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Importance of PGPR in organic farming A Short Review

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Abstract

Farmers' growing reliance on chemical fertilizers has enhanced agronomic output, but it has also increased environmental contamination and put the stability of the world's ecosystem in greater danger. By making abiotic stresses more frequent, climate change has exacerbated the issue. Even if agriculture is only permitted on 50% of the world's livable land, it is critically necessary to ensure its sustainability and security. Boost crop yield and food security while using little to no chemical fertilizers and pesticides is one of contemporary agriculture's greatest problems. The vanguard of environmentally friendly farming methods is rhizobacteria that promote plant development (PGPR). They offer an advantageous and safe alternative to chemical fertilizers as well as a suitable solution to less difficult situations. Numerous bacterial species that function as PGPRs have significantly enhanced plant growth, well-being, and production. The major subjects of this review include the use of these rhizobacteria under various stress circumstances, their significance in sustainable agriculture, and the underlying mechanisms driving growth promotion.

Keywords:** **Beneficial bacteria; Biofertilizer; Colonization; Phytopathogen; Abiotic stress; Agricultural Productivity and Sustainability

Introduction:

By 2030, there will be an additional 8.5 billion people on the planet (Anonymous, 2015). This substantial rise is said to be the outcome of unchecked and continued population growth in developing or poor nations. Hunger and poverty are a direct result of this substantial increase. According to Anonymous (2015), India has the most undernourished people in the world with a population of 194.6 million. Artificial fertilisers and pesticides are now harmful to the environment, plant and soil health, and human well-being when used to increase agricultural productivity. Another problem is climate change. Regular use of agrochemicals has an impact on food texture and quality, but it also significantly impacts how the climate changes. As a safer, greener method of reducing the effects of agrochemicals and climate change, sustainable agriculture employs organic farming. In order to manage crops and livestock, organic agriculture often relies on natural processes rather than outside inputs. Diversity is frequently used in inorganic farming as a management paradigm with the explicit intention of fostering diversity. Ecosystems in the wild heavily rely on variety. In organic farming (OF), biofertilizers including compost, vermicompost, and green manure are used to boost or maintain the fertility and nutritional condition of the soil. It also uses biological management techniques including crop rotation, mixed cropping, and the encouragement of insect predators to stop the spread and onslaught of pest illnesses. Due to their eco-friendly and safe utilisation, several microbial species have also been utilised in OF throughout the past few decades to increase agricultural productivity and in the biocontrol of phytopathogens. The finest living things for maintaining ecological balance are microorganisms. They do the best ecological services. The beneficial input known as plant growth-promoting rhizobacteria (PGPR) plays a role in the promotion of plant growth in agricultural plants (Zhou et al. 2016). They have taken over the host's internal root system as well as the rhizosphere and rhizoplane. These diagnostic indications are state-of-the-art. Additionally, certain Bacteroides can penetrate the root, where they develop an endophytic population that eventually helps the plant survive (Compant et al. 2005). Similarly to this, certain bacterial species can increase the amount of vital nutrients that reach the roots of the plant, increasing plant productivity (Adesemoye and Kloepper 2009).

