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Role of Phosphate Solubilizing Bacteria (PSB) and Organic Amendments in Chickpea Cultivation

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Abstract

Chickpea (*Cicer arietinum* L.) is a critical pulse crop, especially in developing regions, due to its nutritional benefits and role in enhancing soil fertility through symbiotic nitrogen fixation with Rhizobium bacteria. However, phosphorus (P) deficiency in soils poses a major challenge to chickpea production. Phosphorus, vital for energy transfer, photosynthesis, and root development, is often rendered unavailable to plants due to its tendency to form insoluble complexes in soil. Traditional reliance on chemical phosphorus fertilizers, while providing immediate relief, has led to environmental degradation and unsustainable resource depletion. This review examines sustainable alternatives to chemical fertilizers, focusing on the use of phosphate solubilizing bacteria (PSB) and organic amendments. PSB enhance phosphorus availability by converting insoluble forms into soluble ones through mechanisms like organic acid secretion, enzyme production, and siderophore release. Organic amendments, including compost, vermicompost, and farmyard manure (FYM), improve soil structure, microbial activity, and phosphorus cycling. The combined use of PSB and organic amendments offers a synergistic approach that not only boosts phosphorus availability but also enhances chickpea yield, quality, and overall soil health.

The integration of PSB and organic amendments presents significant environmental and economic benefits by reducing chemical fertilizer dependency, promoting sustainable soil management, and potentially lowering production costs. Despite these advantages, challenges such as variability in PSB effectiveness and the availability of organic materials remain. Future research should focus on optimizing these biological and organic inputs for different soil types and conditions, and on supporting policies that promote sustainable agricultural practices.1.

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Keywords: Phosphate Solubilizing Bacteria (PSB), Organic Amendments, Chickpea Cultivation, Soil Fertility, Sustainable Agriculture, Crop Yield Improvement, Microbial Inoculants

1. Introduction

Chickpea (*Cicer arietinum* L.) is one of the most vital pulse crops worldwide, playing a crucial role in ensuring food security, particularly in developing countries. As a rich source of protein, fiber, vitamins, and essential minerals, chickpea is a staple food for millions of people, particularly in South Asia and the Mediterranean region. In addition to its dietary importance, chickpea also enhances soil fertility through its ability to fix atmospheric nitrogen in symbiosis with Rhizobium bacteria. Despite these benefits, one of the major constraints to chickpea production is the limited availability of phosphorus (P) in the soil. Phosphorus is a macronutrient that is essential for several key physiological and biochemical processes in plants, including energy transfer (via ATP), photosynthesis, root development, and nutrient transport. It also plays a critical role in the formation of nucleic acids and cell membranes, thus directly affecting plant growth and productivity. However, phosphorus in soils is often immobilized and becomes unavailable to plants, largely because it tends to form insoluble complexes with calcium, iron, and aluminum. As a result, a significant portion of the phosphorus applied to soils, particularly in alkaline or acidic conditions, becomes "fixed" and inaccessible to plants, leading to widespread phosphorus deficiency.

Phosphorus deficiency in soils is a major issue globally, affecting crop yields and limiting agricultural productivity, especially in developing countries with poor soil management practices. To overcome this problem, farmers have traditionally relied on chemical phosphorus fertilizers, such as superphosphates, which are readily available to plants. While these fertilizers provide an immediate solution to phosphorus deficiency, they come with several drawbacks. Excessive and prolonged use of chemical fertilizers can lead to environmental degradation, including soil acidification, water pollution from runoff, and a decline in soil biodiversity. Moreover, the mining of phosphate rock, the primary source of phosphorus fertilizers, is not sustainable in the long term, as it depletes a finite natural resource.

