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Synergistic and Competence of Native Plant Growth Promoting Rhizobacteria on Direct Mechanism on Growth Plants: A Review

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ABSTRACT: The most significant challenges facing farmers and plant producers worldwide are minimizing or neutralizing the impacts of environmental pressures on agricultural plants, safeguarding against pests and diseases, and simultaneously maintaining optimal plant growth and development. The environment and raising food quality standards require minimizing using of chemicals fertilizer. Plant growth-promoting rhizobacteria (PGPR) have the ability to promote plant growth through a range of mechanisms, both direct and indirect. These mechanisms include mineral solubilization, phytohormone and siderophore synthesis, and the utilization of extra secondary metabolites and enzymes. PGPR have a prospect in biofetilizer can improve the effectiveness of fertilization.

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INTRODUCTION

During the 2020–2022 base period, maize yields averaged more than 10 t/ha, which is 80% larger than the global average, predicted to increase only 5% by 2032 (FAO, 2023). Providing inorganic fertilizer is aimed at balancing the availability of nutrients and increasing the productivity of corn plants. Higher concentrations of labor, money, and agricultural resources such as chemical fertilizer and water per unit of agricultural land area are specifically necessary for intensive farming. In consequence, this reliance on intensive farming produces significant environmental contamination that is detrimental to the health of all living things, including humans (Kumar et al., 2022). Fertilizer effects on soil health are contingent upon a number of variables, such as soil type, climate, nutrient concentration, and management techniques (Skorupka & Nosalewicz, 2021). Nitrogen has a major effect on plant production and is a crucial nutrient for plant growth and development (Zhang et al., 2023). Nevertheless, leaching and denitrification can result in nitrogen loss, which contaminates the environment. The atmosphere is 78% available in the form of triple bonds between the nitrogen atoms in the N_2 molecule, non-reactive, most organisms cannot use it directly (Hu, 2018).

Utilizing biofertilizers inoculants derived from living microorganisms that contribute to availability of plant nutrition and can improve the effectiveness of fertilization (Jannah et al., 2022). Plants can access nitrogen, it is imperative to maintain the soil's microbiome, but can be costly and time-consuming. Biofertilizers are made up of one or more kinds of microorganisms, such as bacteria, which increase the availability of nutrients that can be supplied to soil, seeds, or plant roots, and colonize the rhizosphere to promote plant growth (Nosheen et al., 2021). The majority of naturally occurring soil microorganisms, especially rhizobacteria that live close to plant roots, engage in a variety of advantageous interactions with plants and are essential to sustainable agriculture because they enhance soil health and quality and make nutrients easily accessible to plants (Lyu et al., 2019). Microbial communities can affect plant growth in a variety of ways, including by increasing the intake of nutrients by the plants (Souza et al., 2015).

Indigenous microorganisms (IMOs) were a type of native microbial community that resided in the soil and on living organism surfaces. PGPR may be able to help break down organic materials, fix nitrogen, increase soil fertility, and produce plant growth hormones (Kumar & Gopal, 2015). Rhizosphere competence describes any microorganism's capacity to proliferate, operate, and engage in competition with other organisms for essential nutrients and exudates produced by plant roots. It also describes the microorganism's capacity to colonize the root surfaces of host plants in rhizospheric soil (Saeed et al., 2021).

Nitrogen fixing bacteria have an enzyme called nitrogenase in their cells, they are able to fix nitrogen from the atmosphere..The most extensively sequenced marker gene for identifying nitrogen-fixing bacteria is the *nif*H gene (Gaby & Buckley, 2012). Nitrogen fixing bacteria *Azospirillum* sp. has a dual role, namely fixing N_2, producing growth hormones such as Indole Acetic Acid (IAA), gibberellin, cytokinin, ethylene, suppressing soil based plant diseases by producing siderophores glucanase, chitinase and cyanide, and dissolving phosphate and other nutrients (Sriwahyuni & Parmila, 2019). The conclusion, plant growth promoting rhizobacteria can increase effectivity and efficiency of chemical fertilizer in crop production. This review aims to present the mutualistic interaction, mode of action plant-growth promoting rhizobacteria, direct and indirect mechanism of PGPR and soil health and increasing of crops production to get the sustainability in agriculture.

