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Revitalization Of Plant Growth Promoting Rhizobacteria As An Effective Bioinoculant To Enhance The Growth, Production, And Stress Tolerance Of Vegetable Crops. A Short Review

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Abstract

Now environmental pollution is a serious issue. The use of chemical fertilizers continuously can cause soil and water pollution. We know that the soil is a source of indigenous microorganisms. Among them, the plant-growth-promoting rhizobacteria (PGPR) are promising bioinoculants for vegetable crops that provide sustainable, environmentally friendly ways to increase growth, production, and stress tolerance due to the production of plant-growth-promoting properties (Phosphate solubilization, Indole acetic acid production, etc.). These advantageous bacteria penetrate the rhizosphere, form symbiotic associations, and support nutrient uptake, root growth, and general plant health. By enhancing water and nutrient uptake, controlling osmotic balance, and inducing the plant's immunological response, they also boost vegetable crop stress tolerance. The use of PGPR-based bioinoculants reduces the need for chemical pesticides and fertilizers while minimizing environmental contamination.

Keywords:** **PGPR, soil health, Rhizobacteria,

Introduction:

Food security and essential vegetable consumption are crucial for maintaining health and preventing diseases. To address micronutrient demands and avoid noncommunicable diseases, the WHO advises consuming 400 g of eatable fruits and vegetables per day. Vegetable seed sales were valued at $9.163 billion globally in 2018 and are expected to grow by 9.4% yearly from 2019 to 2024. In India, pepper (*Capsicum annuum L.*) is widely farmed for its therapeutic qualities and high ascorbic acid, vitamins, and protein content. Cucumbers, a member of the Cucurbitaceae family, are a significant vegetable due to their economic and dietary importance. Cucumbers have dietary fiber, pantothenic acid, copper, magnesium, manganese, and phosphorus, and are used in antipyretic and astringent remedies. Brassica oleracea, or broccoli, is a popular vegetable with numerous health benefits and high-quality phytochemicals. Okra, a popular vegetable in tropical and subtropical regions, is also cultivated for its vitamins, carbs, minerals, and lipids. Vegetables are crucial for human sustenance and preventative medicine, with enough consumption of fruits, vegetables, and whole grains resulting in lower disease risk and all-cause mortality. Green leafy vegetables are also the best sources of phytochemicals with possible anti-obesity effects. These include Capsicum, Lactucasativa, cepa (Allium cepa), sabellica, and orange batatas.

The Alliaceae family of vegetables, including tomatoes, are rich in thiosulfides and are linked to a decrease in chronic disorders. Chemical fertilizers and insecticides are the mainstays of modern vegetable farming, which can increase crop yields and soil fertility. However, these fertilizers have the potential to degrade soil, reduce the quantity and quality of the matter in the soil, promote nutrient loss through precipitation as well as evaporation, generate greenhouse gases, and pollute the air and water. A practical option to decrease the detrimental impacts of chemical fertilizers is organic farming, which rigorously forbids the use of synthetic fertilizers. High-quality food is often produced via organic farming without harming the environment or the condition of the soil.

High-quality food may be produced using bio-organic farming, which rigorously forbids the use of synthetic fertilizers and has no detrimental effects on the environment or the wellness of the soil. Researchers found that bio-organic farming produced higher yields and higher-quality tomatoes than traditional farming, with less frequent use of chemical fertilizers and more fertile soil. Rhizosphere microorganisms are soil microbes that promote plant development and prevent illnesses. These bacteria stimulate plant hormones, and increase root development, nutrient absorption, and pathogenic activity, while also decreasing pathogenic activity and restoring soil health by mineralizing organic contaminants. This review focuses on the utilization of plant growth-promoting rhizobacteria to manage soil pollution due to the utilization of chemical fertilizer and improve crop production.