Rhizosphere: The region of soil known as the "rhizosphere" is where different biological and chemical characteristics occur and have an impact on plant root secretions. According to Kumar et al. (2015), it is the centre of strong interactions between the soil and the microflora, with effects that may be beneficial, negative, or neutral. Their interactions have a profound influence on plant growth and production. Rhizobacteria in particular and growth-promoting bacteria in general interact significantly in the rhizosphere. The plant produces a variety of substances like root exudates that are rich in sugars, amino acids, organic acids, flavonoids, proteins, and fatty acids in order to establish an optimal environment inside the rhizosphere. Oftentimes, these root exudates contain tiny, non-metabolically produced chemicals. Depending on the physiological condition, plant species, and microbiota, the exudates serve as signals to either reject certain microbial diseases or to recruit helpful microorganisms (Ahmed et al., 2019). According to Lucini et al. (2019), the exudates may also operate as rhizospheric messenger molecules between plant roots and rhizobacterial organisms. They serve as critical growth triggers for soil microorganisms that are essential for accelerating plant development and mobilising defence against phytopathogens. Plants exude lysates, which are released from diseased cells during autolysis, chemicals that are produced metabolically or secreted, and mucilage, a polysaccharide that is present in plants and is released in the rhizosphere, in addition to root exudates. Each of these secretions acts as a chemoattractant for bacteria in the rhizosphere. A small number of PGPR that reach the root might lead to endophytic interactions (Wozniak et al., 2019; Papik et al., 2020). Some of them mature into endophytes, which eventually form the endodermis barrier over the root collar and vascular systems and develop inside leaves, stems, and other organs. The degree to which these bacteria interact endophytically with their host plants demonstrates their potential to adapt to different biological specialisations.

Role of PGPR in organic farming: Tesami and Maheshwari (2018) claim that plant growth-promoting rhizobacteria (PGPR) are important players in agriculture. By fixing nitrogen, solubilizing phosphates, lowering heavy metals, creating phytohormones like auxin, gibberellins, and cytokinins, mineralizing organic substances in soil, rotting plant waste, stifling phytopathogens, and other processes (He et al., 2019), it enhances crop health. By giving various distinctive genes and comprehending the biochemical enzymatic pathways, antibiotics, and many other value-based biological substances, PGPR gives essential knowledge for agricultural and environmental biotechnology (Backer et al., 2018). The age, species, and developmental stage of the plant or crop, as well as the heterogeneity of the soil ecosystem, all have an impact on the efficacy of PGPR. PGPR modifies the chemistry of the plant-soil system to encourage plant growth and health.

PGPR and abiotic stress: Abiotic stress is the adverse effect that non-living things have on living things in a particular environment. Any unfavourable environmental circumstance that can have an impact on the physicochemical characteristics of soil and the functional diversity of microorganisms might cause biological stress. Because of the state of the ecosystem, abiotic stressors are increasingly common. The slowing pace of plant growth has a substantial influence on global agriculture productivity. Crops including wheat, rice, maize, and barley produce poorly when exposed to situations like high heat, drought, pH, and salt (Mickelbart et al. 2015). The extensive use of synthetic fertilisers continues to be the biggest obstacle to greater agricultural output.

One major environmental stressor that prevents fertile land from producing is soil salinity. By using less water from the soil, plants can fight against the negative effects of salt, such as ion toxicity, nutritional deficiencies, osmotic stress, and oxidative stress (Isayenkov and Maathuis 2019).

The drought issue, on the other hand, has become worse and is now even more harmful to the economy. The mechanisms of salt stress and drought stress can overlap and be closely connected in some areas. The entire physiology and mechanism of a plant are impacted (Ivanov 2015). In dry and semi-arid locations, drought has an impact on agricultural development and profitability. By altering the amount of chlorophyll and bending the photosynthetic process, drought conditions severely harm plants and prevent them from photosynthesis. By 2050, crop-related issues (plant growth and development) are predicted to increase by 50% due to climate change and drought stress (Vinocur and Altman 2005). In addition to the stress caused by sodium chloride, crops are adversely affected by the combination of sodium hydrogen carbonate and sodium carbonate. By preventing plants from absorbing phosphorus, manganese, zinc, iron, and copper, the building of these ions in the soil raises the pH and alkalinity of the soil, which eventually causes osmotic stress and nutritional deficiencies in plants. The plant's physiological health is therefore jeopardised (Chen et al. 2011, 2011). The non-alkalophile rhizosphere residents' biological processes are inhibited by the high pH. Currently, heavy metal contamination is a significant problem. Due to their toxicity and difficulty in removal, heavy metals including lead, cadmium, copper, arsenic, and zinc remain in the environment for a very long period. Plants allegedly collect heavy metals from the soil and release them into the food chain, according to Eteami and Maheshwari (2018). Plants with hormonal irregularities are also far more susceptible to illness under other conditions, such as nutrient deficits, phytopathogen attacks, etc.