PLANT GROWTH PROMOTING RHIZOBACTERIA : MICROBIAL ACTIVITIES

Plant growth-promoting rhizobacteria (PGPR) can stimulate the growth of the plants by direct and indirect mechanisms, variety of mode of action, including mineral solubilization, the synthesis of phytohormones and siderophores, as well as the utilization of additional secondary metabolites and enzymes (Chaudhary Parul et al., 2022). The capacity to colonize both the external and intracellular rhizosphere niches in their quest for a carbon source and a decrease in the amount and free use of agrochemicals is the first of the various ways that plant growth-promoting rhizobacteria (PGPR) labor. PGPR's relationship with the host plant improves the production of chemicals linked to future protection. Elevated concentrations of these defense proteins improve the host plant's ability to hold up adverse environments (Bhattacharyya et al., 2020).

Rhizosphere competence describes an organism's capacity to proliferate, operate, and engage in competition with other microbes for vital nutrients and plant-derived exudates. Most naturally occurring soil microorganisms perform significant functions and engage in a variety of beneficial interactions with plants, particularly with rhizobacteria that are found around plant roots. A vast reservoir of microbial community is established by the interaction that agricultural plants' roots produce between the plant and the soil environment (Kumar & Dubey, 2020).

Table 1. Different Source, Mode of Action of PGPR and Plants responses

No.	Consortium Plant Growth Promoting Rhzobacteria (PGPR)	Source	Mode of Action	Plant Responses	Reference
1.	*Rhizobium mayense* sp. Nov. RSKVG 02	Isolated from groundnut rhizospheric soil in India	Nitrogen fixation, IAA, Ammonium, organic acid production and solubilized inorganic phosphate, and potassium	Green gram and Finger millet's root length, shoot length, dry weight, and chlorophyll content	(Shameem et al., 2023)
2.	*Pseudomonas hunanensis Pseudomonas alcaliphila*, *Bacillus safensis Streptomyces laurentii*, and *Sinorhizobium* sp.	Isolated from rhizosphere of *Ocimum basilicum* (basil plant) in Saudi Arabia	Nitrogen fixation, solubilized inorganic phosphate, IAA, Ammonium, gibberellin and catalase production	Increased dry weight of okra (*Abelmoschus esculentus*) and Improve the root system, dry weight, root length and root braches of red bean (*Phaseolus vulgaris* L.) and okra plants.	(AlAli et al., 2021)
3.	*Rahnella aquatilisi* S11P1, *Rahnella aquatilisi* S11A1a and *Variovorax paradoxus* S12S4.	Isolated from saffron rhizosphere in Taliouine, Marocco.	Solubilized inorganic phosphate, IAA, siderophore, atmospheric nitrogen fixation and antagonistic activity.	Increased of flower production, number of leaves, leaves length, clorophyll content, biomass, root length and weight of corm plants.	(Chamkhi et al., 2023)
4.	*Bacillus subtilis* BS87 and *Bacillus megaterium* BM89	Isolated from rhizosphere of sugarcane in India	Ammonia, IAA, chatalase, chitinase, siderophore, ACC deaminase production and solubilized phosphate and zinc	Improved shoot, root legth, shoot fresh and dry weight, chlorophyll content, nutrient uptake and proline content in	(A. Chandra et al., 2021) (P. Chandra et al., 2018)

