Promoting Rhizobacteria (PGPR), which colonize the roots of plants and stimulate growth. A PGPR is also known as a Plant Health Promoting Rhizobacteria (PHPR) or a Nodule Promoting Rhizobacteria (NPR) and they are associated with the rhizosphere, which is an important soil ecological environment where plants interact with microbes. There are two types of PGPR, symbiotic bacteria and free-living rhizobacteria, based on their relationship with the plants. Based on their location, PGPR can also be divided into two groups: iPGPR (symbiotic bacteria), which live within plant cells, produce nodules, and are confined to the plant cell's specialized structure; ePGPR (free-living rhizobacteria) live outside plant cells, and do not form nodules, but still stimulate plant growth [3]. A number of bacteria have been used as soil inoculants to improve the supply of nutrients to crop plants. The best known PGPR are Rhizobia, which produce nodules in leguminous plants. There have been numerous successful applications of *Rhizobium* species that allow the nitrogen-fixing symbiosis to be established with leguminous crops around the world. However, non-symbiotic nitrogenfixing bacteria like Azotobacter, Azospirillum, Bacillus, and Klebsiella sp are also utilized to enhance plant productivity on a large area of arable land worldwide (Lynch, 1983). To increase the phosphorus status of plants, phosphate-solubilizing bacteria such as Bacillus and Paenibacillus (formerly Bacillus) have been applied to soils (Brown, 1974). PGPR have the potential to contribute in the development of sustainable agricultural systems. Generally, PGPR function in three different ways synthesizing particular compounds for the plants facilitating the uptake of certain nutrients from the soil and lessening or preventing the plants from diseases. A PGPR is capable of contributing to the development of sustainable agricultural systems. In general, PGPRs function in three ways by synthesizing compounds that facilitate the uptake of nutrients from the soil, as well as preventing or reducing the incidence of diseases on plants [4].

LITERATURE REVIEW

There are several possible explanations for PGPR-mediated enhancement of plant growth and yield.

- A plant's ability to produce a vital enzyme, 1-aminocyclopropane-1-carboxylateACC). deaminase, which reduces ethylene levels in its roots, increasing root size and growth.
- It can be used as an enzyme in the root to reduce ethylene levels in the root of developing plants, thereby increasing their root length and growth. A major function of 1-aminocyclopropane-1-carboxylate deaminase is to reduce the level of ethylene in the root of developing plants.
- Produces hormones such as auxin, *i.e.* indole acetic acid (IAA), abscisic acid. (Murray et al.), gibberellic acid and cytokinin.
- The organism produces cyanide, fluorescent pigments, β-1,3-glucanase, chitinases, antibiotics and siderophores that are antagonistic to phytophatogenic bacteria.
- Nutritional ions, such as mineral phosphates, are solubilized and mineralized.
- The plant is more resistant to drought, salinity, waterlogging and oxidative stress.

Additionally, PGPR has been applied to remediate contaminated soils when they are associated with plants. Therefore, maximizing the efficiency of meager amounts of external input in sustainable agriculture production systems requires utilizing the optimal combinations of beneficial bacteria. These bacteria would be a valuable partner in the agricultural industry if different mechanisms were further understood [5].

Symbiotic N_2-fixing bacteria

Nitrogen is essential for the production of enzymes, proteins, chlorophyll, DNA, and RNA. Nitrogen is responsible for plant growth and food production. Rhizobial bacteria fix atmospheric nitrogen as part of their symbiotic nitrogen fixation process. Agriculture currently uses 65% of its nitrogen from this process of Biological Nitrogen Fixation (BNF) and it will continue to be an important component of sustainable crop production in the future. BNF has important biochemical reactions primarily caused by legumes symbiotically interacting with N_2-fixing bacteria that convert atmospheric Nitrogen (N_2) into Ammonia (NH_3). A symbiotic relationship between rhizobia and legumes is marked by chemotactic responses to flavonoids released as signals by legumes. Nodulation (nod) genes are expressed in rhizobia when these compounds are administered, and they produce Lip-Chitooligosaccharide (LCO) signals, which trigger root cell division, leading to nodule formation.

A series of interactions between rhizobia and leguminous plants create nodules, which serve as symbiotic nitrogen fixation sites. However, nodulation on legume roots is affected by a number of factors, including host microsymbiont compatibility, soil physicochemical conditions, and a variety of biomolecules, including flavonoids, polysaccharides, and hormones [6]. 1990 A compatible strain of *Rhizobium* serves as an initiator of nodular development by establishing a molecular dialogue between the host plant and *Rhizobium*. A rhizobial infection begins when bacteria penetrate roots in a host-controlled manner. In the process of curling root hair, *Rhizobium* is trapped inside a cavity. A tube-like structure is formed by invaginating root hair plasma membranes, by which Rhizobium enters the plant and reaches the roots. Thus, the nodule primordium reaches the cortex of the root and develops into a nodule when the *Rhizobium* is released. The strains used in such cases may become exopolysaccharide deficient because of mutation or some unspecified reason, leading to no nodulation despite inoculation with certain rhizobial cultures [7].