Given these challenges, sustainable alternatives to chemical phosphorus fertilizers have become a key focus of agricultural research. One promising solution lies in the use of phosphate solubilizing bacteria (PSB), a group of beneficial microorganisms capable of converting insoluble phosphorus into forms that are readily accessible to plants. PSB achieve this through various mechanisms, including the secretion of organic acids that lower the soil pH and dissolve bound phosphorus, the production of enzymes that release phosphorus from organic matter, and the production of other metabolites that aid in phosphorus solubilization. In addition to PSB, organic amendments such as compost, vermicompost, and farmyard manure (FYM) can further enhance phosphorus availability in the soil. These organic materials not only provide a slow-release source of nutrients, including phosphorus, but also improve soil structure, increase microbial activity, and enhance the overall health and fertility of the soil. When used in combination with PSB, organic amendments create a synergistic effect that enhances phosphorus solubilization and availability, leading to improved plant growth, higher yields, and better soil health.

This review explores the combined role of phosphate solubilizing bacteria and organic amendments in chickpea cultivation. It highlights their potential to enhance phosphorus availability in soils, improve chickpea yield and quality, and promote sustainable agricultural practices. By integrating these biological tools into chickpea farming, it is possible to reduce the reliance on chemical fertilizers, mitigate environmental risks, and ensure long-term soil fertility and productivity.

2. Phosphorus in Chickpea Cultivation

Phosphorus is a critical, non-renewable nutrient essential for the growth and development of leguminous crops like chickpea (Cicer arietinum L.). It plays a vital role in several plant processes, including root development, energy transfer through ATP, photosynthesis, and the synthesis of nucleic acids. For chickpeas, phosphorus is particularly important for nodulation—the process by which the plant forms a symbiotic relationship with nitrogen-fixing bacteria (Rhizobium), allowing it to convert atmospheric nitrogen into a usable form. This nitrogen fixation is crucial for enhancing soil fertility and maximizing chickpea yield.

However, phosphorus deficiency is a common issue in soils globally. In most agricultural soils, phosphorus tends to form insoluble complexes with elements such as calcium in alkaline soils and aluminum or iron in acidic soils. This leads to the immobilization of phosphorus, making it unavailable for plant uptake. As a result, even soils that contain significant amounts of phosphorus often fail to provide adequate levels of this nutrient to crops, including chickpea.

To address phosphorus deficiency, farmers traditionally use chemical phosphorus fertilizers such as superphosphates. While these fertilizers provide an immediate source of available

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phosphorus, their continuous and excessive use can lead to environmental concerns, such as water contamination from runoff, soil acidification, and a reduction in beneficial soil microorganisms. Furthermore, phosphorus rock, the primary source for these fertilizers, is a finite resource, making the over-reliance on chemical fertilizers unsustainable in the long term. An alternative approach involves natural and biological interventions, such as the use of phosphate solubilizing bacteria (PSB) and organic amendments like compost, vermicompost, and farmyard manure (FYM). PSB can release phosphorus from insoluble compounds, making it more accessible to plants, while organic amendments enhance soil structure and microbial activity, further increasing phosphorus availability. This sustainable combination of biological and organic inputs can improve phosphorus uptake, support healthy plant growth, and increase chickpea yield without the environmental drawbacks associated with chemical fertilizers.

3. Role of Phosphate Solubilizing Bacteria (PSB)

Phosphate solubilizing bacteria (PSB) are beneficial microorganisms that play a crucial role in enhancing phosphorus availability for plants by converting insoluble forms of phosphorus, such as calcium phosphate, iron phosphate, and aluminum phosphate, into soluble forms that plants can readily absorb. This transformation is achieved through several key mechanisms:

