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Review Article

Plant Growth Promoting Rhizobacteria (PGPR) for Sustainable Agriculture and Improved Crop Productivity

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Abstract

Plant Growth-Promoting Rhizobacteria (PGPR) are beneficial soil microorganisms that colonize the rhizosphere and enhance plant growth through multiple biological mechanisms. With increasing concerns about environmental degradation and the excessive use of chemical fertilizers and pesticides, PGPR have gained considerable attention as a sustainable alternative for improving crop productivity. These microorganisms promote plant growth by facilitating nutrient acquisition, producing phytohormones, solubilizing essential minerals, fixing atmospheric nitrogen, and suppressing plant pathogens. PGPR enhance plant tolerance to various abiotic stresses such as drought, salinity, and temperature fluctuations. The integration of PGPR into agricultural systems can improve soil fertility, support plant health, and contribute to environmentally friendly farming practices. This review highlights the major mechanisms of PGPR action, their role in sustainable agriculture, and their potential applications in enhancing crop productivity. The challenges associated with PGPR application and future research directions are also discussed to support the wider adoption of microbial-based agricultural technologies.

Keywords: *Plant Growth-Promoting Rhizobacteria; Sustainable agriculture; Biofertilizers; Rhizosphere microorganisms; Crop productivity.*

1. Introduction

Global agriculture is facing significant challenges due to population growth, climate change, declining soil fertility, and environmental degradation. The demand for food is increasing rapidly as the world population continues to expand. Traditional agricultural practices rely heavily on chemical fertilizers and pesticides to enhance crop yields. Although these inputs can increase productivity, their excessive use has led to several environmental problems, including soil degradation, water contamination, and loss of biodiversity. Sustainable agriculture has emerged as an alternative approach aimed at producing sufficient food while maintaining environmental health and conserving natural resources. One of the promising strategies in sustainable agriculture is the use of beneficial soil microorganisms that can enhance plant growth naturally. Among these microorganisms, Plant Growth-Promoting Rhizobacteria (PGPR) play a crucial role in improving plant productivity and soil health. PGPR are a diverse group of bacteria that colonize the rhizosphere, the region of soil surrounding plant roots [1]. These bacteria interact with plants in mutually beneficial relationships by enhancing nutrient uptake, producing growth-stimulating substances, and protecting plants from harmful pathogens.

PGPR species belong to several bacterial genera such as *Pseudomonas*, *Bacillus*, *Azospirillum*, *Rhizobium*, and *Enterobacter*. These microorganisms contribute to plant growth through various mechanisms including nitrogen fixation, phosphate solubilization, siderophore production, and phytohormone synthesis. The application of PGPR in agriculture has gained increasing attention because it offers a sustainable solution to reduce dependence on chemical inputs. An improving soil fertility and plant resilience, PGPR can help farmers achieve higher crop yields while minimizing environmental impacts. PGPR can enhance plant tolerance to abiotic stresses such as drought, salinity, and extreme temperatures, which are becoming more common due to climate change. The use of PGPR as biofertilizers and biocontrol agents has shown promising results in various crops including cereals, legumes, vegetables, and fruits. These beneficial microorganisms improve root development, enhance nutrient absorption, and stimulate plant defense mechanisms [2]. As a result, PGPR have become an important component of integrated nutrient management and sustainable crop production systems. Their numerous benefits, the widespread adoption of PGPR technologies still faces several challenges, including variability in field performance, lack of awareness among farmers, and limitations in large-scale production. Continued research is therefore necessary to understand the interactions between plants, soil microorganisms, and environmental factors in order to optimize PGPR applications. This review aims to provide an overview of Plant Growth-Promoting Rhizobacteria and their role in sustainable agriculture. It discusses the mechanisms through which PGPR enhance plant growth, their contributions to crop productivity, and the potential future developments in this field.