These abiotic pressures (stresses that are not biological) are predicted to worsen throughout time as a result of climate change. It is vital to put in place an environmentally friendly plan to decrease the occurrence and consequences of abiotic stressors. So the best way to ensure sustainability in farming is to incorporate helpful microbes. PGPRs can be used to increase a plant's ability to withstand biotic and abiotic environmental challenges.

According to Grover et al. (2011), a number of taxa, including *Paenibacillus, Rhizobium, Methylobacterium, Bacillus, Achromobacter, and Variovorax*, are thought to be involved in *Burkholderia, Pantoea, Pseudomonas, Azospirillum*, and *Enterobacter*'s capacity to tolerate abiotic stress.

According to Upadhyay et al. (2012), the Arthrobacter sp. SU18 and Bacillus subtilis SU47 strains can resist up to 8% NaCl. Following the co-inoculation of these bacteria, wheat plants showed a rise in biomass, proline content, sugar content, a decrease in salt content, and an increase in antioxidant enzyme activity. According to Jha and Subramanian (2013), inoculating rice plants with *Pseudomonas pseudoalcaligenes* and *Bacillus pumilus* increased germination rates by up to 16%, survival rates by up to 8%, dry weight by up to 27%, and plant height by up to 31%. This reduced the impact of salt on developing plants.

Additionally, there were lower amounts of Na (71%) and Ca (36%), as well as higher concentrations of key nutrients including N (26%), P (16%), and K (31%), as compared to uninoculated control plants. In the rhizosphere of the desert-adapted plant *Suaeda fruticosa*, *Bacillus licheniformis* strain A2 was discovered by Goswami et al. (2014). With the help of this isolation, groundnut plants expanded more swiftly, as evidenced by a 43% increase in biomass and a 31% rise in plant height.

When 50 mM NaCl was added, the rise ranged between 24% and 28% in soil conditions. PGPRs can be used to solve soil fertility issues in alkaline environments. The use of bacteria to increase nodule formation and mitigate the effects of alkalinity on plants was successful. Nitrogenase activity was increased and mycorrhizal dominance was fostered in the roots of the fava bean by the application of *Rhizobium leguminosarum* and mycorrhizal fungi. With its co-inoculation, improvements in fava bean output and resilience to soil alkalinity were also noted.

The rise in soil conditions was between 24% and 28% when 50 mM NaCl was introduced. In alkaline conditions, PGPRs can be employed to address soil fertility problems. It was effective to utilise bacteria to promote nodule development and lessen the negative effects of alkalinity on plants. *Rhizobium leguminosarum* and mycorrhizal fungi were applied to the roots of the fava bean to improve nitrogenase activity and promote mycorrhizal dominance. Improvements in fava bean yield and resistance to soil alkalinity were also reported using its co-inoculation.

Salinity: Salinity issues affect the agricultural sector. According to Rengasamy (2002), the building of salts caused by the prolonged use of agrichemicals is the main cause of the salinity problem. An uneven diet comes from a change in plant homeostasis in salt-stressed soil locations. Since they are sessile, plants cannot escape their environment; instead, they must strive to adapt to it. According to studies (Venkateswarlu et al., 2008), PGPR is crucial for improving the development and production of salt-stressed plants.

