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Review Article: 06 to 10
ISSN: 3041-5322
https://agriculture.researchfloor.org/

Plant Growth Promoting Rhizobacteria Enhancing Vigour and Yield: A Brief Review

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ABSTRACT

Chemical fertilizers are becoming more and more necessary in developing countries like India where they damage the environment, water, and human health, harm the soil's micro-flora and fauna, and also increase production costs. Finding a safer alternative for these harmful compounds is, therefore, essential. The diverse collection of plant growth-promoting rhizobacteria (PGPR) quickly colonizes the rhizosphere and offers direct or indirect protection to agricultural plants. In addition to significantly increasing the seed germination rate, PGPR treatment offered protection against harmful microbes. It has been shown that PGPR significantly increased several crop's yields and their capacity to absorb nutrients and water. PGPR exhibits encouraging outcomes by developing a symbiotic interaction with other beneficial microorganisms, boosting nitrogen fixation, and expanding the supply of primary, secondary, and micro-nutrients. The present review highlights the usefulness of PGPR as a biofertilizer for a safe and effective substitute for chemical fertilizers in environmentally responsible and sustainable agriculture.

Keywords: *PGPR, Sustainable agriculture, Biofertilizer, Rhizosphere, Flora, Fauna*

Introduction

Economically viable and biologically sustainable farming needs good agricultural practices. The quality and productivity of the farm produce were directly or indirectly influenced by soil health. The biggest challenge in today's agriculture world will be the maintenance of soil without altering environmental sustainability. Plant growth is always affected by a narrow area of soil adjacent to the plant root system, the rhizosphere, influenced by microbial activity. Plant growth-promoting rhizobacteria (PGPR), a type of rhizospheric bacteria, greatly improved growth parameters and are essential for suppressing many crop plant diseases. The term (PGPR) was introduced by [23] to describe the population of microorganisms that efficiently colonized plant roots and displayed plant growth promotion. Previous researchers found that rhizobacteria encourage the growth of plants and are connected to the surface of the roots of many plants [12]. The beneficial effects of these rhizobacteria on plant growth can be direct or indirect. PGPR plays a crucial role in nitrogen solublisation and mineralization, increasing nutrient availability to plants in the rhizosphere that involves the release of different organic acids and enzymes, making them more available to plants.

Citation: Smitha Thomas and Lizzy Mathew (2024). Plant Growth Promoting Rhizobacteria Enhancing Vigour and Yield: A Brief Review.
Agriculture Archives: an International Journal.
DOI: https://doi.org/10.51470/AGRI.2024.3.3.06

Received on: July 10, 2024
Revised on: August 21, 2024
Accepted on: September 24, 2024

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Phosphorus Solubilization

Bacteria and fungi can solubilize phosphorus in the soil through several methods and help plants to absorb phosphorus and promote plant growth [38]. Soil bacteria with high levels of acid phosphatase species include *Rhizobium, Enterobacter, Serratia, Citrobacter, Proteus, Klebsiella, Pseudomonas* and *Bacillus*. Four strains were identified by [6] as phosphate-solubilizing bacteria (PSB) capable of secreting organic acids to dissolve tricalcium phosphate in the medium, which includes *Arthrobacter ureafaciens, Phyllobacterium myrsinacearum, Rhodococcus erythropolis* and *Delftia* sp. Sustainable agricultural practices promote beneficial microorganisms to improve phosphorus solubilization in soil, reducing the need for synthetic fertilizers and minimizing the risk of phosphorus runoff into water bodies, which can cause environmental issues such as eutrophication.

Nitrogen Mineralization

Microorganisms, typically bacteria and fungi convert organic nitrogen from plant leftovers and waste into inorganic forms like ammonium (NH_4^+) and nitrate (NO_3^-)via ammonification and nitrification. During the ammonification process, bacteria and fungi break down complex organic nitrogen molecules like proteins and amino acids into simpler forms like ammonia (NH_3) and ammonium (NH_4^+). During the nitrification process, microorganisms turn ammonium into nitrite (NO_2-) and ultimately nitrate (NO_3-). Action of *Bacillus sp., Azotobacter sp., Pseudomonas sp.,* and *Mesorhizobium sp.,* were oserved bt [3] which produces ammonia. Nitrogen fixation and ammonia production were related and were noticed in leguminous rhizobacteria. It is important to note that not every PGPR has all of these qualities and their efficiency in increasing nitrogen availability may vary depending on environmental circumstances and bacterial-plant interactions.