Table 1: Major Plant Growth-Promoting Rhizobacteria and Their Functions

PGPR Genus	Major Function	Benefit to Plants
Bacillus	Phosphate solubilization, disease suppression	Improved nutrient availability and disease resistance
Pseudomonas	Siderophore production, pathogen inhibition	Enhanced plant immunity and improved iron uptake
Azospirillum	Biological nitrogen fixation	Increased nitrogen availability and improved plant growth
Rhizobium	Symbiotic nitrogen fixation in legumes	Enhanced legume productivity and soil fertility
Azotobacter	Nitrogen fixation and phytohormone production	Stimulated root growth and improved plant development

Table 2: Mechanisms of Plant Growth-Promoting Rhizobacteria and Their Effects on Plants

Mechanism of PGPR Activity	Description	Impact on Plant Growth
Biological Nitrogen Fixation	Conversion of atmospheric nitrogen into ammonia by PGPR such as *Azotobacter* and *Azospirillum*.	Improves nitrogen availability and enhances plant growth and productivity.
Phosphate Solubilization	Production of organic acids and enzymes that convert insoluble phosphate compounds into soluble forms.	Increases phosphorus uptake and promotes root development.
Phytohormone Production	Synthesis of plant growth regulators such as auxins, gibberellins, and cytokinins.	Stimulates root elongation, seed germination, and overall plant development.
Siderophore Production	Release of iron-chelating compounds that bind iron and make it available to plants.	Enhances iron nutrition and suppresses pathogenic microorganisms.
Biological Control	Production of antibiotics, enzymes, and metabolites that inhibit plant pathogens.	Reduces disease incidence and improves plant health.
Induced Systemic Resistance (ISR)	Activation of plant defense mechanisms through microbial signaling.	Strengthens plant resistance against pathogens and environmental stress.
Stress Tolerance Enhancement	PGPR help plants tolerate drought, salinity, and heavy metal stress.	Improves plant survival and productivity under adverse environmental conditions.

2. Plant Growth-Promoting Rhizobacteria (PGPR)

Plant Growth-Promoting Rhizobacteria (PGPR) are a diverse group of beneficial soil bacteria that colonize the rhizosphere, the narrow region of soil surrounding plant roots. These microorganisms establish complex interactions with plants and significantly influence plant growth, health, and productivity. The rhizosphere is considered a highly dynamic environment where plant roots release exudates such as sugars, amino acids, organic acids, and secondary metabolites that attract microbial populations. PGPR utilize these compounds as energy sources and, in return, provide multiple benefits that enhance plant development. PGPR can interact with plants through symbiotic, associative, or free-living relationships. In these associations, both the plant and microorganisms benefit from the interaction. Plants gain improved nutrient acquisition, protection against pathogens, and enhanced tolerance to environmental stresses, while bacteria obtain nutrients and a suitable habitat in the rhizosphere [3]. These mutualistic interactions play a crucial role in maintaining soil health and supporting sustainable crop production. The beneficial effects of PGPR on plant growth occur through direct and indirect mechanisms. Direct mechanisms involve improving nutrient availability, fixing atmospheric nitrogen, solubilizing phosphorus and other minerals, and producing plant growth regulators that stimulate plant development. Indirect mechanisms include suppression of plant pathogens through the production of antimicrobial compounds, competition for resources, and induction of systemic resistance in plants. PGPR also contribute to improved root architecture by stimulating root elongation and branching, which increases the root surface area available for water and nutrient absorption [4]. Enhanced root development further improves plant resilience under environmental stresses such as drought and nutrient deficiency.

Several bacterial genera have been widely identified as effective PGPR in agricultural soils. These include *Pseudomonas, Bacillus, Azotobacter, Rhizobium, Azospirillum, Enterobacter, and Serratia*. Each of these genera possesses unique metabolic capabilities that contribute to plant growth promotion. For example, *Rhizobium* species form symbiotic nodules with leguminous plants to fix atmospheric nitrogen, while *Pseudomonas* and *Bacillus* species are well known for their ability to suppress plant pathogens and produce plant growth regulators [5]. The presence and activity of PGPR in soil ecosystems are essential for maintaining microbial diversity and ecological balance. Their application as biofertilizers and biocontrol agents has gained increasing attention in modern agriculture as an environmentally friendly alternative to synthetic agrochemicals. Consequently, PGPR are now considered an important component of sustainable agricultural systems aimed at improving crop productivity while minimizing environmental impacts.