ROS Scavenging-based Halotolerance: Oxidative stress, also known as reactive oxygen species (ROS), which is formed during salinity stress and consists of O2, O2, and H2O2, causes significant damage to cells. By controlling the H2O2 level, an enzymatic and nonenzymatic defence antioxidant mechanism is produced to reduce this toxicity (Bharti and Barnawal, 2019). The levels of ROS are routinely regulated by enzymes like catalase and ascorbate peroxidase as well as non-enzymatic substances such as ascorbate (Kapoor et al., 2015). Under salt stress, the plant releases ROS and dehydrates. The ability of PGPR to create both enzymatic and non-enzymatic components helps the plant tolerate salt stress.
According to Miller et al. (2010), PGPR regulatory genes and ROS-responsive signalling are advantageous. Certain PGPR decreases the increased soil salinity and increases photosynthetic efficiency by increasing the antioxidant and polyamine content (Radhakrishnan and Baek, 2017). Catalase and other antioxidants are produced by PGPR, which lessens the oxidative stress caused by ROS. For superoxide scavenging, plants under salt stress that have undergone PGPR inoculation and have enhanced SOD activity are crucial.

Halotolerance by Reducing Ethylene Concentration: When the plant is stressed, the first peak appears, and a few hours later, the second peak. 1-Aminocyclopropane-1-carboxylate (ACC) is a fast ethylene precursor. ACC deaminase, which shields plants from ethylene stress, is produced by certain PGPR. The quantity of ethylene is decreased by the ACC deaminase in plants, which converts ACC into -ketobutyrate and ammonia. Plant ethylene levels are reduced by PGPR formulations with active ACC deaminase as ACC sinks (Glick, 2014). The amount of ethylene produced by plants under salt stress was decreased in seedlings treated with ACC deaminase-containing bacteria as compared to the control without microbial inoculations, which allowed for a partial reduction in the effects of salt stress (Barnawal et al., 2017).

Drought: Drought is the major barrier to the productivity of agriculture worldwide. It is believed to have underestimated the nation's cereal production by 9–10%, according to Lesk et al. (2016). The capacity of a plant to endure and flourish in dry conditions is known as drought resistance. In order for plants to grow and meet food demands even when water resources are few, it is critical to identify techniques to increase their abiotic stress tolerance (Mancosu et al., 2015). The active signalling genes DSM2, Os-NAP, and OsNAC5 improve the tolerance of abscisic acid (ABA) to drought. 2020 (Goswami and Suresh).

Making the Root System More Water Absorbent: According to Timmusk et al. (2014), bacterial changes to the architecture of the root system increase root surface area, enhance nutrient and water absorption, and promote overall plant development. To comprehend the fundamental process, extensive research is required. In response to abiotic stress, a nanoformulation (SomRE) can lengthen roots without negatively affecting the soil microbiota, claim Naik et al. (2020).

Promoting the Growth of Shoots: In response to drought stress, plants reduce the amount of available leaf surface, which may impede shoot development and increase evaporative loss (Skirycz and Inzé, 2010). Increased agricultural production results from plants infected with potent PGPR strains that sustain close to average shoot growth under drought stress. These plants benefit from PGPR treatments that promote shoot growth.

Relative Water Content: A more precise technique to assess a plant's water condition may be to look at the relative water content (RWC) of its leaves, which is involved in tissue metabolism. Reduced RWC is a sign of turgor insufficiency, which inhibits cellular proliferation and slows plant development (Ngumbi and Kloepper, 2016). RWC tuning might greatly improve drought resistance. According to reports, PGPR-treated plants exhibited better RWC control than untreated ones. Dodd et al. (2010) assert that alterations to physiological processes such as stomatal closure may result in improvements in RWC. Grover et al. (2014) observed a 24% improvement in RWC in drought-stressed sorghum plants after injecting Bacillus sp. strain KB 129.

