ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/25oct015

A Comprehensive Review on the Efficiency of Prokaryotic Rhizobacteria as Biofertilizers

Midhul A. K.[1*]; Greeshma Chandran[2]; Dr. S. Sreeremya[3]

[1,2]Department of Environmental Sciences, Bharathiar University, Coimbatore, Tamil Nadu, India,
[3]Department of Pharmacology, Crescent College of Nursing, Palakkad, Kerala, India,

Corresponding Author: Midhul A. K.[1*]

Publication Date: 2025/10/14

Abstract: Unsustainable agricultural practices and declining soil fertility have led to a notable reduction in global crop productivity. The excessive and indiscriminate use of chemical fertilizers not only deteriorates soil health but also possess a significant risk to human well-being. Consequently, farmers across the globe have increasingly adopted biofertilizers and biopesticides to preserve the natural equilibrium of the soil ecosystem. Biofertilizers represent an environmentally benign and economically viable alternative to chemical fertilizers. Their plant growth-promoting attributes are manifested through direct mechanisms such as biological nitrogen fixation, nutrient solubilization and mobilization (notably of N, P, K, S, Zn and Fe) and the synthesis of phytohormones including auxins, cytokinins, gibberellins and ethylene. Indirectly, plant growth-promoting rhizobacteria (PGPR) contribute to the suppression of phytopathogens via antibiotic production, siderophore secretion, hydrolytic enzyme activity, and the induction of systemic resistance. In contrast to conventional chemical fertilizers, biofertilizers offer a cost-effective, sustainable, and renewable solution that ensures the long-term preservation of soil fertility and agricultural productivity.

Keywords: *Biofertilizers, PGPR, Sustainability, Nutrient Solubilization, Soil Fertility, Biological Nitrogen Fixation.*

How to Cite: Midhul A. K.; Greeshma Chandran; Dr. S. Sreeremya (2025). A Comprehensive Review on the Efficiency of Prokaryotic Rhizobacteria as Biofertilizers. *International Journal of Innovative Science and Research Technology*, 10(10), 639-649. https://doi.org/10.38124/ijisrt/25oct015

I. INTRODUCTION

The exponential growth of the global human population and the escalating demand for food have necessitated an increased dependence on chemical fertilizers and pesticides within the conventional agricultural system (Santos et al., 2012). The widespread application of synthetic fertilizers has significantly contributed to enhanced crop productivity, primarily through the provision of essential macronutrients such as phosphorus, nitrogen and potassium. Their extensive utilization is largely attributed to their perceived cost-effectiveness and the immediate yield benefits they confer upon agriculture (Van Vuuren et al., 2010). However, the prolonged use of these agrochemicals has precipitated a series of detrimental consequences, including the degradation of soil quality, heightened air and water contamination, biodiversity loss and rising threats to human health (Aggani, 2013). Moreover, the indiscriminate application of chemical pesticides has adversely influenced soil fertility, disrupted agricultural ecology and impeded the optimal growth and development of cultivated crops (Rahman & Zhang, 2018). The dynamic interplay among plants, soil and microbial communities exerts a profound influence on soil vitality and overall plant productivity (Harman et al., 2020). Soil microbes, in particular, engage in intricate symbiotic and associative relationships with plant roots and among themselves, executing a multitude of essential biochemical and ecological functions indispensable for sustaining soil health and ecological equilibrium (Kumar et al., 2021).

The bioavailability and bio accessibility of nutrient uptake in plants can be significantly augmented through the application of biofertilizers as eco-friendly, bio-based organic formulations derived from plants or animal residues or from active and dormant microbial cells. The incorporation of fertilizers into irrigation systems, commonly referred to as fertigation, facilitates efficient nutrient delivery (S. Sreeremya, 2017). Certain potent microorganisms possess the capacity to render iron bioavailable to plants by converting it into absorbable forms (Dr.S.Sreeremya, 2019). The utilization of sustainable bioresources constitutes a pivotal strategy for environmental conservation and ecological balance (Dr.S.Sreeremya, 2020). Moreover, biopolymers serve a critical function in enhancing biofertilizer performance by acting as biodegradable carrier matrices or protective coatings (Midhul et al., 2025). Consequently, the deployment of biofertilizers has become indispensable for augmenting the planet's agricultural productivity. Employing biological and organic fertilizers supports farm sustainability within a low-input agricultural framework.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/25oct015

Biofertilizers are predominantly formulated in solid or powdered form and are conventionally immobilized onto suitable carrier materials such as clay minerals, rice bean, peat, lignite, wheat bran, humus and wood charcoal. These carriers enhance the stability, handling, and shelf life of microbial inoculants (Bhattacharjee and Dey, 2014). When judiciously applied, biofertilizers confer numerous agronomic benefits, including the reduction in dependence on synthetic fertilizers (Askary et al., 2009), mitigation of environmental pollution (Bhattarai & Hess, 1993), improvement in nutrient availability and uptake efficiency (Kour et al., 2019), and stimulation of plant growth through the secretion of bioactive compounds (Rao et al., 1983). Collectively, these effects contribute to the soil's biological, chemical, and physical attributes (Hossain, 2015) while also inducing systemic resistance in plants against certain pathogens (Jagnow, 1990). Furthermore, due to their cost-effectiveness, biofertilizers remain accessible to economically marginalized farming communities.

The majority of microorganisms inhibiting the rhizosphere possess the inherent capacity to decompose complex organic substrates into simpler, plant-assimilable compounds, thereby facilitating root proliferation through the serration of growth-promoting phytohormones. Plant growth-promoting microorganisms play an indispensable role in regulating key ecological and biochemical processes, including organic matter mineralization, mobilization of essential nutrients such as nitrogen, phosphorous, potassium, magnesium, and iron, and overall enhancement of plant vigor (Lalitha, 2017). Among these, Plant Growth-Promoting Rhizobacteria (PGPR) constitute a prominent microbial consortium widely employed as biofertilizers. PGPR promote plant development and health through both direct and indirect mechanisms. Directly, they stimulate plant growth via atmospheric nitrogen fixation, phosphorus solubilization, siderophore synthesis, and the production of phytohormones such as indole-3-acetic acid (IAA) gibberellic acid, cytokinins, and ethylene (Backer et al. 2018). Biological nitrogen fixation (BNF), primarily executed by rhizosphere-dwelling prokaryotes, represents a cornerstone process in sustainable nutrient cycling (Kumar & Gera, 2013). Only a limited group of diazotrophic microorganisms possess the enzymatic machinery to convert atmospheric nitrogen (N_2) into ammonium (NH_4^+), a soluble, non-toxic form readily assimilated by plants for biomolecule synthesis (Kumar & Gera, 2013). BNF thereby serves as a natural and eco-efficient alternative to synthetic nitrogen fertilizers, mitigating their detrimental environmental impact (Saikia & Jain, 2007). Another crucial component of soil biota comprises mycorrhizal associations, which significantly enhanced the host plant's ability to withstand adverse edaphic conditions such as drought by expanding the absorptive surface area of roots and facilitating nutrient uptake (Lehmann et al., 2016). Mycorrhizal fungi not only bolster plant growth but also act as biocontrol agents, protecting against pathogenic organisms (Leaungvutiviroj et al., 2010). This study underscores a comprehensive overview of Plant Growth-Promoting Rhizobacteria (PGPR) based biofertilizers and elucidates their multifaceted mechanisms that underpin sustainable agricultural development.

