Importance and Future Prospects of Phosphate Solubilizing Rhizobacteria in Indian Agriculture

***Dr. B.S. Poonia**
****Dr. Lokesh Kumar**

Abstract

Phosphorus (P) is the second most important element for plant growth after nitrogen. Despite its abundance in most soils, phosphorus is rarely available in forms that plants can easily absorb, as it typically exists in insoluble forms such as phosphates. In conventional agriculture, phosphorus is usually provided through chemical fertilizers to meet plant needs, which significantly boosts plant production. However, chemical fertilizers are costly, have a substantial carbon footprint, and are environmentally unsustainable due to the high energy requirements for their synthesis. Additionally, phosphorus-containing agricultural runoff significantly contributes to the eutrophication of water bodies and environmental degradation. Moreover, plants can only utilize a small fraction of chemically-supplied phosphorus because 75-90% of it precipitates into complexes and quickly becomes fixed in the soil. These issues highlight the need for alternative, viable methods of supplying phosphorus to plants. Rhizobacteria have long been studied in vivo and in planta as suitable tools for sustainable agriculture due to their plant-growth-promoting activities, such as nutrient solubilization, nitrogen fixation, and phytohormone production. While extensive research has been conducted on various nutrient-solubilizing rhizobacteria and their potential in sustainable agriculture, their mechanisms of action and prospects remain not fully understood. This review specifically focuses on phosphorus-solubilizing rhizobacteria, evaluating their diversity, mechanisms of action, and prospects in sustainable agriculture based on current and future applications. This information is crucial for assessing their potential and determining their role in promoting sustainable agricultural systems.

Key words:- Phosphorus, sustainable, rhizobacteria

Introduction

Phosphate-solubilizing rhizobacteria (PSRB) are a group of beneficial bacteria that can convert insoluble forms of phosphorus to soluble forms, making it available for plant uptake. These bacteria are found in the rhizosphere, the region of soil surrounding plant roots, and play a critical role in enhancing soil fertility and promoting plant growth.

Phosphorus (P) is the second-most important nutrient after nitrogen in terms of plant growth and development (Kalayu, 2019; Mitra et al., 2020). This essential nutrient plays a critical role in nearly every metabolic process in plants, including photosynthesis, biosynthesis of macromolecules, respiration, energy transfer, and signal transduction (Billah et al., 2019). Phosphorus is a fundamental component of enzymes, proteins, coenzymes, nucleotides, phospholipids, and nucleic acids (Alaylar et al., 2020; Kafle et al., 2019; Kalayu, 2019). According to Mitra et al. (2020), phosphorus availability also enhances other basic plant functions such as cell division, cell enlargement, and the transformation of starches and sugars.

Although phosphorus is present in most soils in large quantities, its accessibility to plants is largely limited because it occurs in complex and insoluble forms, with only about 0.1% available for plant use (Alori et al., 2017). According to Alaylar et al. (2020), phosphorus anions are highly reactive and become immobilized through complex formation with various cations such as Mg^{2+}, Al^{3+}, Ca^{2+}, and Fe^{3+}, especially under low pH conditions. Consequently, the fraction of phosphorus available to plants is generally very low. This scarcity makes phosphorus a major limiting nutrient in most soils, leading to the widespread use of artificial phosphorus fertilizers to address deficits in agricultural lands (Mitra et al., 2020).

According to the FAO (2017), approximately 52.3 billion tons of phosphorus-based fertilizers are applied annually in agriculture. However, these synthetic fertilizers present numerous environmental problems. For instance, increased phosphorus runoff from agricultural fields has been identified as a major cause of eutrophication in surface waters (C. Bhattacharyya et al., 2020). Additionally, the continuous application of phosphorus fertilizers can disturb natural soil microbial ecosystems, contributing to soil fertility loss. The efficiency of chemical phosphorus fertilizers is also low, rarely exceeding 30%, due to phosphorus fixation in the form of iron/aluminium phosphate in acidic soils or calcium phosphate in neutral/alkaline soils (Kalayu, 2019). About 75-90% of added chemical phosphorus fertilizer is immobilized in soils, leading to long-term environmental impacts such as eutrophication, soil fertility depletion, and an increased carbon footprint (Zhang et al., 2017). Moreover, phosphorus is a finite resource, and with its high demand, it is estimated that the world's known reserves could be depleted soon.