Tolerance to Drought by Osmotic Modification: A breakdown in the relationship between plants and water, a reduction in CO2 uptake, an increase in cellular oxidative stress, membrane damage, etc. are only a few of the impacts of drought on plants. According to Farooq et al. (2009), plants often employ osmotic adjustment to combat drought stress. According to Kiani et al. (2007), the active accumulation of appropriate inorganic and organic solutes during drought stress is referred to as osmotic adaptation. They maintain constant water content, reduce water demand, and maintain cell turgor. In plants under drought stress, proline is an essential osmolyte (Huang et al., 2014). By scavenging free radicals, buffering the capacity for cellular redox, and scavenging free radicals, proline also aids in stabilising subcellular structures such as proteins and membranes

(Hayat et al., 2012). Critical investigations have demonstrated that plants are more drought-tolerant when their proline levels are greater (Lum et al., 2014). Proline concentrations are greater in plants that get PGPR infusions. The proline concentration in cucumber leaves increased three to fourfold when three PGPR strains (Bacillus cereus AR156, B. subtilis SM21, and Serratia sp. XY21) were mixed (Wange et al., 2012). Cucumber plants were shielded from extremely dry circumstances by the higher proline content. Free amino acid and soluble sugar contents in maize rose after the application of PGPR (Bano et al., 2013). Proline has to be supported by additional free amino acids and soluble carbohydrates in order to withstand prolonged drought.

It has been claimed that rhizobacteria modify plant physiology in response to floods (Ravanbakhsh et al., 2017). Studies reveal that the amount of ethylene regulation is influenced by the bacterial population in plant roots. Floods restrict gas exchange, which quickly starts to collect inside the plant. Accumulated ethylene, according to Sasidharan and Voesenek (2015), controls variables involved in flood adaptation. In their 2017 study, Ravanbakhsh et al. emphasised the contribution of R. palustris to the generation of ACC deaminase, which decreased ethylene levels. Both the ACC synthase and ACC oxidase genes are responsible for the increase in ACC levels that occurs during the flood (low oxygen situation). ACC deaminase helps ACC diffuse out of the roots by lowering the high ACC concentration that has built up there. This technique aids in lowering ethylene levels both before and after flooding. The responses to flood circumstances are greatly diminished by any disruption of the ethylene signalling system (Ravanbakhsh et al., 2017).

Heavy Metals: Hazardous metals including Hg, As, Cd, and P hyper-aggregate in the soil, stressing plants and abnormally reducing agricultural yield. Such metal particles quickly change the texture of the soil, which has a detrimental impact on several biological processes and hinders crop development (Hamid et al., 2021). Most microorganisms, especially heterotrophs, rely on their host plants for nourishment through a symbiotic relationship. As a consequence, newly imported plants are less affected by pollutants (Zafar-ul-Hyeetal, 2013). While PGPR promotes plant growth and production, it also enhances soil quality by employing a range of methods to lessen the contamination caused by oil and metals. Certain metal-binding peptides are linked to metal chelation or accumulation.

Metal Stress-Induced Systemic Tolerance (IST): Metals' ability to withstand stress is increased through induced systemic resistance. The process' genetic underpinnings are well understood (Hobman and Crossman, 2015; Wheaton et al., 2015). Metal contamination in the rhizosphere slows down plant development by preventing plants from absorbing nutrients (Lal et al., 2018). Immunising PGPR with a metal resistance feature may help to reduce this. When PGPR is engaged, IST can successfully protect plants from abiotic stress. IAA offers PGPR-enhanced nitrogen fixation and other growth conditions while lowering heavy metal stress (Guo et al., 2020). According to Karthik and Arulselvi (2017), when under chromium (Cr_{6+}) stress, cellulosimicrobium allegedly prolonged the blooming period. In the rhizosphere of Phaseolus vulgaris, the detected and defined Cr_{6+}-resistant bacteria could also break down phosphate, create ammonia, and release enzymes including lipase and amylase. There is evidence of a link between the root causes of induced systemic resistance (ISR) and IST in host plants. Bacterial external membrane lipopolysaccharides, biosurfactants, siderophores, volatile organic compounds, and other microbial metabolites are associated with ISR induction. Studies have shown that gibberellic acid (GA) decreased Cd2+ absorption, which in turn decreased metal toxicity (Zhu et al., 2012).

Rhizobacteria adapt their cell wall and membrane as part of their metal rejection process to shield the sensitive cell components from heavy metals.