- *Plant Growth Promoting Rhizobacteria*

Biofertilizers play a pivotal role in enhancing plant productivity through a spectrum of biological mechanisms. Their influence manifests via direct mechanisms such as nitrogen fixing, nutrient solubilization and mobilization, and phytohormone synthesis (Figure: 1) as well as indirect mechanisms, including the production of secondary metabolites like antibiotics, siderophores, and other antimicrobial compounds (Figure: 2). Extensive research has demonstrated that the plant growth-promoting attributes of biofertilizers are primarily attributed to bacterial genera such as *Azospirillum, Rhizobium, Bacillus spp., Pseudomonas spp., Burkholderia, Paenibacillus Enterobacter, Herbaspirillum, Pantoea, Bradyrhizobium, Azotobacter, and Serratia*. These Plant Growth-Promoting Rhizobacteria (PGPR) have been extensively characterized and globally recognized for their agronomic benefits as biofertilizers (Tabassum et al., 2017). Within the rhizosphere, PGPR activities enhance the concentration and bioavailability of essential nutrients to plants. Depending on their ecological functions and symbiotic interactions, biofertilizers exhibit diverse classifications. Remarkably, a single biofertilizer formulation may comprise either a microbial consortium embodying multiple PGP traits or a single PGPR strain exhibiting multifaceted growth-promoting capabilities (Aloo et al., 2022). PGPR may facilitate plant growth directly by modulating endogenous phytohormone levels or by improving resource acquisition, and indirectly by mitigating the deleterious impacts of pathogenic microorganisms that hinder plant growth and development. Prominent examples of growth-promoting bacteria include *Rhizobium, Bradyrhizobium, Sinorhizobium*, *Azospirillum, Nostoc, Anabaena, Acetobacter*, and others includes *Bacillus megaterium, Azolla, and Bacillus polymyxa.* These microbial taxa substantially enhance crop yield, root proliferation, and overall plant vigor (Mahanty et al., 2016). Notably, PGPR can directly stimulate plant growth through the secretion of phytohormones or signalling molecules, while their indirect actions, such as the biosynthesis of antimicrobial and stress-mitigating compounds, confer resilience against biotic and abiotic stressors. Owing to these multifaceted properties, they are often referred to as bio stimulants (Kaushal et al., 2023). PGPR-based biofertilizers can be functionally classified based on their ability to increase the bioavailability of specific mineral nutrients. Distinct PGPR strains are implicated in various processes, including nitrogen fixing (conversion of atmospheric N_2 into bioavailable NH_3 or NH_4^+), nutrient solubilization (transformation of insoluble phosphorus into $H_2PO_4^-$, conversion of bound potassium into ionic K^+, and mobilization of zinc into Zn^{2+}), substrate oxidation (generation of SO_4^{2-} through sulfur compound oxidation), and metal chelation via the secretion of siderophores, phenolic compounds, and organic acids that scavenge Fe^{3+} and other trace elements essential for plants metabolism (Mitter et al., 2021, Colombo et al., 2013, Malusá & Vassilev, 2014).

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/25oct015

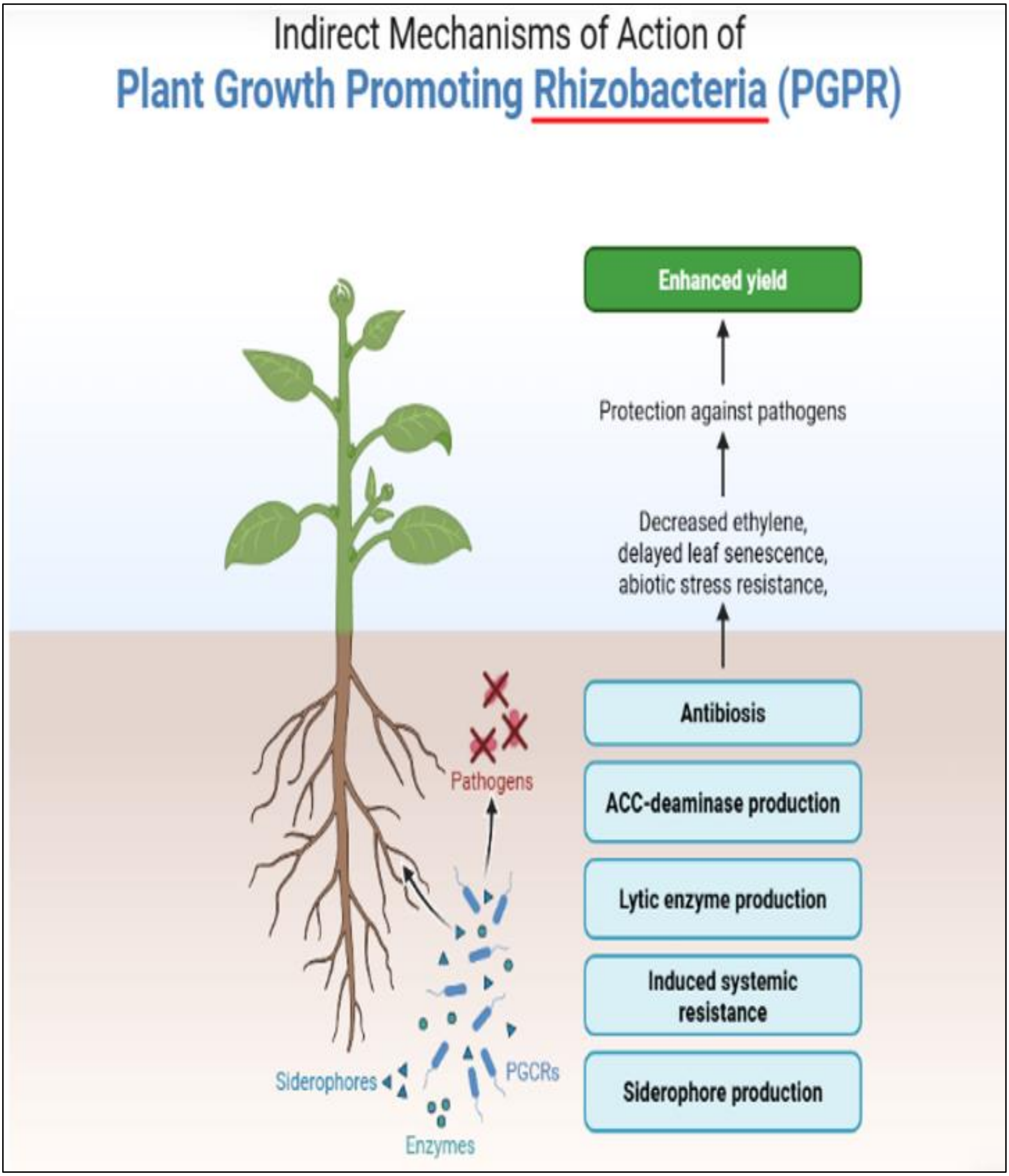

Fig 1 Direct Mechanism of Action of PGPR

Figure: 1 Keenly depicts the direct phenomena by which the PGPR copious the plant growth. The prokaryote precisely boosts the nutrient accretion through the process of biological nitrogen fixation, the other process is solubilizing the available nutrients in the environment and also mobilization (N, P, K, S, and micronutrients), These PGPR's also ooze phytochemicals in the form of phytohormones that simulate root and shoot development. These sequential processes mainly boost the plant nutrition, garners elevated growth, and ultimately aggrandize the crop yield in an eco-friendly manner.