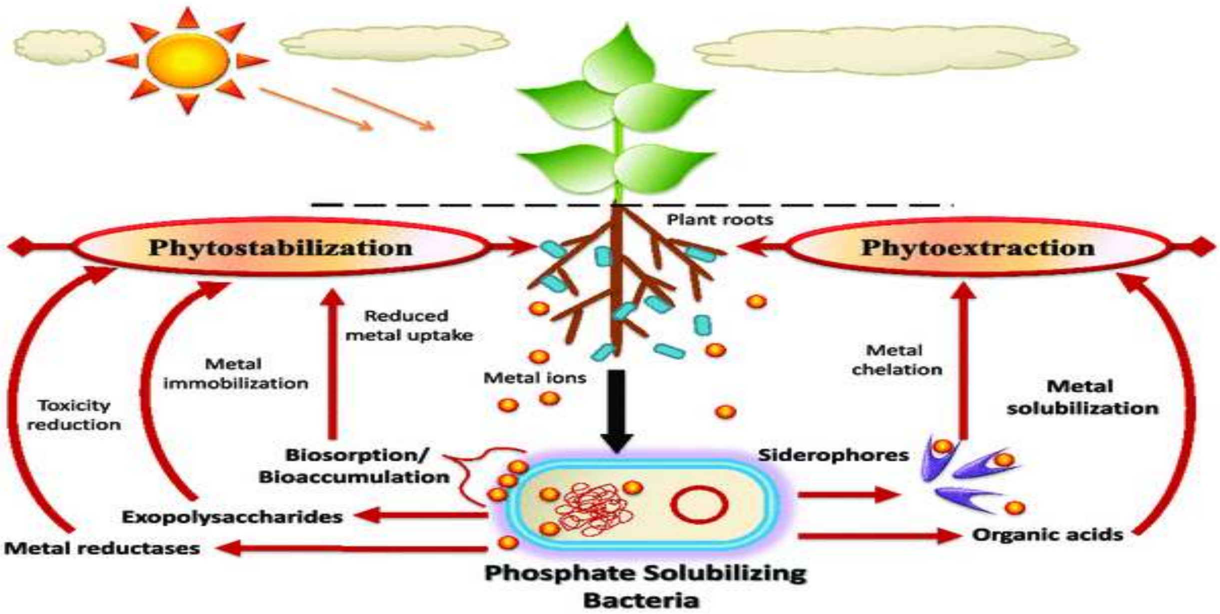

Fig: Role of Phosphate Solubilizing Bacteria

1. Production of Organic Acids: PSB secrete organic acids, such as gluconic, citric, and malic acids, which acidify the soil environment and break down insoluble phosphate compounds. The resulting decrease in soil pH helps release bound phosphates, thereby increasing the bioavailability of phosphorus for plant uptake (Rodríguez & Fraga, 1999).

2. Enzyme Secretion: PSB produce enzymes like phosphatases and phytases, which hydrolyze organic phosphorus compounds into inorganic phosphate, further enhancing phosphorus availability in the soil. These enzymes decompose complex organic phosphorus found in soil organic matter and mineral complexes, converting it into forms that plants can absorb (Khan et al., 2007).

3. Siderophore Production: PSB also release siderophores, which are compounds that chelate iron. By binding to iron, siderophores reduce the fixation of phosphorus with iron compounds, thus increasing the availability of free phosphorus for plant absorption (Vassilev et al., 2006). Several bacterial genera, including Pseudomonas, Bacillus, and Rhizobium, have demonstrated significant phosphate solubilizing potential. For instance, Pseudomonas and Bacillus species are known for their ability to produce organic acids and phosphatase enzymes, while Rhizobium plays a dual role in nitrogen fixation and phosphorus solubilization (Zaidi et al., 2009). In chickpea cultivation, PSB inoculation has been shown to enhance phosphorus availability, stimulate root development, and improve nitrogen fixation due to the symbiotic relationship between chickpeas and Rhizobium bacteria. This symbiosis results in increased biomass production, higher yields, and improved grain quality. Studies have reported that PSB inoculation in chickpea fields can increase phosphorus uptake and utilization, leading to better overall crop performance (Alori et al., 2017).

By utilizing PSB as a sustainable alternative to chemical phosphorus fertilizers, farmers can improve soil fertility, reduce environmental risks, and promote long-term agricultural sustainability.