2. Effect of PGPR in Promoting Plant Growth:

In order to create environmentally friendly, sustainable agriculture, PGPR is crucial in improving soil quality, bioremediation, and stress management. PGPR can be used as biofertilizers and biopesticides by directly promoting plant development by mechanisms such as fixation, phytohormone production, and solubility of phosphates. Seed coating and soil soaking are two of the most popular bioinoculation methods used to promote vegetable growth, while foliar sprays can be used to avoid disease. Phosphate solubilizing bacteria (PSB), PGPR, hydrolyze both biological and chemical insoluble Phosphorus molecules into soluble P forms that plants may use readily. At first, it was believed that the formation of hydrogen cyanide (HCN) contributed significantly to the promotion of plant development by lowering plant infections.

3. Production of Vegetable Crops Using PGPR:

Vegetable crops can benefit from the use of various PGPRs as biofertilizers (F. Ajilogba et al., 2022). Vegetables require phosphorus to flourish, and the potato (*Solanum tuberosum*) in particular requires high soil phosphorus levels to generate significant amounts of biomass. Due to the restricted P availability in soils, global potato yields are reduced by about 40%. Due to the development of tubers, potatoes require more N and P than other vegetables. Bacteria that can dissolve phosphate improved potato tuber development and biomass production. P solubilization and potato production were strongly affected by the interaction of three P solubilizing bacteria, *Pantoeaagglomerans sp.*, *Microbacteriumlaevaniformans* strain P7, and *Pseudomonas sp*. Furthermore, K-solubilizing bacteria can increase the availability of K in the rhizosphere, which can improve potato yield.

Plants protected against diseases and pests by PGPR-treated vegetable crops have the potential to act as biocontrol agents. They do this by inhibiting a range of viral, bacterial, fungal, and nematode diseases directly and by altering the rhizosphere in a way that promotes beneficial microorganisms. The wilt disease caused by *Fusarium* infection in tomatoes is just one of the soilborne fungal diseases that have a negative impact on vegetable crops. In their evaluation of the *Bacillus aryabhattai* PGPR's ability to prevent *Fusarium* wilt disease in tomatoes, Nabi et al. discovered that PGPR-treated plants had greater levels of amino acids and phytohormones. Alternariasolani, the cause of early blight disease, is also responsible for over 80% of tomato crop losses in addition to *Fusarium.* The combination of PGPR (*Bacillus subtilis*) with green waste and wood biochar suppressed the development of *A. solani*'s mycelium in tomatoes by up to 55%. By using a group of bacteria. The findings showed that when PGPR formulations were increased, yields per acre steadily increased. Significant phenotypic and genotypic associations were also identified between the yield/acre and the output in each treatment.

In order to improve plant development and mitigate the negative impacts of soil limits (salinity, pH, and dehydration), PGPR bioinoculation may be beneficial for vegetable crops. The Solanaceae genus of plants, which includes the species Solanum melongena, is grown in tropical, subtropical, and Mediterranean nations. Saline soils with increased Na+ absorption restrict the growth and yield of eggplant. However*, Xanthobacter sp, Enterobacter sp., and Bacillus sp.* were added to eggplant seeds treated with PGPR, which enhanced plant growth by reducing Na+ absorption and increasing K+ uptake. Because of its shallow root structure and sensitivity to water shortage, lettuce (*Lactucasativa L.*) is subject to abiotic stress and this sensitivity rises with plant growth. In order to boost lettuce growth in saltwater circumstances, Julia et al. used a biofertilizer containing PGPR *Azospirillum brasilense* and Macrocystispyrifera algal extracts. In a different investigation, lettuce grown in a greenhouse with PGPR inoculation contained more phenolic and flavonoid compounds than uninoculated plants. Lettuce's resistance to salt is increased by Bacillus and *Pseudomonas species*. The frequently consumed vegetable okra (*Abelmoschusesculentus L. Moench*), which is rich in vitamins and minerals, is a secret weapon for diabetics. Okra roots are colonized by *Pseudomonas* spp., which promotes plant development.