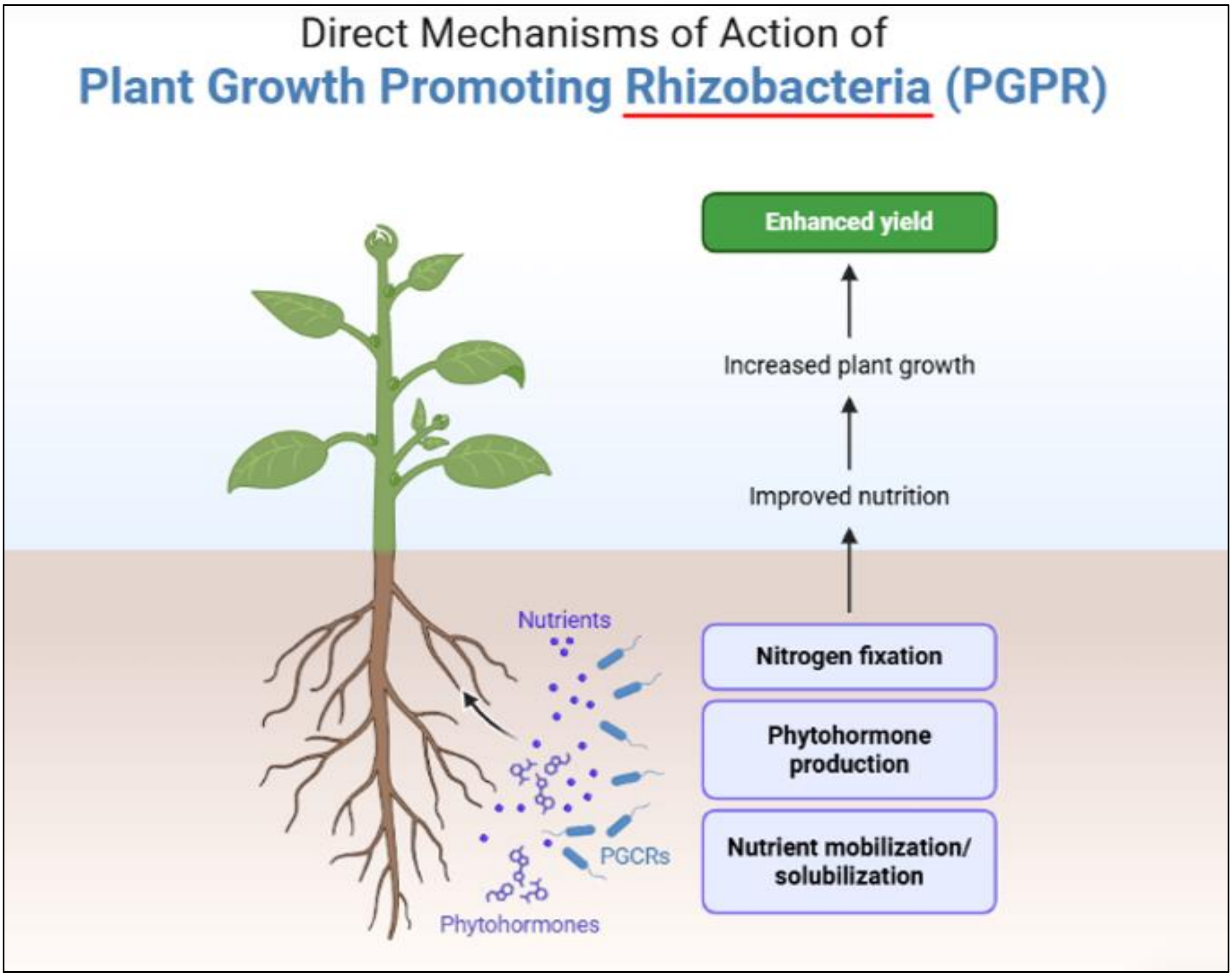

Fig 2 Indirect Mechanism of Action of PGPR

Figure 2 Keenly depicts the direct phenomena by which the PGPR copious the plant growth. The prokaryote precisely boosts the nutrient accretion through the process of biological nitrogen fixation, the other process is solubilizing the available nutrients in the environment and also mobilization (N, P, K, S, and micronutrients), These PGPR's also ooze phytochemicals in the form of phytohormones that simulate root and shoot development. These sequential processes mainly boost the plant nutrition, garners elevated growth, and ultimately aggrandize the crop yield in an eco-friendly manner.

➢ *Nitrogen Fixers*

Nitrogen-fixing microorganisms possess a specialized enzyme complex known as nitrogenase, which facilitates the reduction of atmospheric nitrogen (N_2) into ammonia (NH_3) during the process of Biological Nitrogen Fixation (BNF) (Figure 3) (Chakraborty & Tribedi, 2019). These diazotrophic microorganisms are broadly categorized into two groups which are symbiotic and non-symbiotic. Symbiotic nitrogen fixers, exemplified by members of the family Rhizobiaceae, establish mutualistic associations with leguminous plants, forming nodules on their roots where nitrogen fixation occurs (Ahemad & Kha, 2011). In contrast, non-symbiotic nitrogen fixers, such as *Cyanobacteria, Azospirillum, and Azotobacter*, function independently or as endophytes within plant tissues without forming nodules (Bhattacharyya & Jha, 2011). The symbiotic *Rhizobium* species, belonging to the Rhizobiaceae family within the α-proteobacteria class, infect the root hairs of leguminous plants, initiating a highly regulated and complex host-microbe interaction that culminates in the formation of nodules. Within these nodules, *Rhizobia* differentiate into Bacteroides, functioning as intercellular symbionts that facilitate nitrogen fixation (Allito et al., 2015). A distinct hemoprotien, leghemoglobin, plays a crucial role in modulating oxygen concentration within root nodules, ensuring optimal conditions for nitrogenase activity. The globin portion of leghemoglobin is synthesized by the plant, while the heme cofactor is produced by the bacterial symbiont, both components being expressed exclusively upon successful infection by *Rhizobium*. During this symbiotic exchange, the plant supplies the Bacteroides with organic acids derived from photosynthetically produced sugars, while receiving amino acids rather than free ammonia in return (Mohammadi & Sohrabi, 2012). Collectively, the genera *Rhizobium, Bradyrhizobium, Sinorhizobium,*

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/25oct015

Azorhizobium, and Mesorhizobium are referred to a Rhizobia. On the other hand, non-symbiotic nitrogen-fixing bacteria, commonly known as diazotrophs, can establish facultative associations with non-leguminous plants, fixing nitrogen without forming specialized structures (Verma et al., 2010).

Members of the genus *Azospirillum* are characterized as motile, oxidase-positive, curved rod-shaped bacteria that are Gram-negative to Gram-variable and capable of acetylene reduction under microaerophilic conditions. These bacteria predominantly inhibit the rhizosphere, where their colonization dynamics have been extensively studied through reporter gene fusion and microscopy-based analyses (Steenhoudt & Vanderleyden, 2000). Although the genus encompasses multiple species, such as *A. halopraeferens, Azospirillum amazonense, and A. brasilense*, the most agriculturally beneficial strains include *A. lipoferum and A. brasilense*. These organisms are prolific producers of phytohormones, including gibberellins, naphthalene acetic acid (NAA), and B-complex vitamins, which collectively enhance root development, improve mineral assimilation, and suppress certain root-borne diseases (Mathivanan et al. 2015). Similarly, *Azotobacter* species secrete bioactive compounds that stimulate root proliferation and inhibits the growth of pathogenic microorganisms within the rhizosphere (Youssef and Eissa 2014). Notably, *Azotobacter indicum* synthesizes a diverse array of antifungal antibiotics capable of suppressing pathogenic fungi in the root zone, thereby minimizing nutrient loss, reducing seedling mortality, and improving overall plant vigor (Martin et al. 2011).