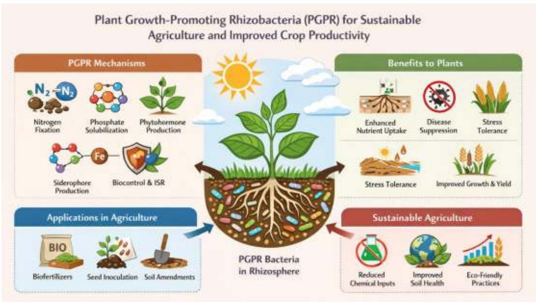

Fig 1: Role of Plant Growth-Promoting Rhizobacteria (PGPR) in Sustainable Agriculture and Crop Productivity

3. Mechanisms of PGPR in Promoting Plant Growth

PGPR enhance plant growth and productivity through a variety of biological and biochemical mechanisms.

These mechanisms operate either individually or synergistically to improve plant nutrition, stimulate plant development, and protect plants from harmful pathogens. The major mechanisms by which PGPR promote plant growth include nitrogen fixation, phosphate solubilization, phytohormone production, siderophore production, and biological control of plant diseases.

3.1 Nitrogen Fixation

Nitrogen is one of the most important nutrients required for plant growth because it is a fundamental component of proteins, nucleic acids, chlorophyll, and enzymes. Although atmospheric nitrogen (N_2) constitutes nearly 78% of the Earth's atmosphere, plants cannot directly utilize this form. Instead, nitrogen must be converted into biologically available forms such as ammonia or nitrate through biological or chemical processes. Certain PGPR species possess the ability to convert atmospheric nitrogen into ammonia through a process known as biological nitrogen fixation. This process is mediated by the enzyme nitrogenase, which catalyzes the conversion of nitrogen gas into ammonia that can be absorbed by plants. Nitrogen-fixing bacteria such as *Rhizobium*, *Azotobacter*, and *Azospirillum* play a crucial role in enhancing soil nitrogen availability. Symbiotic nitrogen fixation occurs mainly in leguminous plants where *Rhizobium* species form specialized structures called root nodules. Within these nodules, bacteria convert atmospheric nitrogen into ammonia, which is then utilized by the host plant for growth. In return, the plant supplies carbohydrates and energy to the bacteria [6]. Associative and free-living nitrogen-fixing bacteria also contribute to soil fertility by increasing nitrogen availability in non-leguminous crops such as cereals and grasses. The use of nitrogen-fixing PGPR reduces the dependence on synthetic nitrogen fertilizers, thereby lowering production costs and minimizing environmental pollution caused by excessive fertilizer use.

3.2 Phosphate Solubilization

Phosphorus is another essential macronutrient required for plant growth and development. It plays a key role in energy transfer, photosynthesis, root development, and the formation of nucleic acids and cell membranes. However, a large proportion of soil phosphorus exists in insoluble forms such as calcium phosphate, iron phosphate, and aluminum phosphate, which cannot be readily absorbed by plants [7]. PGPR enhance phosphorus availability by solubilizing insoluble phosphate compounds in the soil. These bacteria produce organic acids such as gluconic acid, citric acid, and oxalic acid, which lower the soil pH and convert insoluble phosphates into soluble forms that plants can absorb. In addition, PGPR produce phosphatase enzymes that release phosphate ions from organic phosphorus compounds. Phosphate-solubilizing bacteria, including species of *Bacillus*, *Pseudomonas*, and *Enterobacter*, significantly improve plant phosphorus nutrition. The increased availability of phosphorus leads to enhanced root development, improved plant vigor, and higher crop yields. As a result, phosphate-solubilizing PGPR are widely used as biofertilizers in sustainable agriculture.