Non-symbiotic N_2-fixing bacteria

Plant Growth Promoting Rhizobacteria (PGPR) significantly increase the vegetative growth and grain yield of C3 and C4 plants. Free-living heterotrophic diazotrophs like *Azotobacter vinelandii* and *Azotobacter chroococcum* thrive on reduced C compounds such as sugar as a source of energy. Straw application increases their activity in rice cultures, possibly due to the breakdown of cellulose into cellobiose and glucose by microorganisms. A result of *Azotobacter* application, rice and cotton yields and wheat yields increased. According to Kennedy and Tchan Clostridia are obligatory anaerobic heterotrophs capable of fixing N_2 in the absence of oxygen clostridia are usually isolated from rice soils and their activity increases when straw is returned to fields, which raises the C to N ratio [8]. It has been shown that *Azospirillum* soil applications can increase cane yields for both plant and ratoon crops. The PGPR effect also stimulated plant root growth, which in turn increased N and P uptake in field trials [9].

Phosphorus-solubilizing bacteria

Phosphorus one is the essential macronutrient for plant growth. It is contained in soil at a concentration of 400-1200 mg kg^{-1} phosphorus exists in two forms, organic phosphates and inorganic phosphates, and plays an important role in plant growth and development. An important trait for a PGPR is its ability to convert both organic and inorganic phosphate compounds into plant-accessible forms. The amount of soluble phosphorus in soil is often quite low, normally at values of 1 ppm or less. The plant absorbs P in a range of forms, but the majority is taken up as HPO_4^{-2} or $H_2PO_4^{-1}$. In general, pH and soil type have a significant impact on the phenomena of P fixation and precipitation in soil numerous studies have shown that microbial P release from organic P sources occurs. As a result of their ability to solubilize inorganic phosphates (mineral phosphate) such as tricalcium phosphate, dicalcium phosphate, hydroxyl apatite, and rock phosphate, bacteria from genera such as *Pseudomonas*, *Bacillus*, *Rhizobium*, *Burkholderia*, *Achromobacter*, *Agrobacterium*, *Microccocus*, Aerobacter, *Flavobacterium* and Erwinia and others belong to these genera. Some of the most powerful phosphate solubilizing strains are *Pseudomonas*, *Bacillus*, and *Rhizobium*, whereas tricalcium phosphate and hydroxyl apatite appear to have more degradation potential than rock phosphate. Bacteria such as *Pseudomonas* sp., *Erwinia herbicola*, *Pseudomonas cepacia*, and *Burkholderia cepacia* are commonly found to produce organic acids, especially gluconic acid, during mineral phosphate solubilization. A second organic acid found in Rhizobium leguminosarum strains with phosphate-solubilizing ability is 2-ketogluconic acid *Rhizobium meliloti*, *Bacillus firmus* and other soil bacteria have not been identified. Other organic acids have also been found as phosphate solubilizers, including glycolic acid, oxalic acid, malonic acid, succinic acid, citric acid and propionic acid. The metabolic basis of mineral phosphate solubilization in Gram-negative bacteria appears to lie in the direct periplasmic oxidation of glucose to gluconic acid and 2-ketogluconic acid [10]. In addition to organic acids, other possibilities include releasing H+ on the outer surface in exchange for cation uptake, or activating ATPase, which can be used to dissolve mineral phosphates through H+ translocation. Several organic substrates in soil can be used as P sources for plant growth, however, they must be hydrolyzed into inorganic P in order to be available to plants. Enzymes such as phosphatase (phosphohydrolases) are responsible for mineralizing the majority of organic phosphorus compounds. At acidic and neutral pH levels, the inner rhizosphere of maize, barley, and wheat displayed considerable phosphatase activity [11].

Other mechanisms of plant growth promotion

Plants may benefit from the improved uptake of nutrients by rhizosphere bacteria, which may also produce compounds that promote plant growth. The bacteria can also negatively or indirectly affect plant growth by protecting plant root surfaces from colonization by pathogenic microbes through direct competitive effects and antimicrobial production. Symbiotic and non-symbiotic bacteria may directly promote plant growth through the production of plant hormones and other PGP activity. Plant Growth Promoting Rhizobacteria (PGPR) synthesize and export phytohormones called Plant Growth Regulators (PGRs), which are thought to regulate plant growth and development. They are organic compounds that influence plant physiological processes at extremely low concentrations, and are thought to be beneficial to plants [12].