4. Organic Amendments in Chickpea Cultivation

Organic amendments such as compost, farmyard manure (FYM), and vermicompost are widely recognized for their ability to enhance soil health and fertility, particularly in legume crops like chickpea. These amendments are rich in essential nutrients and organic matter, which improve soil structure, water retention, and promote microbial activity, including the activity of phosphate solubilizing bacteria (PSB). In addition to their nutrient content, organic amendments contribute to phosphorus cycling by providing a substrate that supports the growth and activity of soil microorganisms, facilitating the release of bound phosphorus for plant uptake.

Compost

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Compost is a nutrient-rich organic material produced through the controlled aerobic decomposition of organic waste. It releases nutrients slowly over time, providing a steady supply of essential elements like nitrogen, phosphorus, and potassium throughout the growing season. The slow-release nature of compost ensures that nutrients are available when the plant needs them, reducing nutrient losses due to leaching or volatilization. Furthermore, compost improves soil texture and structure, enhancing root development, water retention, and aeration, which are crucial for the growth of chickpea plants (Ghosh et al., 2015). Studies have shown that the application of compost not only increases nutrient availability but also enhances the microbial diversity and activity in the soil, particularly the population of PSB (Kaur et al., 2017).

Vermicompost

Vermicompost is produced by the decomposition of organic matter with the help of earthworms, resulting in a highly nutritious organic fertilizer. Vermicompost is rich in phosphorus and other essential nutrients and has been shown to improve soil fertility and microbial activity significantly (Arancon et al., 2005). The presence of plant growth-promoting microorganisms, including PSB, in vermicompost enhances the solubilization of phosphorus and makes it more accessible to chickpea plants. Vermicompost has also been shown to increase the diversity of soil microbial communities, which further aids in nutrient cycling and promotes sustainable soil health (Sinha et al., 2010). In chickpea cultivation, vermicompost improves plant growth, nutrient uptake, and overall yield by providing both macro and micronutrients in a readily available form.

Farmyard Manure (FYM)

Farmyard manure (FYM) is a traditional organic amendment made from the decomposition of animal waste and bedding materials. FYM is a valuable source of nutrients, particularly phosphorus, and has long been used to improve soil structure, water-holding capacity, and nutrient content (Bhattacharyya et al., 2008). When combined with PSB, FYM enhances phosphorus availability by providing a rich organic substrate for microbial activity. The organic matter in FYM stimulates the growth of PSB and other beneficial microorganisms, which further facilitate the solubilization and mobilization of phosphorus in the soil (Sharma et al., 2013). Research indicates that the combined application of FYM and PSB leads to improved chickpea growth, nodulation, and higher yield (Bashan et al., 2013).

5. Synergy between Phosphate Solubilizing Bacteria (PSB) and Organic Amendments

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The combined application of phosphate solubilizing bacteria (PSB) and organic amendments has been shown to significantly improve chickpea productivity compared to the use of either input alone. Organic amendments, such as compost, vermicompost, and farmyard manure (FYM), create a favorable environment for PSB by providing an abundant source of organic matter, which serves as both a substrate for microbial activity and a medium for nutrient cycling. In turn, PSB enhance the process of phosphorus solubilization and mineralization from organic sources, making it more accessible to chickpea plants. Several studies have demonstrated the benefits of this synergistic interaction in chickpea cultivation. When chickpeas are inoculated with PSB and supplemented with organic amendments, the following positive outcomes are typically observed:

Improved Phosphorus Uptake: PSB increase the availability of phosphorus by breaking down insoluble phosphorus compounds, while organic amendments supply additional nutrients, further promoting phosphorus uptake by plants.

Increased Root Biomass and Nodule Formation: The enhanced phosphorus availability and better soil structure from organic amendments support greater root growth and nodule development, which are essential for the plant's nutrient absorption and nitrogen-fixing capacity.

Enhanced Nitrogen Fixation: Better root growth, facilitated by the combined action of PSB and organic amendments, leads to improved interactions between chickpea roots and rhizobia, resulting in more efficient nitrogen fixation.