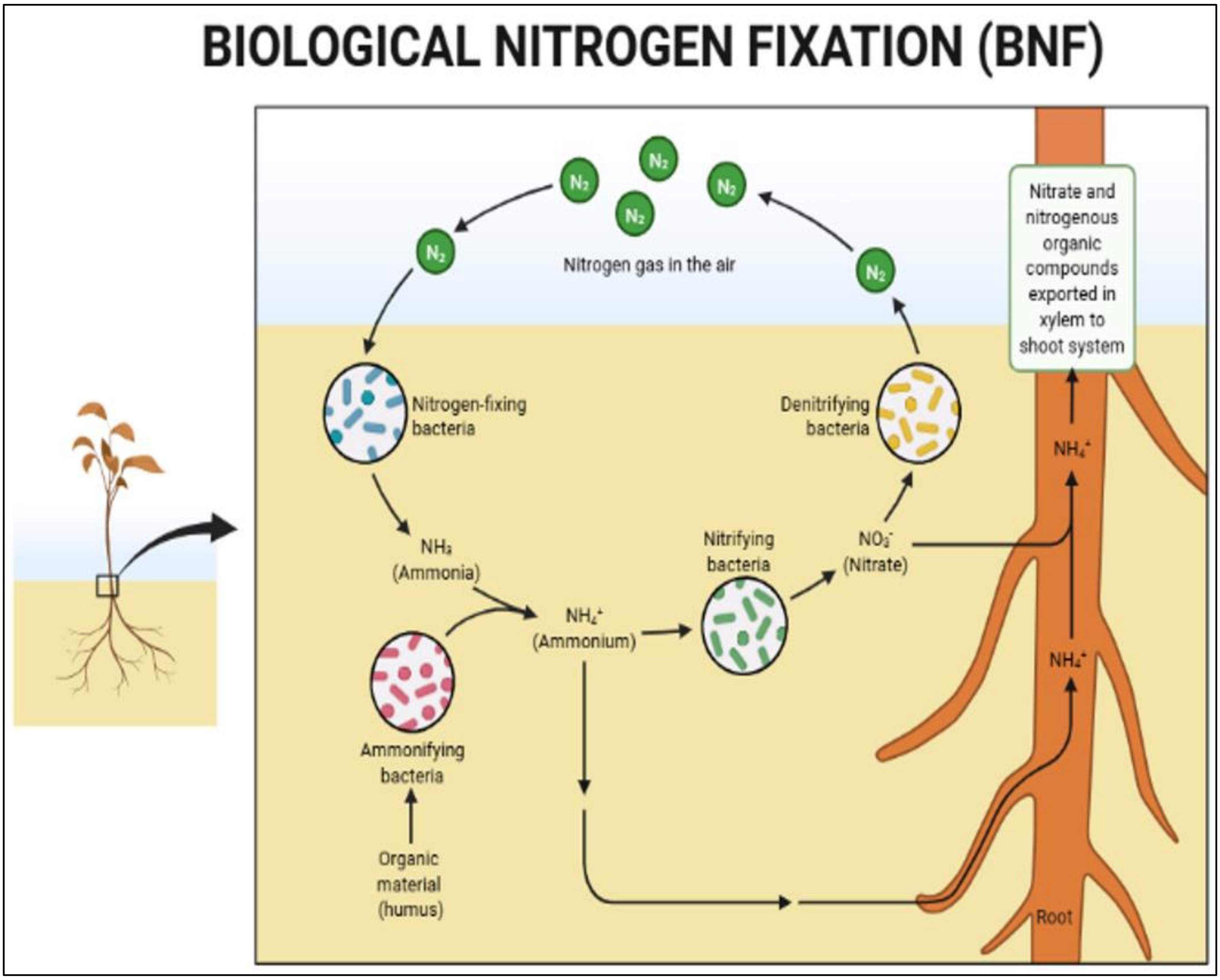

Fig 3 Biological Nitrogen Fixation

Figure: 3 This representation clearly embodies the sequential process of biological nitrogen fixation and subsequent nitrogen transformations in soil; the whole scenario of nitrogen fixation is influenced by different environmentally friendly microbes. In the whole process of nitrogen fixation Atmospheric nitrogen (N_2) is converted into ammonia (NH_3) by the nitrogen-fixing bacteria then it is bio transformed into ammonium (NH_4^+). Ammonification is a key step in nutrient cycling, hence Ammonifying bacteria mediates the decomposition of organic material (humus), releasing the additional ammonium into the soil. The specific Nitrifying bacteria oxidize the chemical compound ammonium into nitrate (NO_3^-), which can be instantly taken by plant root. After these sequential steps, some nitrogen is

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/25oct015

cycled back into the atmosphere through the action of certain denitrifying bacteria, the destined role of these bacteria is to convert nitrates into N_2 gas. The compound formed as ammonium is then up taken by water transport system(xylem) and food transport system (phloem) by the plant root. This cycle mainly delineates the pivotal aspects of soil microbial flora in maintaining nitrogen availability and supporting the plant's enhanced productivity.

➢ *Nutrient Mobilization/Solubilization*

Soil serves as a substantial reserve of essential macro- and micronutrients, such as nitrogen, phosphorus, potassium, and trace elements. Nevertheless, the majority of these nutrients persist in insoluble, inaccessible, or highly complex forms, rendering them unavailable for plant uptake. Biofertilizers play a pivotal role in nutrient solubilization and mobilization by facilitating the bioconversion of these unavailable nutrient forms into soluble, bioavailable derivatives that can be readily assimilated by plants.

- *Phosphate Solubilization*

Phosphorus is indispensable to nearly all primary metabolic pathways, including respiration, photosynthesis, energy translocation, signal transduction, cell division and elongation, and macromolecular biosynthesis. It fortifies plants against abiotic stress such as cold and enhance disease resistance (Khan et al., 2009). Although soils generally contain abundant phosphorus, most of it exists in insoluble forms, unavailable for plant utilization. Plants primarily absorb phosphorus fraction comprises inositol phosphate (soil phytate), phosphomonoesters, and phosphotriesters, whereas apatite represents the predominant inorganic form (Mahdi et al., 2010). Certain soil microorganisms excrete low molecular weight organic acids such as citric and gluconic acid that promote the solubilization of inorganic phosphate (Glick, 2012). The hydroxyl and carboxyl moieties of these acids chelate cations bound to phosphate, liberating phosphorus into its soluble form. Conversely, organic phosphorous undergo mineralization via phosphatase enzyme that catalyse the hydrolysis of phosphoric esters (McComb et al., 2013). Microbial inoculants, biofertilizers, therefore serve as ecologically sustainable alternatives to chemical phosphorus fertilizers (Alori et al., 2017). Among the most efficient phosphate-solublizing bacteria (PSB) are members of genera *Pseudomonas* and *Bacillus* (Babalola and Glick., 2012). *Xanthomonas, Klebsiella, Gordonia, Delftia sp., Gordonia, Enterobacter, Pantoea, Vibrio proteolyticus, Burkholderia, Erwinia, Azotobacter, Flavobacterium, Microbacterium, Beijerinckia, and Rhizobium* are among the other bacteria that have been found (Chen et al., 2006; Sharan et al., 2007, Farajzadeh et al., 2012, Selvakumar et al., 2007, Koulman et al., 2011).

- *Potassium Mobilization*

Potassium, the third essential macronutrient which is integral to plant metabolism, growth and developmental physiology. Deficiency of potassium results in stunted growth, poor seed formation, underdeveloped roots and reduced yields (Hell & Mendel., 2010). Microbial inoculants inhabiting the rhizosphere such as *Aspergillus, Bacillus spp., Clostridium spp., Burkholderia, Acidothiobacillus ferrooxidans, Psedomonas, Paenibacillus spp., Bacillus mucilaginosus, B. circulans and B. edaphicus* have been reported to release potassium from potassium-bearing minerals into bioavailable forms (D. Liu et al., 2012). Microorganisms like *Bacillus mucilaginosus* and *B. edaphicus* organic acids that effectively solubilize rock-derived potassium sources (Sakr et al., 2014). Significant mobilization of potassium from waste mica which is a natural source that has been observed with inoculants such as *B. mucilaginosus, Azotobacter chroococcum* and *Rhizobium,* resulting in enhanced wheat growth (Singh et al., 2010).

- *Sulfur Dissolving Microorganisms*

Sulfur constitutes the fourth major nutrient essential for crop productivity, following nitrogen, phosphorus, and potassium, and is among the sixteen indispensable elements for plant growth. Soil microbial activity mediates sulfur transformations through mineralization, immobilization, oxidation, and reduction processes. Sulfur-oxidizing bacteria synthesize organic molecules from carbon dioxide while producing sulfuric acid as a byproduct of sulfur oxidation. The enzyme sulfatase, secreted by sulfur-dissolving microorganisms, facilitates the conversion of sulfur compounds into bioavailable forms (Hayes et al., 2000).