				sugarcane	
5.	*Azospirillum brasilense* BNCC139156 and *Pseudomonas fluorescens* BNCC159133	Isolated from roots of field grown rice plants in China	Ammonification activity, nitrification activity and nitrogenase enzyme.	Increase nitrogen content, rice grain yield and reduce nitrogen chemical fertilizer	(Zhang et al., 2021)
6.	*Pseudomonas stutzeri* Ab_3 and *Klebsiella pneumoniae* Az_2	Isolated from paddy rhizosphere at salinity in Indonesia.	Nitrogenase activity, organic acid, gibberellic acid and IAA productions	Increasing N-uptake, number of panicles, filled grain, and the rice yield	(Simarmata et al., 2023)
7.	*Bacillus megaterium* CY5 and *Bacillus mycoides* CAI	Isolated from the sugarcane rhizosphere in China	Nitrogenasse activity, *nif*H gene expression in pots, ACC deaminase and biocontrol activity	N-fixing ability, the *Saccharum* spp. growth and development, also biocontrol of pathogens	(Singh et al., 2020)
8.	*Bacillus* sp. A28, *Sinorhizobium* sp. A15, *Sphingomonas* sp. A55 and *Enterobacter* sp. P24	Isolated from the maize rhizosphere in Northeast China.	IAA synthesis, increase nutrient supply, phosphate, potassium solubilized and siderophore released	Reduce of nitrogen and phosphate chemical fertilizer, promote early growth and increase maize grain yield.	(Chen et al., 2021)
9.	*Delftia sp.* strain *MS2As2* (MCE-1) *Delftia tsuruhatensis strain D9* (RE-2) and *Bacillus* sp. (FE-3)	Isolated RE-2 from soil in rice field, MCE-1 from cashew vegetation, and FE-3 from maize vegetation in Indonesia	Organic acid production, Indole-3-acetic acid (IAA) and nitrogenase activity	The increase in the number of grains per plant, grain yield, the weight of 1000 grains, N-fixing bacteria total and the N uptake.	(Harahap et al., 2023)
10.	*Bacillus* sp. IHK-13, *Stenotrophomonas maltophilia* IHK-1, *Enterobacter* sp. IHK3, *Ochrobactrum haematophilum* IHK-15, *Pseudomonas aeruginosa* IHK-25	Isolated from the rhizosphere of rice fields in India	N_2- fixation, inorganic phosphate, zinc, rock phosphate solubilization, siderophore, IAA, ACC deaminase activity, HCN, lytic enzymes production and ammonification activity	Significantly increased rice germination, seed vigor, and total dry biomass	(Mir et al., 2022)
11.	*Pseudomonas stutzeri* S3 and *Klebsiella pneumonia* S5	Isolated from rhizosphere of rice plants and mangroves in Indonesia	Nitrogenase activity, siderophore, IAA, ACC deaminase, Antioxidant enzymes production	Increased shoot height, root length, and plant dry weight of rice seedlings in salinity stress	(Khumairah et al., 2022)
12.	*Bacillus subtilis* GSW-E-6, *Azospirillum brasilense* and Genus of Bacillus, Oceanobacillus, and Halomonas	Isolated from rhizosphere the durum wheat (*Triticum turgidum* subsp. durum) cultivated	Nitrogen fixation, ACC deaminase activity, antifungal activity against *Fusarium culmorum*, siderophore production	Increase growth (shoot length, root length, shoot and root fresh weight) of durum wheat in salinity stress	(Albdaiwi et al., 2020)

		in saline areas in Jordan	auxin production and inorganic phosphate solubilization,		
13.	*Bacillus tequilensis* and *Bacillus aryabhattai*	Isolated from coastal saline areas in Malaysia	Fix atmospheric nitrogen activity, produce IAA solubilize phosphate and potassium on saline media	Increasing the three rice types' rates of transpiration, photosynthesis, and stomatal conductance, grain yield production	(Shultana et al., 2020)
14.	*Rhizobium* sp. and *Actinomycetes* sp.	Isolated from rhizosphere of soybean plants in Indonesia	Nitrogen fixation, siderophore (salicylic and cathecol) production	Increase number of stem, number of soybean pods and number of seeds soybean.	(Sahur et al., 2018)
15.	*Azospirillum* sp., *Pseudomonas* sp., and *Bacillus* sp.	Isolated from rhizosphere of maize (*Zea mays*) in Inceptisols Indonesia.	Nitrogenase activity and biodegradation capability, IAA, kitenin zeatin and giberelin production	Improve plant height of rami under petroleum stressing, They also show hydrocarbon degradation capabilities of 83.70% and 81.78% in a phytoremediation soil system using ramie plant.	(Suryatmana et al., 2022)

Microbial inoculants and resident microorganisms work in concert to enhance plant nutritional activities, which include nutrient mobilization, breakdown, and solubilization. As a result, crop yields have increased and the need for artificial fertilizers has decreased. Microbial inoculants are becoming increasingly accepted and used as plant-improving agents in affluent nations where agriculture is the primary economic engine (Adedeji et al., 2020). Plant roots can modulate the content of their exudate to form mutualistic relationships with different types of bacteria and fungi (Vives-Peris et al., 2020). PGPR can increase the mechanism of nutrient uptake.

In addition to biotic stress, PGPR aids in adaptation to abiotic challenges such salinity, drought, and flood stress. Metabolism is carried out by the PGPR rhizosphere and rhizomicrobiome; the former serves as a source of sustenance for the microorganisms, and the latter biotransforms nitrogen, phosphorus, and iron into forms that are more beneficial to plants (Mohanty et al., 2021). PGPR can be found at surrounding soil, rhizosphere, phyllosphere, endosphere and plant tissues (Shin et al., 2016). PGPR isolated from rhizosphere include : Acinetobacter, Azospirillum, Bulkholderia, Enterobacter, Pseudomonas, Pantoea, Rhizobium and Streptomyces have been reported can increase the plant growth and yield (Herrera-Quiterio et al., 2020).