Iron and Other Micronutrient Solubilization

Siderophores operate as chelators, binding to iron and other micronutrients to create stable complexes that plant roots can more efficiently absorb. Furthermore, PGPR can create organic acids like citric, gluconic, and oxalic acid can help soil micronutrients like zinc, copper, and manganese become more soluble. The organic acids that dissolve the chemical connections between micronutrients were noticed by [8] and soil particles which make them more available for plant absorption by eliminating synthetic micronutrient fertilizer requirements. *In vitro* siderophore pyoverdin was detected by [24] which can prevent the growth of bacteria and fungi with less potent siderophores. *Fusarium oxysporum* was also suppressed by a pseudobactin, siderophore produced by *P. putida* strain in soil lacking in iron; this suppression was removed by re-treating the soil with iron that had inhibitions for the formation of iron chelators by microorganisms.

HCN production

According to [3] *Bacillus* (50%) and *Pseudomonas* (88.89%) at plant root nodes and rhizospheres share the ability to produce HCN and can inhibit infections in roots. HCN synthesis indirectly enhances phosphorus accessibility by metal chelation and sequestration, as well as indirectly inducing nutrient accessibility in rhizobacteria and host plants [39,11]. HCN generation by PGPR is genus-independent; thus, they may be utilised as biofertilizers or biocontrol agents to boost crop production and yields [2]. HCN, a metabolite, inhibits microorganism proliferation and impacts plant growth development [16]. The PGPR enzyme secretes hydrogen cyanide synthases, which break down harmful bacteria cell walls [4] rhizobacteria such as *Rhizobium, Aeromonas, Bacillus, Pseudomonas, Enterobacter,* and *Alcaligenes* were reported by [43].

Phytohormones

Some PGPR may create auxins, including Indole-3-acetic acid (IAA), the most prevalent and physiologically active auxin in plants that can boost plant development by boosting root elongation, lateral root production, and general vigor [5]. Cytokinins are plant hormones that control cell division, shoot growth, and leaf senescence. Plants utilize cytokinins to maintain totipotent stem cells in shoot and root meristems [26]. Plants rely on auxins and cytokinins to regulate several developmental processes, including apical dominance, and root and shoot growth. *In vitro* organogenesis relies heavily on the equilibrium of auxin and cytokinin. Callus cultures with a high auxin to-cytokinin ratio create roots, whereas those with a low ratio develop shoots. Some PGPR can indirectly boost gibberellin production in plants by raising the expression and activity of essential enzymes, including ent-kaurene synthase and ent-kaurene oxidase. PGPR-mediated gibberellin production can enhance plant growth, including stem elongation and fruit formation [19]. Gibberellin production has been verified in *Acetobacter diazotrophicus, Herbaspirillum seropedicae,* and *Bacillus* sp. by physicochemical approaches like GC-MS. Species of *Rhizobium* and Pseudomonas that produce ACC deaminase are responsible for ethylene destruction [9]. Rhizospheric bacteria are beneficial in reducing ethylene buildup and promoting root strength, which is essential for survival in environmental challenges. The significance of the rhizosphere was highlighted by [21] with beneficial bacteria to increase the synthesis of phytohormones and other metabolites that directly influence plant growth is one of the abundant ecological and functional properties of the plant in the rhizosphere and soil.