3.3 Production of Phytohormones

Many PGPR produce plant growth regulators, commonly referred to as phytohormones, which influence various physiological processes in plants. These hormones play an important role in regulating plant growth, cell division, root development, and stress responses. One of the most commonly produced phytohormones by PGPR is indole-3-acetic acid (IAA), a type of auxin that promotes root elongation and lateral root formation. Increased root growth improves the plant's ability to absorb water and nutrients from the soil. Other hormones produced by PGPR include gibberellins and cytokinins, which stimulate seed germination, enhance shoot growth, and regulate cell division. These hormones contribute to improved plant vigor and increased biomass production, producing phytohormones, PGPR can modify plant root architecture, stimulate plant metabolism, and promote overall plant growth [8]. This hormonal interaction between plants and rhizobacteria is one of the key mechanisms through which PGPR enhance crop productivity.

3.4 Siderophore Production

Iron is an essential micronutrient required for various metabolic processes in plants, including chlorophyll synthesis and electron transport. Despite its abundance in soils, iron is often present in forms that are poorly available to plants, particularly under aerobic and alkaline soil conditions. Many PGPR produce specialized compounds known as siderophores, which are high-affinity iron-chelating molecules. These compounds bind to insoluble iron in the soil and convert it into soluble complexes that can be taken up by plants and microorganisms. In addition to improving iron availability for plants, siderophore production also helps suppress plant pathogens. Many pathogenic microorganisms require iron for growth and virulence [9]. The sequestering iron, PGPR limit its availability to competing pathogens, thereby inhibiting their growth in the rhizosphere. Thus, siderophore production contributes both to plant nutrition and biological disease suppression, making it an important mechanism of PGPR activity.

3.5 Biological Control of Plant Pathogens

Another important mechanism by which PGPR promote plant growth is through the biological control of plant diseases. Soil-borne pathogens can cause significant crop losses worldwide, and PGPR provide an environmentally friendly alternative to chemical pesticides for disease management. PGPR suppress plant pathogens through several mechanisms. Some species produce antibiotics, antifungal compounds, and lytic enzymes that directly inhibit pathogenic microorganisms. These antimicrobial substances can disrupt pathogen cell walls, interfere with metabolic processes, or inhibit spore germination. PGPR can also compete with pathogens for nutrients and ecological niches in the rhizosphere.

Because beneficial bacteria colonize plant roots rapidly, they can prevent pathogenic microorganisms from establishing themselves in the root environment. Another important mechanism is the induction of systemic resistance in plants. Certain PGPR stimulate plant defense responses, enabling plants to better resist infections by pathogens. This process enhances the plant's natural immune system and provides long-lasting protection against a wide range of diseases [10]. Through these mechanisms, PGPR function as natural biocontrol agents that reduce the need for synthetic pesticides while maintaining plant health.

4. Role of PGPR in Sustainable Agriculture

Sustainable agriculture aims to maintain high levels of agricultural productivity while minimizing environmental damage and conserving natural resources. In recent years, the excessive use of chemical fertilizers and pesticides has led to soil degradation, water pollution, and loss of biodiversity. PGPR offer an environmentally friendly solution to these challenges by promoting plant growth naturally and improving soil health. One of the primary contributions of PGPR to sustainable agriculture is their ability to reduce dependence on chemical fertilizers. By fixing atmospheric nitrogen, solubilizing phosphorus, and enhancing nutrient uptake, PGPR improve soil fertility and nutrient availability for plants. This reduces the need for synthetic fertilizers, which are often associated with environmental pollution and greenhouse gas emissions. PGPR also play a crucial role in improving soil structure and microbial diversity. The activities of beneficial rhizobacteria stimulate microbial interactions in the soil, leading to enhanced nutrient cycling and improved soil biological activity. Healthy soils with diverse microbial communities are more resilient to environmental stresses and better able to support plant growth.