Siderophores' Metal Sequestration: By connecting to siderophores, which are produced by microbes, bacteria and fungi may absorb iron from their surroundings. They result from a lack of iron and can stop iron from turning into insoluble compounds. For a number of biological activities, including DNA synthesis and respiration, iron) interacts with trace metals to create complexes. These chemical molecules with lower molecular weight are highly attracted to iron. In times of iron shortage, microbes produce them. Siderophores produced by microbes can effectively and noticeably withstand metal stress. For all living things to develop, iron is a must. Soil-solubilized ferric ions are not readily available to soil microorganisms at neutral and alkaline pH. By producing Fe_{3+} in an area proximal to the root, the siderophore produced by PGPRs may prevent the development of harmful organisms (Wandersman and Delepelaire, 2004). Microbial siderophores might access the restricted metal ion after making a link with it. Iron absorption was enhanced and Cd_{2+} retention was decreased by streptomycetes siderophores (Dimkpa et al., 2009a). Bacterial siderophores decreased metal toxicity while promoting the growth of plant biomass (Dimkpa et al., 2009b).

Biosurfactants in the Reduction of Metals: The majority of amphiphilic composite biosurfactants are found on the surfaces of microorganisms. They facilitate soil metal removal and increase trace metal tolerance. Biosurfactants continuously exhibit a link with trace metals due to their higher ties to harmful metals as a result of their amphiphilic nature (Gupta and Kumar, 2017). Heavy metal levels in the soil are reduced as a result of biosurfactants' capacity to bind to heavy metals (Lal et al., 2018).

Acids, both organic and inorganic and the reduction of heavy metals: According to Archana et al. (2012), PGPR produces low-molecular-weight natural (organic) acids including citric and oxalic acids that greatly lessen metal stress in agriculture. They assist plants to flourish in metal-polluted soils by forming less harmful metal complexes. These complexes, like metallic oxalate crystals, increase resistance in plants by lessening the cytological effects of native metal ions by inactivating them that are harmful to the plant(Gao et al., 2010). The PGPR-precipitated inorganic acids may reduce mental stress. According to Gadd (2010), microbial organic acid is anticipated to have a solids limit in order to successfully chelate heavy metals. By precipitating, inorganic acids produced by PGPR may reduce mental stress. According to Gadd (2010), the chelation of heavy metals by microbial organic acid may have a solids limit. Enzymatic activity, bacterial iron oxidation, participation of microbial inorganic acids including H_2S, H_2CO_3, and H_3PO_4, and circuitry are all capable of instantly insolubilizing and immobilising heavy metals, according to Pagnanelli et al. (2010).

EPS from Bacteria in Metal Reduction: Staudt et al. (2004) defined extracellular polymeric substances (EPS) as microbial polymers with heavy molecular weight homo- or heteropolysaccharides. It either sticks to the bacterial cells' surfaces or secretes itself outside. Many anion-restraining sites found in the extracellular polysaccharides produced by rhizospheric bacteria, such as the lipopolysaccharides, polysaccharides, dissolvable peptides, and glycoproteins (Hassan et al., 2017), aid in the removal or recovery of heavy metals from the rhizosphere through biosorption. Because it reduces the availability of heavy metals in soil and plant systems, it is crucial for heavy metal decontamination (Rajkumar et al., 2012).

Bacteriocin: The peptide secretions known as bacteriocins are produced by bacteria and have a specific antibacterial action. Both Gram-positive (like nisin) and Gram-negative (like colicin) bacteria have the ability to create bacteriocins (Zimina et al., 2020). These poisons kill rival bacterial species by a highly focused method of action (Rooney et al., 2020). In vitro studies using bacteriocins against tomato bacterial spot disease have produced encouraging results (Prncipe et al., 2018).