A diverse consortium of sulfur bacteria is involved in the oxidation and reduction of inorganic sulfur compounds. *Thiobacillus spp* are particularly significant, as they generate soil acidity through sulfur oxidation, thereby enhancing nutrient solubilization and soil fertility (Yang et al., 2010). Additionally, various fungal taxa, including *Penicillium spp., Epicoccum nigrum, Alternaria tenuis, Scolecobasidium constrictum, Aspergillus, Auerobasidium pullulans, and Myrothecium cinctum,* are capable of oxidizing elemental sulfur and thiosulfate (Shinde et al., 1996).

➢ *Phytohormones Production*

Phytohormones, or plant growth regulators, are crucial for orchestrating plant growth, differentiation, and developmental processes (Peleg & Blumwald, 2011). Rhizospheric microorganisms have been found to synthesize or modulate the endogenous concentrations of these hormones in host plants, thereby influencing hormonal balance and stress physiology (Glick, 2012). Numerous PGPR (Plant Growth Promoting Rhizobacteria) strains, such as *Arthrobacter giacomelloi, Azospirillum brasilense, Pseudomonas fluorescens, Bradyrhizobium japonicum, Bacillus licheniformis, and Paenibacillus polymyxa* are known to produce cytotoxins that stimulate cell division, tissue differentiation, and organogenesis, while reducing the root-to-shoot ratio (Perrig et al., 2007; Arkhipova et al., 2007). Auxins, particularly indole-3-acetic acid (IAA), are the most extensively studied microbial phytohormones, with approximately 80% of rhizospheric isolates reported to secrete IAA as a secondary metabolite (Ahemad & Khan, 2011). IAA enhances root initiation and elongation, improving nutrient and water uptake efficiency (Khare & Arora, 2010). Ethylene, another critical phytohormone, functions in plant defence and senescence regulation. Although excessive ethylene can inhibit root elongation and auxin transport, moderate levels, often induced by

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/25oct015

Azospirillum brasilense, promote root hair proliferation and development in plants such as tomato (Ribaudo et al., 2006). Gibberellins, similarly, foster primary root elongation and lateral root expansion, and are synthesized by bacterial genera such as *Acinetobacter spp., Achromobacter, Azotobacter spp., Azospirillum, Rhizobium, Gluconobacter, Bacillus, and Herbaspirillum* (Dodd et al., 2010).

II. INDIRECT MECHANISM OF BIOFERTILIZERS -ANTIBIOTIC AND SIDEROPHORE PRODUCTION

Numerous microbial strains produce antibiotic metabolites, such as aldehydes, hydrogen cyanide, alcohols, sulfides, ketones, diacetylphloroglucinol, viscosinamide, mupirocin, pyocyanin, phenazine derivatives, zwittermicin A, pyrrolnitrin, pyoluteorin, and oomycin A, that suppress phytopathogens (Bhattacharyya & Jha, 2011). Biofertilizer including *Trichoderma harzianum, Pseudomonas fluorescens, and Bacillus subtilis* enhance plant growth and mitigate diseases caused by *Fusarium, Pythium, Rhizoctonia, and Sclerotium species.* Additionally, rhizobacteria synthesize compounds such as phenazines, cyclic lipopeptides, and 2,4-diacetylphloroglucinol, which trigger Induced Systemic Resistance (ISR) in plants, thereby enhancing immunity (Pieterse et al., 2014). Siderophores, low molecular weight (400-1500 Da) ferric ion chelators, are secreted by bacteria, fungi, actinomycetes, and some algae under iron-limited conditions (Arora et al., 2013). They facilitate iron acquisition by form Fe siderophore complexes that are easily assimilated by plants. For instance, *Pseudomonas fluorescens C7* produces pyoverdine, which enhances iron uptake and plant vigor in *Arabidopsis thaliana* (Parray et al., 2016). Moreover, under heavy metal stress, siderophore-producing microbes alleviate toxicity by sequestering metals, thereby safeguarding plant health (Rajkumar et al., 2010).

Table 1 Role of Biofertilizer in Plant Growth Promotion and Biocontrol

Biofertilizer	**Function**	**Role in biocontrol**	**Reference**
Rhizobium	Nitrogen fixing	NA	(Vessey, 2003)
R. leguminosarum	Solubilization of minerals such as phosphorus and cytokinin	By secreting antibiotics and cell wall-degrading enzymes that can inhibit the phytopathogens	(Afzal and Bano, 2008)
Bradyrhizobium sp.	By solubilizing phosphate, siderophores and IA	By producing HCN	(Afzal and Bano,2008)
B. japonicum	Phosphate solubilization, IAA, siderophores	By secreting antibiotics and cell wall-degrading enzymes that can inhibit the phytopathogens	(Bardin et al., 2004)
Acidothiobacillus, Thiomicrospira, Thiosphaera, Paracoccus, Xanthobacter,	Sulphte Solubilizing Microorganism	NA	(González-López et al., 2005) (Sahoo et al., 2014) (Bhattacharyya & Jha, 2011)
Frankia	Nitrogen fixing	NA	(Simonet et al., 1990)
Azorhizobium	Nitrogen fixing	NA	(Sabry et al., 1997)
Beijerinckia	Nitrogen fixing	NA	(De Felipe, 2006)
M. mediterraneum	Phosphate solubilizing	NA	(Afzal and Bano, 2008)
Burkholderia	Phosphate solubilizing	Producing the antibiotics pyrrolnitrin	(Bhattacharyya and Jha, 2012)
Mycobacterium	IAA synthesis	Induction of the plant stress resistance	(Egamberdiyeva, 2007)
Acidothiobacillus ferrooxidans	By solubilizing potassium	NA	(Liu et al., 2012)
Phyllobacterium	Siderophore production	NA	(Flores-Felix et al., 2015)
Chryseobacterium	Siderophore production	NA	(Radzki et al., 2013)
Paenibacillus	Indole acetic acid synthesis	Chitinases and glucanases	(Bent et al., 2001)
Streptomyces	IAA synthesis, siderophore	Producing glucanases	(Verma et al., 2010)

III. CONCLUSION

Plant Growth Rhizobacteria (PGPR), functioning as potent biofertilizers and biostimulants, constitute an indispensable component of sustainable agriculture paradigms. These microorganisms facilitate plant development through direct physiological processes such as biological nitrogen fixation, nutrient solubalization, and phytohormone biosynthesis. Concurrently, they indirectly fortify plant health by mitigating pathogenic invasions through the synthesis of antibiotics, siderophores, and the induction of systematic resistance mechanism. Prominent genera, includes Rhizobium, Azospirillum, Azotobacter, Bradyrhizobium, Pseudomonas spp., and Bacillus, exemplify remarkable ecological versatility across diverse edaphic and crop environments. By augmenting the bioavailability of vital macronutrients which are nitrogen, potassium, phosphorus and sulfur, PGPR effectively curtail the dependence on synthetic fertilizers, thereby diminishing their adverse ecological ramifications. Moreover, these Rhizobacteria

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/25oct015

bolster plant resilience under abiotic stress conditions by modulating endogenous hormonal equilibria and reinforcing stress adaptation pathways. Consequently, PGPR not only enhance soil fertility and crop productivity but also underpin ecologically harmonious, economically viable, and environmentally benign agricultural practices. In the face of escalating global challenges such as soil nutrient exhaustion, climatic fluctuations, and mounting food security concerns, PGPR-based biofertilizers emerge as a promising and sustainable alternative to conventional agronomic approaches.

REFERENCES

[1]. Abd El-Lattief, E. A. (2016). Use of Azospirillum and Azobacter bacteria as biofertilizers in cereal crops: A review. *Int J Res Eng Appl Sci*, *6*(7), 36-44.

