AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 02, Issue: 12 (December, 2025)
Available online at http://www.agrimagazine.in

Use of Phosphate-Solubilizing Bacteria (PSB) in Enhancing Nutrient Availability in Orchard Systems

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Phosphorus (P) is an essential macronutrient for orchard crops, influencing root development, flowering, fruit set, and overall productivity. However, a large proportion of soil phosphorus remains unavailable to plants due to its fixation by calcium, iron, and aluminium compounds. Phosphate-Solubilizing Bacteria (PSB) play a crucial role in converting insoluble forms of phosphorus into bioavailable forms through organic acid production and enzymatic activity. This review explores the mechanisms by which PSB solubilize phosphorus, their applications in orchard systems, their benefits and limitations, and the future prospects of PSB use in sustainable fruit production.

Introduction

Orchard crops, including mango, citrus, banana, guava, and pomegranate, require adequate phosphorus for optimal growth and development. Phosphorus is particularly important for root development, flowering, fruit set, and overall yield. However, in many soils, 75–90% of applied phosphorus becomes fixed and unavailable to plants (Sharma et al., 2013). Traditional methods of phosphorus fertilization, particularly the application of phosphatic fertilizers, do not fully resolve this issue due to the fixation of phosphorus by soil cations like calcium (Ca^{2+}), iron (Fe^{3+}), and aluminum (Al^{3+}). Phosphate-Solubilizing Bacteria (PSB) represent a promising biological solution to this challenge. PSB enhance the bioavailability of phosphorus in the soil by solubilizing insoluble forms of phosphorus, which can then be utilized by plants. These bacteria offer an eco-friendly alternative to chemical fertilizers, promoting sustainable nutrient management in orchards.

What is Phosphate-Solubilizing Bacteria (PSB)?

Phosphate-Solubilizing Bacteria (PSB) are a group of beneficial microorganisms capable of solubilizing insoluble inorganic phosphates such as tricalcium phosphate and rock phosphate. Additionally, PSB can mineralize organic phosphorus sources in the soil, converting them into forms that are available for plant uptake.

Key genera of PSB include:

- *Bacillus spp.*
- *Pseudomonas spp.*
- *Rhizobium spp.*
- *Burkholderia spp.*
- *Enterobacter spp.*
- *Azotobacter spp.*

Mechanisms of Phosphate Solubilization

PSB solubilize phosphorus through a variety of **biological mechanisms**:

1. **Organic Acid Production:** PSB produce organic acids, such as citric acid, gluconic acid, oxalic acid, and lactic acid. These acids:
- Lower soil pH, which facilitates the release of phosphorus from insoluble compounds.
- Chelate metal ions (e.g., Ca^{2+}, Fe^{3+}, Al^{3+}), releasing bound phosphorus into solution (Rodríguez & Fraga, 1999).
2. **Enzymatic Activity:** PSB secrete enzymes like **phosphatases** (acidic and alkaline) and **phytases**, which mineralize organic phosphorus compounds, thus enhancing the availability of phosphorus to plants.
3. **Proton Extrusion:** Some PSB release protons (H^+), which dissolve insoluble phosphate complexes in the soil, converting them into soluble forms that plants can utilize.
4. **Siderophore Production:** Certain PSB produce **siderophores**, which chelate iron (Fe^{3+}) from iron-phosphate complexes, indirectly releasing phosphorus into the soil solution.

Role of PSB in Orchard Systems

PSB offer several key benefits to orchard systems:

1. **Improved Root Growth and Nutrient Uptake:** PSB enhance root growth, resulting in increased root length, density, and branching. This improved root architecture facilitates better uptake of phosphorus and micronutrients like zinc (Zn) and iron (Fe) (Singh et al., 2014).
2. **Enhanced Flowering and Fruit Quality:** Adequate phosphorus availability supports improved fruit set, enhanced sugar-acid ratios, more uniform fruit ripening, and better shelf life. These benefits have been reported in mango, citrus, banana, and papaya orchards.
3. **Integration with Organic Inputs:** PSB work synergistically with organic inputs such as:
- Farmyard manure (FYM)
- Compost or vermicompost
- Rock phosphate
- Biochar

This synergy further enhances phosphorus availability in the soil, providing an integrated approach to nutrient management.

4. **Reduction in Chemical Fertilizer Requirement:** PSB have been shown to reduce the need for phosphatic fertilizers (e.g., SSP, DAP) by 25–50% without compromising crop yield, thus reducing input costs for orchard production (Vessey, 2003).

Application Methods of PSB in Orchard Systems

PSB can be applied to orchards in various ways to maximize their benefits:

1. **Nursery Stage Application**
- **Root dip treatment** with PSB suspension (**10^8 CFU/ml**) before planting.
- **Soil mix inoculation** (2–3 kg PSB culture per tonne of nursery soil).
2. **At Planting**
- **25–50 g of PSB culture** per planting pit, mixed with organic matter like FYM or compost.
3. **Annual Application to Bearing Trees**
- **200–500 g of PSB powder** or **1–2 liters of PSB liquid culture** per tree, mixed with FYM and applied around the tree basin.
4. **Drip Fertigation**

Liquid PSB can be applied through **drip irrigation systems**, promoting better colonization of the rhizosphere.

5. **Foliar Sprays**

Although less common, PSB-based formulations can be applied as **foliar bio-stimulants** to enhance plant growth.

Benefits of PSB in Orchard Systems

1. **Increased Phosphorus Use Efficiency**

PSB convert unavailable phosphorus into plant-available forms, leading to an increase in phosphorus uptake by **20–40%**.

2. **Cost Reduction**

By reducing the need for expensive phosphatic fertilizers, PSB help lower input costs in orchard production.

3. **Sustainability and Soil Health**

PSB support beneficial soil microflora, enhance soil enzyme activity, and improve soil structure and organic matter content, contributing to long-term soil health.

4. **Enhanced Crop Growth and Yield**

Orchard crops such as mango, grapes, citrus, pomegranate, and apple have shown yield increases of **10–25%** when PSB are used.

Limitations of PSB Use

Despite their many benefits, PSB performance can be influenced by several factors:

- Soil temperature extremes
- High soil pH (above 8.5)
- Low organic matter
- Agrochemical toxicity
- Competition with native microflora

To mitigate these challenges, using high-quality carrier-based PSB and integrating them with organic amendments can enhance their performance.

Future Prospects

Future research on PSB may focus on:

- Development of **nano-encapsulated PSB** for controlled, slow release.
- Formulation of **consortium-based biofertilizers**, combining PSB with **N-fixers** and **K-mobilizers**.
- **Genetically improved strains** of PSB with higher organic acid production.
- Integration with **precision horticulture** practices.
- Application of PSB via **seed coatings** and **gels**.

PSB-based technologies will likely play a key role in reducing the dependence on chemical fertilizers and enhancing the sustainability of orchard systems.

Conclusion

Phosphate-Solubilizing Bacteria (PSB) are a critical component of sustainable orchard nutrient management. By improving the bioavailability of phosphorus, enhancing plant growth, and reducing the need for chemical fertilizers, PSB contribute to higher productivity, better fruit quality, and long-term soil health. Their integration into orchard management systems offers an eco-friendly, cost-effective solution to meet the growing demand for sustainable agriculture.

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