The potential problems associated with chemical phosphorus fertilizers, along with the high costs involved in their production, have led to the search for alternative plant fertilization mechanisms. Plant Growth-Promoting Rhizobacteria (PGPR) are plant-root-residing bacteria that engage in symbiotic interactions and have been investigated for decades as alternative, environmentally friendly, and cost-effective plant fertilization tools (P. N. Bhattacharyya et al., 2016). Phosphate-solubilizing bacteria (PSB) are a subset of PGPR that can convert complex phosphorus forms into accessible forms for plants. While considerable research has been conducted on various nutrient-solubilizing rhizobacteria and their potential in sustainable agriculture, their mechanisms of action and future prospects remain to be fully understood.

This review focuses on the diversity, mechanisms of action, and prospects of PSB in sustainable agriculture, considering both the current state and future scenarios of their application. Such information is crucial for determining their potential and evaluating their role in promoting sustainable agricultural systems.

Diversity of Phosphorus-Solubilizing Rhizobacteria

PSRB are a diverse group of bacteria found in various environments, including soils, rhizospheres, and plant tissues. This diversity is reflected in their taxonomy, physiology, and mechanisms of phosphorus solubilization. Some of the most studied genera of PSRB include:

Pseudomonas: Pseudomonas species are among the most effective phosphorus solubilizers. They produce organic acids such as gluconic acid and 2-ketogluconic acid, which help solubilize inorganic phosphorus. Pseudomonas fluorescens and Pseudomonas putida are commonly found in the rhizosphere and are known for their plant growth-promoting properties.

Bacillus: Bacillus species are another important group of PSRB. They are known for their ability to produce a wide range of extracellular enzymes and organic acids that can solubilize phosphorus. Bacillus megaterium and Bacillus subtilis are well-studied examples that have been shown to enhance plant growth and phosphorus uptake.

Rhizobium: Rhizobium species are primarily known for their role in nitrogen fixation in leguminous plants. However, many Rhizobium species also possess the ability to solubilize phosphorus. They achieve this through the production of organic acids and phosphatases, contributing to improved nutrient availability in the soil.

Enterobacter: Enterobacter species are found in various environments, including soil and water. They produce organic acids such as citric acid and gluconic acid, which can solubilize inorganic phosphorus. Enterobacter cloacae is a well-known example that has been studied for its phosphorus-solubilizing capabilities.

Azotobacter: Azotobacter species are free-living nitrogen-fixing bacteria that are also capable of solubilizing phosphorus. They produce a variety of organic acids and phosphatases that help convert insoluble phosphorus into forms that plants can absorb. Azotobacter chroococcum is a notable example of this group.

Serratia: Serratia species, such as Serratia marcescens, are known for their ability to produce siderophores and organic acids that can solubilize phosphorus. They are commonly found in the rhizosphere and have been shown to enhance plant growth and phosphorus uptake.

Mechanisms of Phosphorus Solubilization

PSRB employ various mechanisms to solubilize phosphorus, which can be broadly categorized into organic acid production, enzymatic activity, and siderophore production.

Organic Acid Production: The most common mechanism of phosphorus solubilization involves the production of organic acids such as gluconic acid, citric acid, lactic acid, and oxalic acid. These acids lower the pH of the soil microenvironment, leading to the dissolution of insoluble phosphate compounds. For example, gluconic acid produced by Pseudomonas and

Enterobacter species can chelate cations like calcium and iron, freeing up phosphorus ions for plant uptake.

Enzymatic Activity: PSRB produce various phosphatases and phytases that can hydrolyze organic phosphorus compounds, releasing inorganic phosphorus. Phosphatases break down phosphomonoesters into phosphate ions, while phytases degrade phytate, a common form of organic phosphorus in soil, into usable phosphorus forms. Bacillus and Rhizobium species are known for their production of these enzymes.