[2]. Afzal A, Bano A (2008) Rhizobium and phosphate solubilising bacteria improve the yield and phosphorus uptake in wheat (Triticum aestivum L.). International Journal of Agricultural Biology 10:85– 88.

[3]. Aggani, S. L. (2013). Development of bio-fertilizers and its future perspective. *Scholars Academic Journal of Pharmacy*, *2*(4), 327–332. https://www.cabdirect.org/cabdirect/abstract/20133337412.

[4]. Ahemad, M., & Kha, M. S. (2011). Assessment of plant growth promoting activities of rhizobacterium pseudomonas putida under Insecticide-Stress. *Microbiology Journal*, *1*(2), 54–64. https://doi.org/10.3923/mj.2011.54.64.

[5]. Allito, B., Nana, E., & Alemneh, A. (2015). Rhizobia Strain and legume genome Interaction Effects on nitrogen fixation and yield of grain legume: a review. *Molecular Soil Biology*. https://doi.org/10.5376/msb.2015.06.0004.

[6]. Aloo, B. N., Tripathi, V., Makumba, B. A., & Mbega, E. R. (2022). Plant growth-promoting rhizobacterial biofertilizers for crop production: The past, present, and future. *Frontiers in Plant Science*, *13*. https://doi.org/10.3389/fpls.2022.1002448.

[7]. Alori, E. T., Glick, B. R., & Babalola, O. O. (2017). Microbial phosphorus solubilization and its potential for use in sustainable agriculture. *Frontiers in Microbiology*, *8*. https://doi.org/10.3389/fmicb.2017.00971.

[8]. Arkhipova, T. N., Prinsen, E., Veselov, S. U., Martinenko, E. V., Melentiev, A. I., & Kudoyarova, G. R. (2007). Cytokinin producing bacteria enhance plant growth in drying soil. *Plant and Soil*, *292*(1–2), 305–315. https://doi.org/10.1007/s11104-007-9233-5.

[9]. Arora, N. K., Tewari, S., & Singh, R. (2013). Multifaceted plant-associated microbes and their mechanisms diminish the concept of direct and indirect PGPRs. In *Plant microbe symbiosis: Fundamentals and advances* (pp. 411-449). New Delhi: Springer India.

[10]. Askary, M., Mostajeran, A., Amooaghaei, R., & Mostajeran, M. (2009). Influence of the co-inoculation Azospirillum brasilense and Rhizobium meliloti plus 2,4-D on grain yield and N, P, K content of Triticum aestivum (cv. Baccros and Mahdavi). *American-Asian-Journal of Agricultural & Environmental Sciences/American-Eurasian Journal of Agricultural & Environmental Sciences*, *5*(3), 296–307. https://www.cabdirect.org/abstracts/20093162655.html.

[11]. Babalola, O. O., & Glick, B. R. (2012). The use of microbial inoculants in African agriculture: current practice and future prospects. *J. Food Agric. Environ*, *10*(3), 540-549.

[12]. Backer R, Rokem JS, Ilangumaran G, Lamont J, Praslickova D, Ricci E, Subramanian S, Smith DL. 2018. Plant growth-promoting rhizobacteria: Context, mechanisms of action, and roadmap to commercialization of biostimulants for sustainable agriculture. Front Plant Sci 9: 1-17. DOI: 10.3389/fpls.2018.01473.

[13]. Bent E, Tuzun S, Chanway CP (2001) Alterations in plant growth and in root hormone levels of lodgepole pines inoculated with rhizobacteria. Can J Microbiol 47(9):793–800.

[14]. Bhattacharjee, R., and Dey, U. (2014). Biofertilizer, a way towards organic agriculture: A review. Afr. J. Microbiol. Res. 8, 2332–2343. doi: 10.5897/AJMR2013.6374.

[15]. Bhattacharyya, P. N., & Jha, D. K. (2011). Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. *World Journal of Microbiology and Biotechnology*, *28*(4), 1327–1350. https://doi.org/10.1007/s11274-011-0979-9.

[16]. Bhattarai, T., & Hess, D. (1993). Yield responses of Nepalese spring wheat (Triticum aestivum L.) cultivars to inoculation with Azospirillum spp. of Nepalese origin. *Plant and Soil*, *151*(1), 67–76. https://doi.org/10.1007/bf00010787.

[17]. Chakraborty, P., & Tribedi, P. (2019). Functional diversity performs a key role in the isolation of nitrogen-fixing and phosphate-solubilizing bacteria from soil. *Folia Microbiologica*, *64*(3), 461–470. https://doi.org/10.1007/s12223-018-00672-1.

[18]. Chen, Y., Rekha, P., Arun, A., Shen, F., Lai, W., & Young, C. (2006). Phosphate solubilizing bacteria from subtropical soil and their tricalcium phosphate solubilizing abilities. *Applied Soil Ecology*, *34*(1), 33–41. https://doi.org/10.1016/j.apsoil.2005.12.002.

[19]. Colombo, C., Palumbo, G., He, J., Pinton, R., & Cesco, S. (2013). Review on iron availability in soil: interaction of Fe minerals, plants, and microbes. *Journal of Soils and Sediments*, *14*(3), 538–548. https://doi.org/10.1007/s11368-013-0814-z.

[20]. De Felipe MR (2006) Fijación biológica de dinitrógeno atmosférico en vida libre. In: Bedmar E, Gonzálo J, Lluch C et al (eds) Fijación de Nitrógeno: Fundamentos y Aplicaciones. Granada: Sociedad Española de Microbiología. Sociedad Española de Fijación de Nitrógeno, Granada, pp 9–16.

[21]. Dodd, I., Zinovkina, N., Safronova, V., & Belimov, A. (2010). Rhizobacterial mediation of plant hormone status. *Annals of Applied Biology*, *157*(3), 361–379. https://doi.org/10.1111/j.1744-7348.2010.00439.x.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/25oct015