ACC Deaminase

Enzyme ACC deaminase converts 1-aminocyclopropane-1-carboxylate (ACC), an intermediate precursor of ethylene in higher plants, into α-ketobutyrate and ammonia [18]. A sufficient amount of ethylene derived from the existing pool of ACC, also known as the small peak of ethylene in the biphasic ethylene response model described by [13] and [32] was thought to be beneficial to plants in activating plant defensive responses to stress stimuli (e.g., temperature extremes, drought or flooding, insect pest damage, phytopathogens and mechanical wounding) [1]. However, excessive ethylene accumulation, also known as stress ethylene or the more outstanding peak of ethylene in the biphasic model, can hurt plant development (e.g., chlorosis, abscission, and senescence) and can cause death when present in high concentrations in plant tissues [12]. The ACC deaminase-producing PGPR that dwells on plant surfaces or zcolonizes in plant tissues acts as an ACC sink [7], and using ACC as a nitrogen (N) source is favorable to plant health because N absorption is always reduced under salt conditions [10]. *B. subtilis* and *B. safensis* produced more ACC deaminase, biofilm, EPS and Alginate (Alg) when NaCl concentrations rose in the nutritional broth were reported by [27].

Potassium Solubilization

Potassium is the third most essential plant growth nutrient, contributing significantly to plant metabolism, growth, and development. Without enough potassium, the plants would have poorly formed roots, develop slowly, generate little seeds, and have poorer yields [44] as well as greater susceptibility to diseases and pests [42]. Potassium-solubilizing microorganisms create organic acids that may dissolve potassium rock [18]. Microbial inoculants in the rhizosphere, such as *Aspergillus, Bacillus sp., Clostridium, Burkholderia, Acidothiobacillus ferrooxidans, Pseudomonas, Paenibacillus sp., Bacillus mucilaginous, Bacillus circulans* and *Bacillus edaphic,* have been found to release potassium-bearing minerals in an accessible form [25]. Microorganisms in the soil produce organic acids like oxalate, citrate, acetate, ferulic acid, and coumaric acid, which accelerate mineral dissolution and produce protons in the rhizosphere which leads to mineral K solubilization [22]. Using potassium solubilizing bacteria (PSB) can improve plant nutrient availability and reduce the need for chemical fertilizers [34].

Manganese Solubilization

Manganese (Mn), a co-factor for enzymes involved in antioxidant production, photosynthesis, and defense against pathogens, is essential for plant growth. The amount of organic matter present, the pH of the soil, the mineralogy, and the redox potential of the soil can all have an impact on the availability of Mn in the soil. To increase Mn bioavailability, beneficial bacteria play various roles, such as creating organic acid, lowering pH, and encouraging root growth. In addition, they create siderophores, anti-pathogenic chemicals, and symbiotic partnerships with plants, which facilitate Mn uptake and transportation, promote plant growth, and lessen adverse environmental effects. The microbial interactions was explored by [23] that may be a helpful strategy for enhancing plants' Mn uptake, increasing crop yield, and preserving environmental sustainability.

ISR- Induced Systemic Resistance

Plants with PGPR develop systemic resistance, which means their immune system is better prepared to respond to pathogens called induced systemic resistance (ISR) or systemic acquired resistance (SAR). Pathogen-induced systemic acquired resistance (SAR) was similar to Rhizobacteria-mediated ISR are *Pseudomonas* sp. and *Bacillus* sp., where both forms of induced resistance increase the resistance of uninfected plant sections to nematodes, insects, and bacterial, viral, and fungal plant diseases [33]. SAR was used to report salicylic acid-dependent induced resistance activated by localized infection, operating via many signaling pathways. ISR requires the signaling pathways for jasmonic acid (JA) ethylene (ET), and SAR is induced by salicylic acid (SA). Jasmonate is a signal molecule in the second plant sdefense process, called Systemic Resistance Induction (SRI), certain non-pathogenic rhizospheric bacteria can trigger this system by producing diffusible chemicals that the plant detects and responds to by inducing a resistance mechanism and is primarily triggered by the presence of determinants incorporated in the wall of the bacteria. However, when combined, ISR and SAR offer more protection than any of them alone, demonstrating that they might function additively to increase the resistance to pathogens [43].