Higher Yield and Grain Quality: The overall improvement in nutrient uptake, root development, and nitrogen fixation translates into increased biomass, higher grain yield, and improved grain quality.

This synergistic combination not only boosts chickpea productivity but also enhances soil health by increasing microbial diversity and activity. This microbial stimulation leads to improved nutrient cycling, better soil structure, and long-term soil fertility, which are critical factors for sustainable agriculture. The use of PSB and organic amendments together creates a self-sustaining system that minimizes the need for chemical fertilizers while maintaining crop productivity and soil quality.

6. Environmental and Economic Benefits:

The integration of phosphate solubilizing bacteria (PSB) and organic amendments in chickpea cultivation offers substantial environmental and economic benefits. One of the key environmental advantages is the reduction in dependency on chemical fertilizers. Chemical

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phosphorus fertilizers contribute to environmental degradation, including water contamination and soil acidification. In contrast, the use of PSB and organic amendments reduces nutrient runoff and promotes more sustainable nutrient cycling within the soil. This practice not only preserves soil health but also minimizes the risk of soil degradation over time, leading to enhanced biodiversity and ecosystem stability.

Organic amendments such as compost and vermicompost, often sourced from farm or household waste, further enhance sustainability by recycling organic matter. The use of these materials reduces the need for synthetic inputs, helping farmers decrease their environmental footprint. Moreover, the combination of PSB and organic matter fosters healthier soil ecosystems by enhancing microbial activity, improving soil structure, and promoting long-term soil fertility.

Economically, the use of PSB and organic amendments reduces farmers' reliance on expensive chemical fertilizers, lowering production costs. Over time, this can increase profitability as improved soil health leads to sustained productivity and higher crop yields. Additionally, the adoption of organic practices enables farmers to access premium markets that favor sustainably produced crops, further enhancing economic returns.

7. Challenges and Future Prospects

Despite the considerable benefits of using PSB and organic amendments, several challenges impede their widespread adoption. One of the main challenges is the variability of PSB effectiveness across different soil types and environmental conditions. Not all soils possess the same capacity to support the activity of PSB, and further research is needed to identify the most effective bacterial strains for specific regions.

Another challenge lies in the availability and accessibility of organic amendments, especially for smallholder farmers. The production and transportation of organic materials such as compost and vermicompost can be labor-intensive and costly. Farmers may also lack sufficient knowledge about the proper application and management of PSB and organic amendments, underscoring the need for education and training programs. Looking ahead, future research should focus on optimizing the interaction between PSB and organic amendments for maximum efficiency. Identifying region-specific PSB strains and formulating strategies for more effective organic material use will be key to addressing phosphorus deficiencies in diverse agricultural settings. Additionally, efforts to scale up organic farming practices can be supported by government policies and incentives that encourage the use of sustainable inputs.

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8. Conclusion

Chickpea (Cicer arietinum L.) is an essential pulse crop that significantly contributes to food security, particularly in regions with limited agricultural resources. However, phosphorus deficiency in soils remains a critical challenge to maximizing chickpea productivity. The reliance on chemical fertilizers to address this issue is unsustainable, leading to environmental degradation and long-term soil health decline. The integration of phosphate solubilizing bacteria (PSB) and organic amendments offers a sustainable and effective solution to this problem. PSB improve phosphorus availability by converting insoluble phosphorus into forms that plants can readily absorb, while organic amendments such as compost, vermicompost, and farmyard manure enhance soil structure, microbial activity, and nutrient cycling. Together, these biological inputs create a synergistic effect that not only boosts phosphorus uptake, root development, and nitrogen fixation but also improves chickpea yield and soil health. Adopting these practices offers significant environmental and economic benefits. They reduce dependency on chemical fertilizers, minimize environmental pollution, and promote long-term soil fertility; all while lowering production costs for farmers. However, challenges such as variability in PSB effectiveness across different soils and limited availability of organic amendments must be addressed to scale up these practices.

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