Another important role of PGPR in sustainable agriculture is their ability to enhance plant tolerance to abiotic stresses. Climate change has increased the frequency of drought, salinity, and temperature fluctuations, which negatively affect crop productivity. PGPR help plants cope with these stresses by producing stress-related enzymes, osmoprotectants, and growth-promoting substances that improve plant resilience. PGPR contribute to biological control of plant diseases, reducing the need for chemical pesticides. The suppressing harmful pathogens and stimulating plant defense mechanisms, these microorganisms help maintain plant health and protect crops from infections [11]. The integration of PGPR into agricultural systems has the potential to significantly improve crop productivity while maintaining environmental sustainability. The use of PGPR as biofertilizers, biostimulants, and biocontrol agents is increasingly being adopted in modern farming practices as part of climate-smart and sustainable agriculture strategies. PGPR represent a promising tool for achieving sustainable food production, improving soil fertility, and supporting environmentally responsible agricultural practices.

5. Applications of PGPR in Crop Production

Plant Growth-Promoting Rhizobacteria (PGPR) have gained considerable attention in modern agriculture due to their ability to enhance crop productivity while maintaining environmental sustainability. These beneficial microorganisms are widely applied in agricultural systems as biofertilizers, seed inoculants, soil amendments, and biocontrol agents. Their application supports plant growth through improved nutrient availability, enhanced root development, and protection against plant pathogens [12]. One of the most common applications of PGPR is in the form of biofertilizers, which contain living microorganisms capable of colonizing the rhizosphere and improving plant nutrition. When applied to seeds, soil, or plant surfaces, PGPR facilitate nutrient mobilization and increase the efficiency of nutrient uptake. Biofertilizers based on PGPR are particularly effective in improving the availability of nitrogen, phosphorus, and micronutrients in soil.

Seed inoculation is another widely used technique in which seeds are coated with PGPR before planting. This method ensures early colonization of plant roots by beneficial bacteria, promoting faster seed germination, stronger root development, and improved seedling establishment. Seed treatment with PGPR has been shown to enhance crop growth and yield in several major crops including wheat, rice, maize, soybean, legumes, and various horticultural crops. The seed treatment, PGPR can be applied directly to the soil as soil amendments. Soil inoculation helps establish beneficial microbial populations in the rhizosphere, improving soil fertility and enhancing microbial diversity. These microorganisms also contribute to nutrient cycling and organic matter decomposition, which are essential for maintaining soil health.

PGPR also play a significant role in integrated nutrient management (INM) systems. Integrated nutrient management involves the combined use of organic fertilizers, chemical fertilizers, and microbial inoculants to achieve optimal plant nutrition. PGPR improve the efficiency of fertilizer use by enhancing nutrient solubilization and uptake, thereby reducing the amount of chemical fertilizers required. Another important application of PGPR is their role in biological control of plant diseases. Certain PGPR strains produce antimicrobial compounds, siderophores, and enzymes that inhibit the growth of plant pathogen [10]. The suppressing disease-causing microorganisms, PGPR help protect crops from infections and reduce the need for chemical pesticides, the application of PGPR in crop production has been associated with increased crop yields, improved soil fertility, enhanced stress tolerance, and reduced environmental pollution, making them a valuable tool for sustainable agriculture.

6. Challenges in the Application of PGPR

The numerous benefits associated with Plant Growth-Promoting Rhizobacteria, the widespread adoption of PGPR technologies in agriculture faces several challenges. These challenges are mainly related to environmental variability, microbial survival, formulation stability, and limited farmer awareness.