Benefits of PGPR as Biofertilizers

Biopesticides represent a lower danger to humans and the environment than conventional pesticides and they are garnering global interest as a novel tool for killing or managing pest species such as weeds, plant diseases and insects. Bacterial biopesticides control weeds, plant diseases, nematodes, and insects. Spore formers such as *Pseudomonas aeroginosa*, *Serratia marcesens, Pseudomonas syringae, Bacillus thuringiensis* and *Bacillus popilliae* are commercially employed because of their effectiveness and safety [38]. Specific *Pseudomonas* species act as biopesticides by producing antimicrobial compounds such as pyrrolnitrin and pyoluteorin, which inhibit the spread of plant diseases. *Trichoderma* species serve as biopesticides and biocontrol agents for various plant diseases. Plants produce enzymes that break down infection cell walls and trigger sdefense responses to diseases [30]. The use of PGPR as biofertilisers and biopesticides in agriculture offers environmentally friendly alternatives to typical chemical inputs.

Commercialization of PGPR

The development and commercialization of PGPR strains rely on collaboration between research organisations and the industry. Various stages of commercialization was identified by [29] including antagonist strain isolation, screening, pot tests, field efficacy, mass production, formulation development, fermentation methods, formulation viability, toxicology, industrial linkages, and quality control. Isolating a successful strain from pathogen-suppressive soils is crucial for agricultural growth and can be done by dilution plate techniques or by baiting the soil with fungal structures like sclerotia [28]. Promising antagonists are investigated for effectiveness in field trials with traditional fungicides [31]. Liquid, semisolid, and solid fermentation processes can be used for mass manufacturing [26]. According to PGPR can directly stimulate plant growth by supplying phytohormones or signalling molecules or indirectly affect plant health by producing bioactive compounds with antimicrobial or stress-tolerance properties, referred to as biostimulants [20]. These substances can enhance a plant's ability to photosynthesise, alter the architecture development of the root system, or trigger the antioxidant defence system [39,15]. The links between microbial populations, microbial inoculants, and plant systems were recognised by [35] with a focus on enhancing plant development, the environmental resilience of agricultural systems, ecosystem services, and biological problems under stressful situations. Commercial success for PGPR strains involves economic market demand, consistent and broad spectrum activity, safety, stability, extended shelf life, minimal capital costs, and simple access to necessary materials.

Future Challenges and Prospects

Various microbial species that interact directly encourage vital plant growth and health activities. Biotechnological techniques, such as genetically engineering crops to improve growth and stress tolerance may increase agricultural production and sustainability by using hitherto novel PGPR strains with unique characteristics. Bioinoculants derived from these strains may offer targeted plant nutrition and pest control. Climate-resilient agriculture will get profit from strains that are drought, heat, or salt tolerant, such strains may increase agricultural production that might boost the efficacy of agricultural output. Characterizing PGPR strains enables the targeted and site-specific deployment of beneficial microbes for precision agriculture, they degrade pollutants rejuvenate degraded soils, and facilitate land use. Using PGPRin farming can improve food security by increasing crop productivity and resistance, particularly in places with limited resources these bioinoculants regularly will increase vegetable yields and productivity, especially under stressful situations. The world's population is steadily growing, but there is a discernible decline in arable land because of soil salinisation, sudden climate shifts, and decreased precipitation. The significance of identifying environmentally sound solutions to guarantee global food security has grown due to these issues [35].

Conclusions

Enriched rhizospheric soils with PGPR bacteria protect cultivated plants directly or indirectly. Several PGPR species such as species of *Bacillus, Pseudomonas, Rhizobium, Azotobacter, Enterobacter,* and *Azospirillum* are highly resistant to biotic and abiotic influences. The effectiveness of rhizoplane products and the survival of beneficial microorganisms rely on effective soil management. Combining cultural techniques with PGPR formulations can increase the amount of inoculate in soil. Farmers need to be aware of the adverse impacts of chemical zfertilizers and the advantages of using PGPR as a bio-fertilizer through multiple resources, including print media, extension staff, and internet services.

Acknowledgements

This research was guided by Prof. Dr. Lizzy Mathew, Department of Botany and Centre for Research, St. Teresa's College, Ernakulam, Kerala and Prof. Dr. K. Surendra Gopal, Head Department of Agricultural Microbiology, College of Agriculture, Vellanikkara, Thrissur, Kerala, India.

Conflict of Interest

The authors had declared, that there were no competing interests.

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