Antibiosis: Due to their antibacterial, insecticidal, antiviral, phytotoxic, cytotoxic, and anthelminthic characteristics, antibiotics generated by PGPR are more effective than conventional antibiotics (Fernando et al., 2018). According to Ramadan et al. (2016), Pseudomonas species produce a wide range of antifungal antibiotics, such as butyrolactones, rhamnolipids, 2,4-diacetyl phloroglucinol (2,4-DAPG), and N-butylbenzene sulfonamide. The Bacillus species also secretes additional chemicals including antibiotics like bacilysin, bacillaene, and mycobacillin. They also create a variety of lipopeptide biosurfactants, including the antibiotic bacillomycin (Wang et al., 2015).

VOC Production: For certain bacteria and nematodes, the many volatile organic compounds (VOC) released by PGPR are effective biocontrolling agents. Benzene, cyclohexane, tetradecane, and 2-(benzyloxy)-1-ethanolamine are a few examples of VOCs. According to Kanchiswamy et al. (2015), HCN is one of the VOCs (made by rhizospheric bacteria) that can biocontrol a number of phytopathogens. Numerous pathogenic growths can be prevented by Pseudomonas sp. HCN (Hamid et al., 2021). Santoro et al. (2016) claim that Bacillus spp. VOCs also effectively inhibit fungi. VOCs play a part in biological control and pollinator recruitment by sending out signals (Liu and Brettell, 2019).

Lysis via Extracellular Enzyme: Stronger systems can be breached by infectious bacteria using the lytic chemicals generated by PGPR. Chitinase and 1,3-glucanase, two extracellular rhizobacteria enzymes, are connected to cell wall lysis (Goswami et al., 2016). Since chitin and 1,4-N-acetylglucosamine make up the majority of the fungal cell wall, rhizobacteria's chitinase and 1,3-glucanase may break them down and have potent antifungal effects. For instance, -glucanases and chitinases produced by *P. fluorescens* LPK2 and *S. fredii* KCC5 aid in preventing the growth of wilts caused by Fusarium udum and *F. oxysporum* (Ramadan et al., 2016). Protease, lipase, and chitinolytic activities of microbes have been linked to their capacity to kill insects (Rakshiya et al., 2016). In addition, PGPR with ACC deaminase activity is crucial when all stressors, including biocontrol, are combined.

PGPR as Biofertilizer: Biofertilizers are living combinations of advantageous microorganisms that increase the availability of nutrients and enhance the health of the soil and, as a result, the soil microflora. In other words, plant growth-promoting microorganisms (PGPM) are the major ingredient in this biofertilizer. These bacteria are intended to support plant growth and nutrient uptake. It has been acknowledged, nevertheless, that PGPR has been used as a biofertilizer to improve soil quality and crop production all over the world.

Table: Classification of diverse types of biofertilizer and their groups.

Groups	Examples
N_2 Fixing biofertilizer Free-living,Symbiotic, Associative symbiotic	*Azotobacter, Rhizobium, Azospirillum, Frankia, Azospirillum, Mesorhizobium, Sinorhizzobium, Pseudomonas*
P solubilizing biofertilizer P solubilizing Biofertilizers, P Mobilizing Biofertilizers	*Bacillus cirulans, Pseudomonas, Rhizobium, Serratia, Mycorrhiza*
Biofertilizers for mono-nutrients Silicates and zinc solubilizers	*Bacillus spp., Burkholderia spp., Pseudomonas*
Phytohormones Siderophore	*Pseudomonas, Rhizobium, Bacillus, Azotobacter*
Bio-control Antifungal	*Streptomycetes, Bacillus, Pseudomonas*

Promotion of plant growth: In general, PGPRs boost plant growth indirectly by reducing the pathogenic impact on plant growth and development by using bio-control mediators, environmental protectors, and bacteria that colonise plant roots, according to Gupta et al. (2015). Providing nutrients (such as nitrogen, potassium, and phosphorus) or adjusting plant hormone levels are two common ways to directly boost plant development.