[22]. Dr. S. Sreeremya, Green Chemistry- An Overview, *Journal of Biochemistry and Molecular Science,* 2020.Vol 2(1):1-7.
[23]. Dr. S.Sreeremya, Microbial Siderophores, *Journal of Pharmacy and Medicinal Research,* 2019.Vol 1(1):1-12.
[24]. Egamberdiyeva D (2007) The effect of plant growth promoting bacteria on growth and nutrient uptake of maize in two different soils. Appl Soil Ecol 36(2):184–189.
[25]. Farajzadeh, D., Yakhchali, B., Aliasgharzad, N., Sokhandan-Bashir, N., & Farajzadeh, M. (2012). Plant Growth Promoting Characterization of Indigenous Azotobacteria Isolated from Soils in Iran. *Current Microbiology*, *64*(4), 397–403. https://doi.org/10.1007/s00284-012-0083-x.
[26]. Flores-Felix JD, Silva LR, Rivera LP, Marcos-Garcia M, Garcia-Fraile P, Martinez-Molina E, Mateos PF, Velazquez E, Andrade P, Rivas R (2015) Plants probiotics as a tool to produce highly functional fruits: the case of Phyllobacterium and vitamin C in strawberries. PLoS One 10(4): e0122281.
[27]. Glick, B. R. (2012). Plant Growth-Promoting Bacteria: Mechanisms and Applications. *Scientifica*, *2012*, 1–15. https://doi.org/10.6064/2012/963401.
[28]. Glick, B. R., Cheng, Z., Czarny, J., & Duan, J. (2007). Promotion of plant growth by ACC deaminase-producing soil bacteria. *European Journal of Plant Pathology*, *119*(3), 329–339. https://doi.org/10.1007/s10658-007-9162-4.
[29]. González-López, J., Rodelas, B., Pozo, C., Salmerón-López, V., Martínez-Toledo, M. V., & Salmerón, V. (2005). Liberation of amino acids by heterotrophic nitrogen fixing bacteria. *Amino Acids*, *28*(4), 363–367. https://doi.org/10.1007/s00726-005-0178-9.
[30]. Harman,G., Khadka, R., Doni, F., and Uphoff, N. (2020). Benefits to plant health and productivity from enhancing plant microbial symbionts. Front. Plant Sci. 11, 610065. doi: 10.3389/fpls.2020.610065.
[31]. Hayes, J. E., Richardson, A. E., & Simpson, R. J. (2000). Components of organic phosphorus in soil extracts that are hydrolysed by phytase and acid phosphatase. *Biology and Fertility of Soils*, *32*(4), 279–286. https://doi.org/10.1007/s003740000249.
[32]. Hell, R., & Mendel, R. R. (Eds.). (2010). *Cell biology of metals and nutrients*. Berlin, Heidelberg: Springer.
[33]. Hider, R. C., & Kong, X. (2010). Chemistry and biology of siderophores. *Natural product reports*, *27*(5), 637-657.
[34]. Hossain, M. M. (2015). Effects of Azospirillum isolates isolated from paddy fields on the growth of rice plants. *Research in Biotechnology*, *6*(2). http://updatepublishing.com/journal/index.php/rib/article/view/2467.
[35]. Jagnow, G. (1990). Differences between cereal crop cultivars in root-associated nitrogen fixation, possible causes of variable yield response to seed inoculation. *Plant and Soil*, *123*(2), 255–259. https://doi.org/10.1007/bf00011278.
[36]. Kaushal, P., Ali, N., Saini, S., Pati, P. K., & Pati, A. M. (2023). Physiological and molecular insight of microbial biostimulants for sustainable agriculture. *Frontiers in Plant Science*, *14*. https://doi.org/10.3389/fpls.2023.1041413.
[37]. Khan, M. S., Zaidi, A., Ahemad, M., Oves, M., & Wani, P. A. (2009). Plant growth promotion by phosphate solubilizing fungi – current perspective. *Archives of Agronomy and Soil Science*, *56*(1), 73–98. https://doi.org/10.1080/03650340902806469.
[38]. Khare, E., & Arora, N. K. (2010). Effect of Indole-3-Acetic Acid (IAA) Produced by Pseudomonas aeruginosa in Suppression of Charcoal Rot Disease of Chickpea. *Current Microbiology*, *61*(1), 64–68. https://doi.org/10.1007/s00284-009-9577-6.
[39]. Koulman, A., Lee, T. V., Fraser, K., Johnson, L., Arcus, V., Lott, J. S., Rasmussen, S., & Lane, G. (2011). Identification of extracellular siderophores and a related peptide from the endophytic fungus Epichloë festucae in culture and endophyte-infected Lolium perenne. *Phytochemistry*, *75*, 128–139. https://doi.org/10.1016/j.phytochem.2011.11.020.
[40]. Kour, D., Rana, K. L., Yadav, A. N., Yadav, N., Kumar, M., Kumar, V., Vyas, P., Dhaliwal, H. S., & Saxena, A. K. (2019). Microbial biofertilizers: Bioresources and eco-friendly technologies for agricultural and environmental sustainability. *Biocatalysis and Agricultural Biotechnology*, *23*, 101487. https://doi.org/10.1016/j.bcab.2019.101487.
[41]. Kumar, S., Kumar, S., and Mohapatra, T. (2021c). Interaction between macro- and micro-nutrients in plants. Front. Plant Sci. 12, 665583. doi: 10.3389/fpls.2021.665583.
[42]. Kumar, V., & Gera, R. (2013). Isolation of a multi-trait plant growth promoting Brevundimonas sp. and its effect on the growth of Bt-cotton. *3 Biotech*, *4*(1), 97–101. https://doi.org/10.1007/s13205-013-0126-4.
[43]. Lalitha, S. (2017). Plant Growth–Promoting Microbes: A Boon for Sustainable agriculture. In *Springer eBooks* (pp. 125–158). https://doi.org/10.1007/978-981-10-6647-4_8.
[44]. Leaungvutiviroj, C., Ruangphisarn, P., Hansanimitkul, P., Shinkawa, H., & Sasaki, K. (2010). Development of a New Biofertilizer with a High Capacity for N2Fixation, Phosphate and Potassium Solubilization and Auxin Production. *Bioscience Biotechnology and Biochemistry*, *74*(5), 1098–1101. https://doi.org/10.1271/bbb.90898.
[45]. Lehmann, A., Leifheit, E., & Rillig, M. (2016). Mycorrhizas and soil aggregation. In *Elsevier eBooks* (pp. 241–262). https://doi.org/10.1016/b978-0-12-804312-7.00014-0.
[46]. Liu, D., Lian, B., & Dong, H. (2012). Isolation of Paenibacillussp. and Assessment of its Potential for Enhancing Mineral Weathering. *Geomicrobiology Journal*, *29*(5), 413–421. https://doi.org/10.1080/01490451.2011.576602.
[47]. Mahanty, T., Bhattacharjee, S., Goswami, M., Bhattacharyya, P., Das, B., Ghosh, A., & Tribedi, P. (2016). Biofertilizers: a potential approach for sustainable agriculture development. *Environmental Science and Pollution Research*, *24*(4), 3315–3335. https://doi.org/10.1007/s11356-016-8104-0.

[48]. Mahdi, S. S., Hassan, G. I., Samoon, S. A., Rather, H. A., Dar, S. A., & Zehra, B. (2010). Bio-fertilizers in organic agriculture. *The Journal of Phytology*, *2*(10), 42–54. http://scienceflora.org/journals/index.php/jp/article/download/2180/2158.

[49]. Malusá, E., & Vassilev, N. (2014). A contribution to set a legal framework for biofertilisers. *Applied Microbiology and Biotechnology*, *98*(15), 6599–6607. https://doi.org/10.1007/s00253-014-5828-y.

[50]. Martin, X. M., Sumathi, C. S., & Kannan, V. R. (2011). Influence of agrochemicals and Azotobacter sp. application on soil fertility in relation to maize growth under nursery conditions. *Eurasian Journal of Biosciences*, *5*.

[51]. Mathivanan, R., Umavathi, S., Ramasamy, P. K., & Thangam, Y. (2015). Influence of vermicompost on the activity of the plant growth regulators in the leaves of the Indian butter bean plant, Dolichos lab lab L. *Int. J. Adv. Res. Biol. Sci*, *2*(7), 84-89.

[52]. McComb, R. B., Bowers, G. N., Jr, & Posen, S. (2013). *Alkaline phosphatase*. Springer Science & Business Media.

[53]. Midhul, A. K., & Sreeremya, S. General Perspectives of Biopolymers-Review. *Journal homepage: www. ijrpr. com ISSN*, *2582*, 7421.

[54]. Mitter, E. K., Tosi, M., Obregón, D., Dunfield, K. E., & Germida, J. J. (2021). Rethinking crop Nutrition in Times of Modern Microbiology: Innovative biofertilizer technologies. *Frontiers in Sustainable Food Systems*, *5*. https://doi.org/10.3389/fsufs.2021.606815.

[55]. Mohammadi, K., & Sohrabi, Y. (2012). Bacterial biofertilizers for sustainable crop production: a review. *Journal of Agricultural and Biological Science*, *7*(5), 307–316. https://www.cabdirect.org/cabdirect/abstract/20123213194.

[56]. Parray, J. A., Jan, S., Kamili, A. N., Qadri, R. A., Egamberdieva, D., & Ahmad, P. (2016). Current Perspectives on Plant Growth-Promoting Rhizobacteria. *Journal of Plant Growth Regulation*, *35*(3), 877–902. https://doi.org/10.1007/s00344-016-9583-4.

[57]. Peleg, Z., & Blumwald, E. (2011). Hormone balance and abiotic stress tolerance in crop plants. *Current Opinion in Plant Biology*, *14*(3), 290–295. https://doi.org/10.1016/j.pbi.2011.02.001.