One of the major challenges affecting the effectiveness of PGPR is the influence of environmental conditions. Soil properties such as pH, temperature, moisture content, salinity, and nutrient availability can significantly affect the survival and activity of introduced microbial strains. In some cases, native soil microorganisms may compete with introduced PGPR strains, reducing their effectiveness in promoting plant growth [11]. Another important challenge is the inconsistency between laboratory and field results. Many PGPR strains demonstrate strong growth-promoting effects under controlled laboratory or greenhouse conditions. However, their performance in field environments can be variable due to complex ecological interactions in soil ecosystems. Factors such as microbial competition, climatic conditions, and plant genotype can influence the establishment and activity of PGPR in agricultural soils.

The formulation and storage of PGPR-based biofertilizers also present significant challenges. Microbial inoculants must be formulated in a way that maintains the viability and stability of bacterial cells during storage and transportation. Improper formulation can reduce the shelf life of biofertilizer products, limiting their commercial viability. Another constraint is the limited awareness among farmers regarding the benefits and proper use of microbial inoculants. In many agricultural regions, farmers rely heavily on chemical fertilizers and pesticides due to their immediate and predictable effects. As a result, the adoption of PGPR-based technologies remains relatively low in some areas. Regulatory issues and quality control standards for microbial products can also affect the commercialization of PGPR. Ensuring consistent quality, effectiveness, and safety of microbial formulations is essential for gaining farmer trust and promoting large-scale adoption. Addressing these challenges requires increased research efforts, improved microbial formulations, better extension services, and farmer education programs. Enhancing collaboration among researchers, policymakers, and agricultural stakeholders will be essential for overcoming these limitations and promoting the successful use of PGPR in sustainable agriculture.

7. Future Perspectives

The growing demand for sustainable food production and environmentally friendly agricultural practices has increased interest in the potential applications of Plant Growth-Promoting Rhizobacteria. Future research efforts are expected to focus on improving the understanding of complex interactions among plants, soil microorganisms, and environmental factors. One important research direction involves the use of advanced molecular and genomic tools to identify new PGPR strains with enhanced plant growth-promoting abilities. Techniques such as metagenomics, transcriptomics, and proteomics allow scientists to explore the diversity and functional potential of microbial communities in the rhizosphere. These approaches can help identify beneficial microbial traits that contribute to plant growth and stress tolerance.

Another promising area of research is the development of microbial consortia, which involve the combined use of multiple beneficial microorganisms rather than a single bacterial strain. Microbial consortia can provide complementary functions, such as nitrogen fixation, phosphate solubilization, and disease suppression, resulting in improved plant growth and soil health [12]. Advances in biotechnology and microbial formulation technology will also play an important role in enhancing the effectiveness of PGPR-based products. Improved carrier materials, encapsulation techniques, and shelf-stable formulations can increase the viability and field performance of microbial inoculants. The integration of PGPR with precision agriculture and climate-smart farming practices is another promising approach for improving agricultural sustainability. Precision agriculture technologies, including remote sensing, data analytics, and smart irrigation systems, can help optimize the application of microbial inoculants and improve crop management strategies, the use of PGPR can contribute to climate change mitigation and adaptation by improving soil carbon sequestration, enhancing plant resilience to environmental stresses, and reducing greenhouse gas emissions associated with synthetic fertilizers, future advancements in microbial biotechnology, soil microbiology, and sustainable farming practices will significantly enhance the role of PGPR in global food production systems.

8. Conclusion

Plant Growth-Promoting Rhizobacteria represent a promising and environmentally sustainable approach to improving agricultural productivity. These beneficial microorganisms enhance plant growth through multiple mechanisms, including nutrient mobilization, nitrogen fixation, phytohormone production, and biological control of plant pathogens. The use of PGPR offers a viable alternative to excessive reliance on chemical fertilizers and pesticides, which have been associated with environmental pollution and soil degradation. By improving soil fertility, increasing nutrient uptake efficiency, and enhancing plant resistance to environmental stresses, PGPR contribute significantly to sustainable agricultural systems, the challenges associated with field performance, formulation, and farmer awareness, ongoing research and technological advancements continue to improve the effectiveness and accessibility of PGPR-based biofertilizers. Future developments in microbial biotechnology, precision agriculture, and climate-smart farming practices are expected to further expand the role of PGPR in global food production. Integrating PGPR into modern agricultural practices will not only improve crop yields but also promote soil health, environmental sustainability, and long-term food security. As a result, PGPR-based technologies are likely to play an increasingly important role in the development of sustainable and resilient agricultural systems worldwide.