Siderophore Production: Some PSRB produce siderophores, which are molecules that bind to iron and other cations. By chelating these cations, siderophores can indirectly enhance phosphorus solubilization by preventing the formation of insoluble phosphate complexes.

Serratia and Pseudomonas species are well-known siderophore producers.

Ecological and Agricultural Significance

The diversity of PSRB is not just a scientific curiosity but has practical implications for agriculture. By harnessing the capabilities of these bacteria, farmers can improve soil fertility and crop yields in a sustainable manner. The use of PSRB as biofertilizers has gained increasing attention as a means to reduce the reliance on chemical fertilizers and mitigate their environmental impact.

Biofertilizers: Formulations containing PSRB can be applied to seeds, soil, or plant roots to enhance phosphorus availability. These biofertilizers can be particularly beneficial in lowphosphorus soils, where chemical fertilizers are less effective. The use of biofertilizers can also reduce the cost of crop production and promote sustainable farming practices.

Crop-Specific Applications: Different crops have varying phosphorus requirements and respond differently to PSRB. For example, legumes benefit from the dual role of Rhizobium species in nitrogen fixation and phosphorus solubilization. Similarly, cereals like wheat and maize can benefit from PSRB such as Pseudomonas and Bacillus species. Understanding the crop-specific interactions with PSRB can help in developing targeted biofertilizer formulations.

Soil Health and Microbial Diversity: The application of PSRB can enhance soil health by promoting microbial diversity and activity. A diverse microbial community contributes to nutrient cycling, disease suppression, and overall soil fertility. The introduction of beneficial rhizobacteria can also outcompete harmful pathogens, reducing the incidence of soil-borne diseases.

Environmental Impact: The use of PSRB can mitigate the environmental impact of phosphorus fertilizers. Chemical fertilizers often lead to phosphorus runoff, which can cause eutrophication of water bodies and harm aquatic ecosystems. By improving phosphorus use efficiency, PSRB can reduce the need for chemical fertilizers and minimize their environmental footprint.

Challenges and Future Prospects

Despite the potential benefits of PSRB, there are several challenges to their widespread adoption in agriculture. These include:

Consistency and Reliability: The effectiveness of PSRB can vary depending on soil conditions, climate, and crop types. Ensuring consistent performance across different environments is a significant challenge.

Formulation and Shelf Life: Developing stable and effective formulations of PSRB that can be stored and applied easily is crucial for their commercial success. Maintaining the viability and activity of these bacteria over time is essential.

Regulatory and Market Acceptance: The regulatory framework for biofertilizers varies across regions, and gaining market acceptance can be challenging. Demonstrating the economic and environmental benefits of PSRB to farmers is necessary for their adoption.

Research and Development: Continued research is needed to explore the diversity of PSRB, understand their mechanisms of action, and identify the most effective strains for different crops and soil conditions. Advances in biotechnology and genomics can aid in the discovery and development of new PSRB strains.

Mechanisms of P solubilizing Plant Root Residing Bacteria

Phosphorus-solubilizing bacteria play a crucial role in making phosphorus more available to plants. They do this through various mechanisms:

Production of Organic Acids: Bacteria like Bacillus and Pseudomonas species produce organic acids (such as citric, gluconic, and oxalic acids) that dissolve insoluble phosphates into soluble forms that plants can absorb.

Chelation: Some bacteria produce chelating agents like siderophores, which bind to metal ions in insoluble phosphates, making them soluble and available for plant uptake.

Ion Exchange: Bacteria can alter the pH of the soil around the roots, releasing hydrogen ions that displace phosphorus ions from soil particles, making phosphorus more accessible.

Phosphatase Enzymes: Many phosphorus-solubilizing bacteria produce phosphatase enzymes that break down organic phosphorus compounds into simpler forms that plants can absorb.

Biofilm Formation: Bacteria can form biofilms around the roots, enhancing nutrient uptake and solubilization processes.