4. Mechanistic Overview of Stress-Induced Vegetable Crop Plant Growth Promotion Mediated by PGPR:

Symbiotic bacteria and free-living rhizobacteria make up the majority of plant-microbe PGPR interactions (Kumar et al., 2021). These two groups can then be further subdivided based on whether they operate indirectly or directly. Rhizoremediation, root growth stimulation, biofertilization, and the management of biotic and abiotic stresses are examples of direct processes, whereas disease repression and the development of systemic resistance are examples of indirect mechanisms. ePGPR (Extracellular), which resides on the root's surface, along with iPGPR(intracellular), which resides within the root cortex, are two kinds of PGPR that may be distinguished depending on where they are colonized. Numerous symbiotic bacteria live in the intercellular spaces between plant cells. A few bacteria enter plant cells through relationships with their hosts that are mutualistic. Others work with plants physiologically and contribute to structural modifications. Rhizobia, for example, are well known for their mutualistic behavior, creating specialized root formations (nodules) to fix environmental N, and forming symbiotic interactions with leguminous plants.

Due to land degradation and climate change, plant stress is increasing due to biotic stressors like diseases and herbivores as well as abiotic stresses including dehydration, salt, low temperature, as well as heat. With hormonal and nutritional imbalances, as well as physiologic and metabolic alterations, stress circumstances can have an adverse effect on plant development. PGPR can help plants recover from these situations. PGPR can also begin the production of exopolysaccharides, hydrolytic enzymes, toxic metal bioremediation, and the encouragement of systemic resistance that is induced (ISR). They also improve ISR by accelerating the physical and physiological responses of plant cells to environmental stresses. In order to promote the production of defense-related molecules, PGPR interactions with host plants raise the number of defense-responsive proteins that help with survival under stress.

Salinity has an impact on plant vigour, output, phase transition, and germination. Through increased root and shoot development, food absorption, chlorophyll content, vigour, and yield, salt-resistant PGPR promotes osmoprotectants in plants. Acids, plant antibiotics, proteins, and other chemical substances secreted by PGPR enable plants to develop resistance to harmful heavy metal stress.

4.1. PGPR's function in protecting vegetable crops from biotic stresses:

4.1.1. Role of PGPR in Stress-Induced by Fungal and Bacterial Organisms in Vegetable Crops:

Extracellular enzymes and other compounds that compete for resources in the rhizosphere, hydrolyze microbial cell walls, and produce ISR to cure harmful diseases in plants can be secreted, which can lead to the management of pathogenic illness (Kumar et al., 2021). *Bacillus xiamenensis* strain PM14, for instance, is highly effective against a variety of fungi. The fungicidal actions of PGPR on phytopathogenic fungi are caused by the production of diffusible and volatile antimicrobial chemicals that either prevent the development of the fungus or cause it to lyse its mycelia. In plants, PGPR can produce hormones like indole-3-acetic acid, antibiotics like iturin, surfactants, fengycin, 2,4-diacetyl phloroglucinol (DAPG), and phenazine, as well as enzymes that break down cell walls like protease, chitinase, and cellulase and siderophores that inhibit the growth of pathogens.

Rhizobacteria that stimulate plant development can be employed as phytopathogen biocontrol agents. By directly eradicating the pathogens or by enhancing host plant defenses and engaging in nutritional competition with plant pathogens, they help plants develop disease resistance. Reactive oxygen species (ROS) production is a sign of numerous physiological changes brought about by biotic and abiotic stressors in plant cells. These defense enzymes work to scavenge ROS, convert them into harmless byproducts, and shield cells from oxidative stress. To combat oxidative damage, plant cells also produce a number of antioxidant compounds, including carotenoids and phenylpropanoids.