[58]. Perrig, D., Boiero, M. L., Masciarelli, O. A., Penna, C., Ruiz, O. A., Cassán, F. D., & Luna, M. V. (2007). Plant-growth-promoting compounds produced by two agronomically important strains of Azospirillum brasilense, and implications for inoculant formulation. *Applied Microbiology and Biotechnology*, *75*(5), 1143–1150. https://doi.org/10.1007/s00253-007-0909-9.

[59]. Pieterse, C. M., Zamioudis, C., Berendsen, R. L., Weller, D. M., Van Wees, S. C., & Bakker, P. A. (2014). Induced systemic resistance by beneficial microbes. *Annual Review of Phytopathology*, *52*(1), 347–375. https://doi.org/10.1146/annurev-phyto-082712-102340.

[60]. Radzki W, Manero FG, Algar E, García JL, García-Villaraco A, Solano BR (2013) Bacterial siderophores efficiently provide iron to ironstarved tomato plants in hydroponics culture. Antonie Van Leeuwenhoek 104(3):321–330.

[61]. Rahman, K., & Zhang, D. (2018). Effects of fertilizer broadcasting on the excessive use of inorganic fertilizers and environmental sustainability. *Sustainability*, *10*(3), 759. https://doi.org/10.3390/su10030759.

[62]. Rajkumar, M., Ae, N., Prasad, M. N. V., & Freitas, H. (2010). Potential of siderophore-producing bacteria for improving heavy metal phytoextraction. *Trends in Biotechnology*, *28*(3), 142–149. https://doi.org/10.1016/j.tibtech.2009.12.002.

[63]. Rao, V. R., Nayak, D. N., Charyulu, P. B. B. N., & Adhya, T. K. (1983). Yield response of rice to root inoculation withAzospirillum. *The Journal of Agricultural Science*, *100*(3), 689–691. https://doi.org/10.1017/s0021859600035462.

[64]. Ribaudo, C. M., Krumpholz, E. M., Cassán, F. D., Bottini, R., Cantore, M. L., & Curá, J. A. (2006). Azospirillum sp. Promotes Root Hair Development in Tomato Plants through a Mechanism that Involves Ethylene. *Journal of Plant Growth Regulation*, *25*(2), 175–185. https://doi.org/10.1007/s00344-005-0128-5.

[65]. S. Sreeremya, Fertigation-Review, *International Journal of Advance Research and Development,* Vol:1(2),2017.

[66]. Sabry SR, Saleh SA, Batchelor CA, Jones J, Jotham J, Webster G, Kothari SL, Davey MR, Cocking EC (1997) Endophytic establishment of Azorhizobium caulinodans in wheat. Proceedings of the Royal Society of London B: Biological Sciences 264(1380):341– 346.

[67]. Saikia, S. P., & Jain, V. (2007). Biological nitrogen fixation with non-legumes: An achievable target or a dogma? *Current Science*, *92*(3), 317–322. http://neist.csircentral.net/262/1/2459_Current_Science92(3)p-317-322.pdf.

[68]. Sakr, W. R. A., Elbagoury, H. M., Sidky, M. A., & Ali, S. A. (2014). Production of organic roselle by natural minerals and biofertilizers. In IDOSI Publications, *American-Eurasian J. Agric. & Environ. Sci.* (Vol. 14, Issue 10, pp. 985–995). IDOSI Publications. https://doi.org/10.5829/idosi.aejaes.2014.14.10.1241.

[69]. Santos, E. a. D., Ferreira, L. R., Costa, M. D., Santos, J. B. D., De Cássia Soares Da Silva, M., & Aspiazú, I. (2012). The effects of soil fumigation on the growth and mineral nutrition of weeds and crops. *Acta Scientiarum Agronomy*, *34*(2). https://doi.org/10.4025/actasciagron.v34i2.12971.

[70]. Selvakumar, G., Kundu, S., Joshi, P., Nazim, S., Gupta, A. D., Mishra, P. K., & Gupta, H. S. (2007). Characterization of a cold-tolerant plant growth-promoting bacterium Pantoea dispersa 1A isolated from a sub-alpine soil in the North Western Indian Himalayas. *World Journal of Microbiology and*

Biotechnology, *24*(7), 955–960. https://doi.org/10.1007/s11274-007-9558-5.
- [71]. Sharan, A., Shikha, N., Darmwal, N. S., & Gaur, R. (2007). Xanthomonas campestris, a novel stress tolerant, phosphate-solubilizing bacterial strain from saline–alkali soils. *World Journal of Microbiology and Biotechnology*, *24*(6), 753–759. https://doi.org/10.1007/s11274-007-9535-z.
- [72]. Shinde, D. B., Patil, P. L., & Patil, B. R. (1996). Potential use of sulphur oxidizing micro-organisms as soil inoculant.
- [73]. Simonet P, Normand P, Moiroud A (1990) Identification of Frankia strains in nodules by hybridization of polymerase chain reaction products with strain-specific oligonucleotide probes. Arch Microbiol 153(3):235–240.
- [74]. Singh, G., Biswas, D. R., & Marwaha, T. S. (2010). Mobilization of potassium from waste mica by Plant Growth Promoting Rhizobacteria and its assimilation by Maize (zea mays) and wheat (Triticum aestivuml.): a hydroponics study under phytotron growth chamber. *Journal of Plant Nutrition*, *33*(8), 1236–1251. https://doi.org/10.1080/01904161003765760.
- [75]. Steenhoudt, O., & Vanderleyden, J. (2000). Azospirillum, a free-living nitrogen-fixing bacterium closely associated with grasses: genetic, biochemical and ecological aspects. *FEMS Microbiology Reviews*, *24*(4), 487–506. https://doi.org/10.1111/j.1574-6976.2000.tb00552.x.
- [76]. Tabassum, B., Khan, A., Tariq, M., Ramzan, M., Khan, M. S. I., Shahid, N., & Aaliya, K. (2017). Bottlenecks in commercialisation and future prospects of PGPR. *Applied Soil Ecology*, *121*, 102–117. https://doi.org/10.1016/j.apsoil.2017.09.030.
- [77]. Van Vuuren, D., Bouwman, A., & Beusen, A. (2010). Phosphorus demand for the 1970–2100 period: A scenario analysis of resource depletion. *Global Environmental Change*, *20*(3), 428–439. https://doi.org/10.1016/j.gloenvcha.2010.04.004.
- [78]. Verma JP, Yadav J, Tiwari KN, Lavakush SV (2010) Impact of plant growth promoting rhizobacteria on crop production. Int J Agric Res 5:954–983.
- [79]. Verma, J. P., Yadav, J., Tiwari, K. N., Lavakush, & Singh, V. (2010). Impact of plant growth promoting rhizobacteria on crop production. *International Journal of Agricultural Research*, *5*(11), 954–983. https://doi.org/10.3923/ijar.2010.954.983.
- [80]. Yang, Z., Stöven, K., Haneklaus, S., Singh, B., & Schnug, E. (2010). Elemental Sulfur Oxidation by Thiobacillus spp. and Aerobic Heterotrophic Sulfur-Oxidizing Bacteria. *Pedosphere*, *20*(1), 71–79. https://doi.org/10.1016/s1002-0160(09)60284-8.
- [81]. Yaxley, J. R., Ross, J. J., Sherriff, L. J., & Reid, J. B. (2001). Gibberellin biosynthesis mutations and root development in PEA. *PLANT PHYSIOLOGY*, *125*(2), 627–633. https://doi.org/10.1104/pp.125.2.627.
- [82]. Youssef, M. M. A., & Eissa, M. F. M. (2014). Biofertilizers and their role in management of plant parasitic nematodes. A review. *Journal of Biotechnology and Pharmaceutical Research*, *5*(1), 1-6.