References

1. Prasad, M., Srinivasan, R., Chaudhary, M., Choudhary, M., & Jat, L. K. (2019). Plant growth promoting rhizobacteria (PGPR) for sustainable agriculture: perspectives and challenges. *PGPR amelioration in sustainable agriculture*, 129-157.
2. Kumari, B., Mallick, M. A., Solanki, M. K., Solanki, A. C., Hora, A., & Guo, W. (2019). Plant growth promoting rhizobacteria (PGPR): modern prospects for sustainable agriculture. In *Plant health under biotic stress: volume 2: microbial interactions* (pp. 109-127). Singapore: Springer Singapore.
3. Hasan, A., Tabassum, B., Hashim, M., & Khan, N. (2024). Role of plant growth promoting rhizobacteria (PGPR) as a plant growth enhancer for sustainable agriculture: A review. *Bacteria*, *3*(2), 59-75.
4. Adedeji, A. A., Häggblom, M. M., & Babalola, O. O. (2020). Sustainable agriculture in Africa: Plant growth-promoting rhizobacteria (PGPR) to the rescue. *Scientific African*, *9*, e00492.
5. Yang, P., Condrich, A., Scranton, S., Hebner, C., Lu, L., & Ali, M. A. (2024). Utilizing plant growth-promoting rhizobacteria (PGPR) to advance sustainable agriculture. *Bacteria*, *3*(4), 434-451.
6. Malik, L., Sanaullah, M., Mahmood, F., Hussain, S., Siddique, M. H., Anwar, F., & Shahzad, T. (2022). Unlocking the potential of co-applied biochar and plant growth-promoting rhizobacteria (PGPR) for sustainable agriculture under stress conditions. *Chemical and biological technologies in agriculture*, *9*(1), 58.
7. Chandran, H., Meena, M., & Swapnil, P. (2021). Plant growth-promoting rhizobacteria as a green alternative for sustainable agriculture. *Sustainability*, *13*(19), 10986.
8. Kashyap, B. K., Solanki, M. K., Pandey, A. K., Prabha, S., Kumar, P., & Kumari, B. (2019). Bacillus as plant growth promoting rhizobacteria (PGPR): a promising green agriculture technology. In *Plant health under biotic stress: volume 2: Microbial Interactions* (pp. 219-236). Singapore: Springer Singapore.
9. Rasool, A., Mir, M. I., Zulfajri, M., Hanafiah, M. M., Unnisa, S. A., & Mahboob, M. (2021). Plant growth promoting and antifungal asset of indigenous rhizobacteria secluded from saffron (Crocus sativus L.) rhizosphere. *Microbial Pathogenesis*, *150*, 104734.
10. Kumar, A., Patel, J. S., Meena, V. S., & Ramteke, P. W. (2019). Plant growth-promoting rhizobacteria: strategies to improve abiotic stresses under sustainable agriculture. *Journal of Plant Nutrition*, *42*(11-12), 1402-1415.
11. Kalyanasundaram, G. T., Syed, N., & Subburamu, K. (2021). Recent developments in plant growth-promoting rhizobacteria (PGPR) for sustainable agriculture. *Recent Developments in Applied Microbiology and Biochemistry*, 181-192.
12. Rai, Pankaj K., Manali Singh, Kumar Anand, Satyajit Saurabh, Tanvir Kaur, Divjot Kour, Ajar Nath Yadav, and Manish Kumar. "Role and potential applications of plant growth-promoting rhizobacteria for sustainable agriculture." In *New and future developments in microbial biotechnology and bioengineering*, pp. 49-60. Elsevier, 2020.