4.1.2 PGPR against Insect and Nematode Pests:

By boosting yield effectiveness and reducing losses brought on by plant parasites (nematodes), it is possible to meet the rising demand for agricultural goods. However, the present chemical-based approach has unintended and harmful impacts on the flora and animals. A biocontrol agent, such as PGPR, is required for nematode management because it has the ability to either directly inhibit nematodes by creating enzymes, and poisons, and either directly by influencing parasitic behaviour and altering root diffusates, or indirectly through other metabolic products In reaction to PGPR, the host plant produces repellents that negatively affect host recognition and alter the formation of nematode-feeding sites or reproduced within root cells. PGPR enhances antioxidant activity and nutrient absorption by controlling the levels of plant hormones and encouraging root development.

4.2. Abiotic Stress and the Function of PGPR in Vegetable Crops:

The physiological and molecular alterations caused by PGPR in plants that improve their resistance to external stressors such as salt, cold, high temperatures, and heavy metals are known as induced systemic tolerance (IST). These environmental factors have a considerable, up to 70%, negative impact on the yields of staple food crops, which affects the safety of the world's food supply. Aridity stress caused by heat, salt, and drought is the main abiotic stress that restricts plant growth and productivity. The usage of PGPR in the context of abiotic stresses has been the subject of several investigations.

4.2.1 Vegetable Crop Salinity Tolerance Mediated by PGPR:

The majority of vegetable crops are impacted by salinity stress, which alters morphological and physiological traits and lowers crop growth and yield (Patani et al., 2023). Due to osmotic or water-deficit stress, salt accumulation in branches, a lack of nutrients, or a combination of these, salinity stress affects the growth of vegetable crops (Patani et al., 2023). Numerous vegetable crops have had their susceptibility to salt stress tested. Okra (Abelmoschusesculentus) was able to withstand salt stress better because to PGPR's higher water usage efficiency and ROS-scavenging enzymes. Additionally, Saravanakumar et al. investigated how PGPR influenced soils affected by salinity when it came to groundnuts. In order to reduce salt stress, PGPR demonstrated ACC-deaminase activity through modifying antioxidant enzymatic activities.

4.2.2 A PGPR-Mediated Mechanism for Heat Tolerance, Metal Toxicity, and Other Stresses in Vegetable Crops

In different agroclimatic zones, elevated temperatures limit essential plant processes and lower output. Globally, it is a significant environmental problem. However, PGPR has been linked to some plants' ability to tolerate heat stress. According to Bensalem et al., potato plants that had been inoculated with the *Burkholderia phytofirmans* strain *PsJN* fared better under extreme heat stress. Martin and Stutz looked at how pepper (*Capsicum annum L.*) growth and productivity were improved by arbuscular mycorrhizal fungal isolates by increasing the amount of dry matter and P absorption at higher temperatures. Similar findings were made by Mukhtar et al. when they evaluated the capacity of the rhizobacterium Bacillus cereus to mitigate the effects of heat stress on tomatoes. They found that ACC-deaminase, exopolysaccharides, as well as external metabolic features of PGPR, controlled tomato growth characteristics under high temperatures.

Conclusions:

Contrary to chemical fertilizers, which may have negative effects on the soil, environment, and human well-being, biofertilizers are naturally occurring compounds that do not affect the soil ecology or humans. A crucial component of sustainable agriculture is the use of PGPR-based biofertilizers in order to protect crop production and maintain long-term soil fertility. The availability of phytohormones (like IAA) and improved nutrient uptake (such as N, P, and K) are two ways that PGPR stimulates the growth and yield of vegetable crops. Taking into account the beneficial effects of PGPR as a biofertilizer on crop production and yield. Additionally, PGPR shields plants against a variety of biotic and abiotic challenges by producing siderophores, and ACC-deaminases, and engaging in biocontrol activities. PGPR are beneficial soil bacteria that can promote biological, chemical, and physical changes in vegetable crops and counteract the negative impacts of abiotic and biotic pressures. PGPR-mediated bioinoculants should be applied often to increase vegetable output, especially in times of stress. Governments and private organizations should encourage the use of biofertilizers as an eco-friendly alternative to chemical fertilizers. The benefits of PGPR-based natural fertilizers for environmentally friendly farming must also be made known to farmers (Kumar et al., 2021).

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