Conclusion

Phosphorus-solubilizing rhizobacteria represent a diverse group of microorganisms with significant potential for enhancing phosphorus availability in soils and promoting sustainable agriculture. The diversity of PSRB, encompassing genera such as Pseudomonas, Bacillus, Rhizobium, Enterobacter, Azotobacter, and Serratia, highlights the various mechanisms these bacteria employ to solubilize phosphorus. By harnessing the capabilities of PSRB, farmers can improve crop yields, reduce the reliance on chemical fertilizers, and mitigate the environmental impact of agricultural practices. However, challenges such as ensuring consistent performance, developing effective formulations, and gaining market acceptance need to be addressed. Continued research and development are essential to fully realize the potential of PSRB in sustainable agriculture.

***Associate Professor (Agronomy)**
B.B.D. Govt. College
Chimanpura, SKNAU, Jobner (Raj.)
****Assistant Professor (Agri-Extention)**
Government Agriculture College
Didwana, Agriculture University,
Jodhpur (Raj.)

References

1. Abdelmoteleb, A., & Gonzalez-Mendoza, D. (2020). Isolation and Identification of Phosphate Solubilizing Bacillus spp. From Tamarix ramosissima Rhizosphere and Their Effect on Growth of Phaseolus vulgaris Under Salinity Stress. Geomicrobiology Journal, 1–8. https://doi.org/10.1080/01490451.2020.1795321
2. Alaylar, B., Egamberdieva, D., Gulluce, M., Karadayi, M., & Arora, N. K. (2020). Integration of molecular tools in microbial phosphate solubilization research in agriculture perspective.
3. Aloo, B. N., Mbega, E. R., Makumba, B. A., Hertel, R., & Danel, R. (2020). Molecular identification and in vitro plant growth-promoting activities of culturable Potato (Solanum tuberosum L.) rhizobacteria in Tanzania. Potato Research. https://doi.org/10.1007/s11540- 020-09465-x Alori, E. T., Glick, B. R., &
4. Babalola, O. O. (2017). Microbial phosphorus solubilization and its potential for use in sustainable agriculture. Frontiers in Microbiology, 8, 971. https://doi.org/10.3389/fmicb.2017.00971

5. Bioformulations: For sustainable agriculture (pp. 3–33). Springer.
6. Borgi, M. A., Saidi, I., Moula, A., Rhimi, S., & Rhimi, M. (2020). The Attractive Serratia plymuthica BMA1 Strain With High Rock Phosphate-Solubilizing Activity and Its Effect on the Growth and Phosphorus Uptake by Vicia faba L. Plants. Geomicrobiology Journal, 37(5), 437–445. https://doi.org/10.1080/01490451.2020.1716892
7. https://www.researchgate.net/publication/303833637_Bioformulations_for_Plant_Growth_Promotion_and_Combating_Phytopathogens_A_Sustainable_Approach
8. Kumar, G., & Sarma, B. K. (2016). Eco-friendly Management of Soil-borne Plant Pathogens through Plant Growth-Promoting Rhizobacteria. SATSA Mukhapatra, 20, 167–171.
9. Kumar, S., Bauddh, K., Barman, S. C., & Singh, R. P. (2014). Amendments of microbial bio fertilizers and organic substances reduces requirement of urea and DAP with enhanced nutrient availability and productivity of wheat (Triticum aestivum L.). Ecological Engineering, 71, 432–437.
10. Kumar, V., Singh, P., Jorquera, M. A., Sangwan, P., Verma, A. K., & Sanjeev, A. (2013). Isolation of phytase-producing bacteria from Himalayan soils and their effect on growth and phosphorusuptake of Indian mustard (Brassica juncea). World Journal of Microbiology and Biotechnology, 29, 1361–1369.
11. Mishra, J., & Arora, N. K. (2016). Bioformulations for plant growth promotion and combating phytopathogens: A sustainable approach. In N. K. Arora, S. Mehnaz, & R. Balestrini (Eds.),