DISCUSSION

In addition to auxins and gibberellins, five types of PGRs are known, including cytokinins, ethylene, abscisic acid, and ethylene. The physiologically most active auxin in plants is Indole-3-Acetic Acid (IAA), which is known to stimulate both rapid (*i.e.,* elongation of cells) and long-term (*i.e.,* division and differentiation of cells) responses inplants. Plant growth regulator IAA is the most common and well-characterized phytohormone [13]. Plant growth regulator IAA is present in 80% of bacteria isolated from rhizosphere soils. Cytokinins which are usually present in small amounts in biological samples and are difficult to identify and quantify. The primary effect of cytokinin on plants is enhanced cell division: However It has been found that over 30 growth-promoting compounds in plants and associated microorganisms belong to the cytokinin group and that 90 percent of microorganisms present in the rhizosphere possess the ability to produce. There are numerous and perhaps all species of bacteria capable of synthesizing ethylene (Primrose, 1979) [14].

Ethylene regulates very many aspects of plant growth, development, and senescence (Reid, 1995). Ethylene also produces several cytokinins that can influence plant growth and development *in vitro*. Aside from its role as a crop ripening hormone, ethylene promotes adventitial root formation, stimulates germination, and breaks dormancy in seeds. However, root elongation (as well as symbiotic N_2 fixation in leguminous plants) is prevented if ethylene concentration is kept high after germination. In addition to producing phosphates, gluconase, dehydroginase, antibiotics, PGPR has also been shown to solubilize minerals phosphates and other nutrients, stabilize soil aggregates, and improve soil structure and organic matter [15].

In plant-soil systems, the mechanisms involved regulate soil organic nitrogen and other nutrients, thereby reducing the need for fertilizers and enhancing nutrient release. Indirect plant growth promotion involves preventing phytopathogenic organisms from causing adverse effects. A siderophore is a small iron-binding molecule found in soils that can be produced by microorganisms in order to compete with pathogens by removing iron from the environment. Iron is found primarily as ferric ions in soils, which can't be directly assimilated by microorganism. As another mechanism of phytopathogen inhibition, rhizobacteria produce Hydrogen Cyanide (HCN) and/or enzymes that degrade fungal cell wall, such as chitinase and beta-1, 3-glucanase [16-18].

In general, pectinolytic enzymes are important in the invasion of roots by bacteria. In spite of the fact that PGPRs are found in a wide range of species of Bacillus, the most commonly developed ones come from endospores which provide population stability during product formulation and storage. It is possible for some PGPR to establish themselves on seeds if they are inoculated prior to planting. The use of PGPR for biological control of diseases, pathogens and insects in different crops PGPR crops diseases/pathogens/insect reference *Bacillus amyloliquefaciens* strain 1 N 937a Tomato Tomato mottle virus. Through their use of scarce resources, PGPR helps to reduce damping-off in many crops by preventing or limiting the growth of pathogenic microorganisms [19]. Even if nutrients are not limiting, the establishment of beneficial organisms on roots reduces the likelihood that pathogenic organisms will find a place to establish themselves later. There are numerous rhizosphere organisms that produce compounds that are toxic to pathogens (plant disease) *Bacillus subtilis* is one such commercialized PGPR organism, and it affects a large number of pathogenic fungi [20].

CONCLUSION

Soil bacteria, they convert atmospheric nitrogen into ammonia and play a pivotal role in cycling nutrients within the soil. Numerous species of bacteria live in the soil, some of which play important roles in nutrient cycling and protect crops. By acting in several ways, Plant Growth-Promoting Rhizobacteria (PGPR) improve the growth and development of plants directly and indirectly. Secondary metabolites, or plant growth substances, result in a change in root morphology that increases root surface area for nutrient uptake, siderophores production, soil-borne root pathogen encounter prevention, phosphate solubilization and nitrogen fixing. Biological inoculums for legumes have attracted much attention around the world because they optimize nutrient cycling in the event of stress due to unsuitable weather or soil conditions. PGPR inoculants can also be used separately or in combination with *Rhizobium* sp. for a variety of crops. In laboratory and greenhouse settings, these technologies have shown positive results; however, the effects of PGPR on the field are difficult to predict because of natural variations. As PGPR are not able to live in soil forever, it is suggested that they be reinoculated every year or season to maximize their viability and biological activity.

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