MECHANISM OF PGPR TO PROMOTE PLANT GROWTH

Plant rhizodeposits contain a variety of compounds that present enormous potential for both attracting and inhibiting particular microbial strains (Chagas et al., 2018). The mechanism of PGPR, such as : nitrogen fixation, solubilizing phosphate and potassium, antioxidant release, osmotic adjustment through the accumulation of compatible solutes, production of 1-aminocyclopropane-1-carboxylate (ACC) deaminase and exopolysaccharide (EPS), production of phytohormones (e.g., indole-3-acetic acid (IAA), ABA, gibberellic acid, and cytokinins), and defense strategies, such as pathogenesis-related gene expression, are mechanisms linked to the induction of systemic tolerance and plants with greater drought tolerance (Riseh et al., 2021).

NITROGEN FIXATION

Nitrogen gas (N_2) eighty percent (80%) of the atmosphere, but most of living things cannot use N_2. In the presence of N_2 that they cannot use, nitrogen shortage can cause plants, animals, and microbes to perish. One of the main mechanisms in the global N cycle is nitrogen fixation. The biosphere is exposed to dinitrogen in the form of chemically triple-bonded,can break the triple bond and change it to NH (Ladha et al., 2022). Nitrogen is utilised by all creatures in the ammonia (NH_3) form to create proteins, nucleic acids, amino acids, and other nitrogen-containing elements required for life. The process known as biological nitrogen fixation (BNF) converts inert N_2 into usable NH_3. In nature, only particular kinds of actinomycetes and bacteria mediate this process. Biomass of bacteria and release nitrogen into the environment, or the bacteria are only tangentially attached to plant roots, plants benefit in the free-living system (Soumare et al., 2020). Nitrogen fixing bacteria have two mechanism symbiotic and non-symbotic, and can supply nitrogen for the use of plants. Nitrogen fixing bacteriacan increase supply nitrogen to the plant and focused on plant growth stimulation (Bhattacharyya, 2014).

Nitrogen fixing microorganism is catalyzed by nitrogenase enzyme, such as : the Mo (molybdenum)-dependent nitrogenase (Nif), V (vanadium)-dependent nitrogenase (Vnf), and Fe-only nitrogenase (Anf) (Mus et al., 2019). Dinitrogenase, the catalytic component, and dinitrogenase reductase, the electron transfer component, are two metalloproteins that form the nitrogenase enzyme (Burén et al., 2020). According to Hu et al. (2018) every year, 7 to 80 kg of N_2 are provided per hectare by PGPR strains such *Azospirillum* sp. and *Azotobacter* spp. and endophytes like Cyanobacteria (Gluconoacetobacter diazotrophicus, Anabaena, Noctoc, and Azocarus).

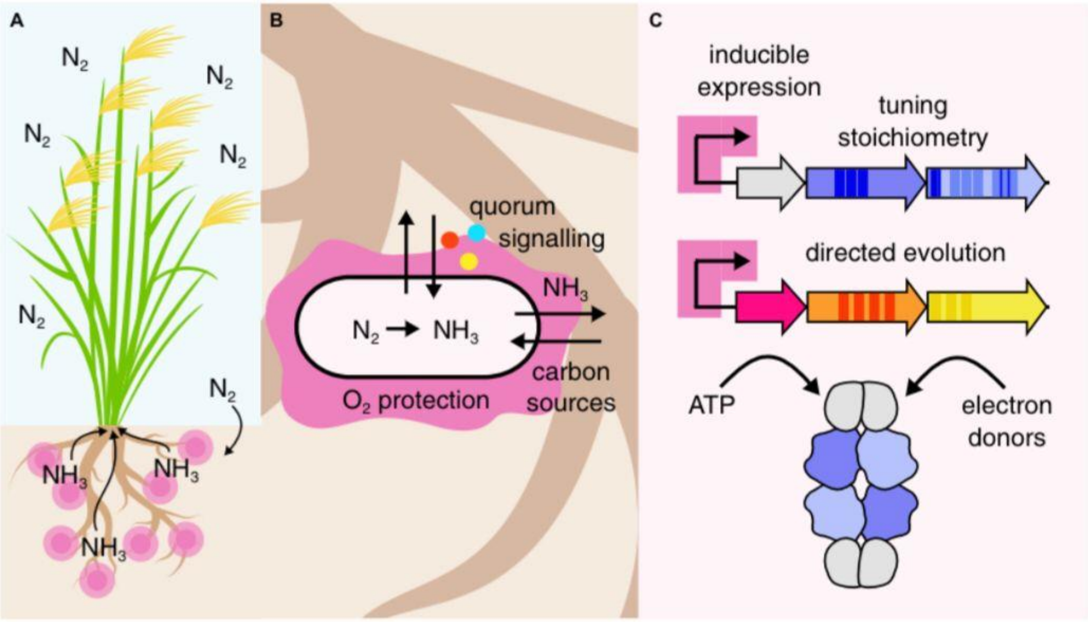

Figure 1. Nitrogen Fixation Activity by Nitrogen Fixing Bacteria (Bennett et al., 2023)