- **N2 fixation:** Nitrogen fixation is the process by which atmospheric nitrogen (N_2) is converted to ammonia (NH3) and subsequently made available to plants. This most likely entails the coexistence of bacteria and plants in a symbiotic relationship, with the bacteria using the environment to change di-nitrogen into a form that plants can absorb. The transformation of atmospheric di-nitrogen into ammonia is the second-most important biological activity on land (Datta et al., 2015). It has been suggested that turning N_2 into NH_3 is necessary for the N2 fixation process. 16 hydrogen- and ATP-mixed ATP molecules are used in this process, which is carried out by a complex network of enzymes.

$N_2 + 8\ H_2 + 16\ ATP\ \ 16\ ADP + 16\ Pi + 2\ NH_3 + 2\ H_2 +$

- **Phosphate solubilization:** In addition to fixing nitrogen, the phosphate solubilization (PS) process increases soil fertility. Phosphorus shortage seriously hinders crop output. According to Singh and Singh (2018), the macronutrient phosphorus is essential for biological development. By giving plants access to the insoluble inorganic P, microorganisms offer a biological method of solubilizing it. One crucial component of PGPR that increases plant yields is the procedure by which various microorganisms considerably contribute to turning insoluble phosphorus (P) into usable forms (i.e. orthophosphate). In balancing the expensive inorganic resources of P fertilisers, phosphate solubilizers bacteria (PSB) play a more advantageous economic, ecological, and agronomic function (Podile and Kishore, 2007).

- **Phytohormones production:** Phytohormones have two fundamental purposes: they promote responses and promote plant growth. These are often generated hormone-carrying chemical messengers that accelerate plant growth and output. Here are a few illustrations: (Ahmad et al., 2008) ABA, auxin, cytokines, gibberellins, ethylene, indole-3-acetic acid, etc. Auxins found in nature, such as indole acetic acid (IAA), have a beneficial effect on how roots develop in plants. Around 80% of soil rhizobacteria are capable of producing indole acetic acid (IAA). IAA has the power to quicken cell division, activate plant hormones that help plants absorb nutrients from the soil, and promote root development.

Conclusion:

Utilising alternative tactics, such as those that make use of PGPRs, is necessary to maintain soil fertility and agricultural productivity. Unquestionably, PGPRs today play a multitude of roles that contribute to the sustainability of agriculture. A reduction in the global reliance on dangerous agrochemicals that imperil the stability of agroecosystems has been brought about by increased production through the use of PGPRs in various agroclimatic settings on a variety of crops. Even though different PGPR strains have continuously demonstrated their value as biofertilizers, there are still knowledge gaps about the function and functioning of PGPRs, and more study has to be done to fill these gaps. It's important to comprehend how PGPRs behave in the rhizospheric environment of specific crops (Li et al. 2020). Ankati and Podile 2019; Xiong et al. 2020), the role of PGPRs in the rhizosphere, and interactions between the various microbial communities in the rhizosphere can all have a significant impact on the structure of the rhizobium. for rhizome-mediated agricultural techniques that provide more stability and greater efficiency. For instance, have demonstrated that it is possible to construct microbial consortia for use as biofertilizers using microbial taxa isolated from high-yield plant varieties. A less-examined area is the assessment of enzymatic and non-enzymatic components in preserving homeostasis under difficult circumstances including drought (Mishra et al. 2020), salt concentration (Grossi et al. 2020), and heavy metals (Wu et al. 2019). To increase the lifespan, cell count, and performance of PGPRs, stable bioinoculant formulations containing carrier materials such as biochar, compost, and crushed maize cob have been created. Promote the inclusion of signal molecules that affect the interaction between plants and microorganisms in biodegradable polymers to ensure their longer release and close contact with plant roots in order to boost the marketability of bioinoculants (Cesari et al. 2019).

So it wouldn't be very ambitious to anticipate that biofertilizers will eventually entirely replace chemical fertilisers. It can mature beyond its infancy if the impact of this technology on agriculture is given more consideration. In a variety of agroecological situations, it can then significantly increase agricultural output and sustainability.

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