SOLUBILIZING PHOSPHATE, ZINC AND POTASSIUM

Microorganisms that can be used as biofertilizers include those that solubilize minerals and provide nutrients, such as potassium, phosphorus, zinc, and selenium, which are essential for plant growth and development. In addition to helping with biological nitrogen fixation and the creation of siderophores, ammonia, hydrogen cyanide, hydrolytic enzymes, and bioactive compounds/secondary metabolites, mineral dissolving microorganisms can dissolve phosphorus, potassium, zinc, selenium, and silicon (Devi et al., 2022). Nutrients such as phosphorus, potassium, and zinc are bonded to minerals, salts, or metals, they prevent the plant from growing and developing. Important plant nutrients, such phosphorus, potassium, and zinc, are determined by how soluble they are in the rhizosphere. (Ruzzi & Aroca, 2015).

Organic acids include carboxylic acids, lactic acid, succinic acid, glycolytic acid, formic acid, fumaric acid, and propionic acid (Xiao et al., 2017). Microorganisms can release fixed phosphate by the production of soluble complexes with metal ions that would otherwise bind phosphate tightly, releasing phosphatase enzymes, reducing pH, through chelation activity, and competing with phosphate for adsorption sites (Ghosh et al., 2023). The mechanism of potassium solubilization via microbes also involves organic acid production and protons by acidolysis (Devi et al., 2022). Zinc strains bacterial release organic acids, vitamins, and phytohormones; they also dissolve forms of zinc that are unavailable through the production of chelating ligands, the oxide-reductive system, and proton extrusion (Yasmin et al., 2021).

PHYTOHORMONE AND INCREASING OF CROPS PRODUCTION

Plants are able to grow more root surface area and increase the amount of nutrients available in the soil due to the ability of PGPR to create phytohormones. Endogenously generated chemical compounds called phytohormones are essential for controlling plant development and productivity. Plant hormones can be classified into five categories: indole acetic acid (IAA), cytokinin, gibberellin (GA), abscisic acid (ABA), and ethylene. (Kende & Zeevaart, 1997). Plant growth promoting rhizobacteria, include : *Bacillus*, *Rhizobium*, *Sinorhizobium*, *Azospirillum*, *Bradyrhizobium*, *Pseudomonas* dan *Paenibacillus* have a capability can produce phytohormone auxin, cytokinin, ABA and gibberllins (Ladha et al., 2022).

Indigenouse isolated PGPR from rhizosphere of the rice plant have been reported, including, *Pseudomonas* sp., *Bacillus* sp., *Thiobacillus*, *Bryobacter*, *Sphingomonas*, *Anaeromyxobacter*, *Streptococcus* and *Staphylococcus* (Osman et al., 2017). Consortium PGPR and nitrogen fixing bacteria Rhizobium sp. LM-5 can produce IAA. Effect of consortium can increasing clorophyll content and nutrient uptake in rice plant. Nitrogen fixing bacteria can produce IAA, developed and increase rice crop productivity. PGPR combination with Rhizobium sp. LM-5 have a capability of the highest grain yield and can increase rice yield until 177.38% (Purwanto et al., 2019)

CHALLENGES AND FUTURE PROSPECT PGPR

Microbes have a different condition in laboratory and after application in the field. Also need to research about capability PGPR to adapt in field condition with biological capability and viability. PGPR not have a long time to live in the field, need to make a inoculant to increase the capability and viability of PGPR. PGPR have a capability to nitrogen fixation, solubilized phosphate, potassium and zinc, can produce phytohormone to adapt abiotic stress (salinity, drought, flood and biotic stress). PGPR can isolated from rhizosphere, phyllosphere, endosphere, soil and plant tissue. PGPR can increase plant growth, development and can increase the yield of plant. PGPR can synergistic between microorganism and to be consortium, and have a capability and viability highest than one isolate.

CONCLUSION

Microorganisms (bacteria, fungi, and actinomycetes) interact in PGPR. *Pseudomonas*, *Bacillus*, *Azotobacter* and *Azospirillum* are examples of PGPR or PGPB, which enhance a plant's capacity to absorb water and nutrients, promote root growth, and are crucial to the nitrogen, phosphorus, and potassium nutrient cycles. Because PGPR may produce phytohormones, plants can expand the size of their roots and the amount of nutrients they can absorb from the soil. Through their effects on root shape, plant growth, and physiological and biochemical processes, these bacteria contribute to the preservation of the ecological balance of the soil and enhance plant tolerance to drought.

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