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PGPR FOR SUSTAINABLE RICE CULTIVATION

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Abstract: Agriculture shares a sizeable allocation of national income and export incentives in several developing countries while ensuring food security and employment. Because of the global population boom, food demand is expected to rise by 3-5 times in the coming years. Rice is staple to more than half of the world's population. Globally, plant growth and yield are being hampered by various biotic and abiotic stresses. Among abiotic stresses, soil salinity, wastewater and, heavy metal stress are causing serious threats to agriculture. Plant growth promoting rhizobacteria (PGPR) are soil bacteria occurring naturally in the plant root system which aid in their development. Plant growth promoting bacteria (PGPB) have myriad roles based on their long-term stability such as production of secondary metabolites, antagonistic activity and defense mechanisms against heavy metals stress. Hence PGPR help to maintain sustainable plants development and growth. Expansion of agriculture services via an ecologically sound approach is a major challenge in today's scenario of increasing population. Plant growth promoting bacteria is considered as one of the best plans of action for sustainable agriculture, and an improved mechanism to meet the coupled challenges of global food security and environmental stability. Therefore, in this review we highlight the utilization of plant growth promoting bacteria for the development of a safe biological strategy to obtain sustainable rice productivity.

Keywords: Heavy metal; PGPR; Salinity; Sustainable agriculture; Wastewater

1. Introduction:

Plant growth promoting rhizobacteria (PGPR) are naturally occurring soil bacteria that colonize plant roots and help in their growth. They help by enhancing the supply of nutrients, producing plant hormones and siderophores, providing free-living nitrogen-fixing bacteria, and improving disease resistance. These bacteria are not simply add-ons to biodiversity of the rhizosphere but are also necessary to the host plants. They can be considered as a new, safe biological strategy that can replace the use of chemical fertilizers and pesticides in agriculture. Hence rhizobacteria play a pivotal role in the ecosystem imparting several benefits.

Rice is one of the major staple foods for more than half of the global population. An estimated 3.5 billion people depend on rice for more than 20% of their total calorie intake [1]. Globally rice is grown in more than 100 countries spread across 6 continents and in different climatic conditions [2]. About 90% of the world rice comes from Asia, with the major producers being India and China [2].

By 2050, the world food production must expand by 70% to feed the booming population [2]. So, there is a great challenge lying ahead for scientists and agriculturists alike. Globally, rice growth and yield are being hampered by various biotic and abiotic stresses. Rice production faces tremendous risk from various abiotic stresses such as soil, salinity, extreme temperature, drought, wastewater, and heavy metal stress.

1.1. Abiotic stresses and rice production:

Soil salinity is a massive environmental threat to world agriculture and food production. Rice is considered as a salt sensitive crop [3,4]. On the basis of tolerance ability, the growth and yield of rice are considerably affected by soil salinity [5]. It is alarming for food security of rapidly growing populations like Asia. About 20% of irrigated land producing one-third of the world's food is affected by salt stress [6]. Salt stress affects the vegetative stage as well as reproductive stage of rice that reduces production and yield [7-11].

Table 1: Nutrient deficiency during salinity stress in rice plant

Nutrient Deficiency	**Adversarial**	**Coactive**	**References**
Potassium ion (K^+)	High $Na^+$and low K^+ in the cytoplasm of the cell	_	[12]
Magnesium (Mg)	_	Concentration of Na^+ increases as salinity stress increases	[13]
Zinc (Zn)	When salt stress increases Zn deficiency occurs	_	[13]
Nitrogen (N)	Under salt stress N dificiency occur	_	[14]
Phosphorous (P)	P decreases in rice grain under salinity stress	_	[15]
Iron (Fe)	When Na^+ increase Fe dificiency occur	_	[16]
Calcium ion (Ca^{2+})	Under high Na^+ concentration Ca^{2+}decreases	_	[14]

The contamination of heavy metal in the soil has serious implication on crops. Heavy metal accumulation in plants causes production of reactive oxygen species which leads to cell death and thus affecting the crop productivity [17]. Studies reveal the impact of heavy metals toxicity on rice at numerous levels such as molecular, biochemical, physiological, cellular and tissue, and demonstrated a relation between heavy metals toxicity and decreasing the rice productivity [18,19]. The heavy metals gradual agglomeration in rice grain and their subsequent transfer to food chain is a major threat to agriculture and human [20-24].

Table 2: Effects of Heavy metals on Rice plant

Heavy metals	**Effects**	**References**
Arsenic (As)	Reduce seed germination; decrease in height of seedling; reduced leaf and dry matter production.	[25]
Lead (Pb)	Reduction of chlorophyll, nitrogen and protein content and carotenes	[26]
Mercury (Hg)	Decreases plant height, reduces tiller and panicle productivity. Increases its bioaccumulation in shoot and root of seedlings	[26,27]
Nickel (Ni)	Inhibition of root and shoot growth, decline in fresh and dry weight	[28]
Cadmium (Cd)	Inhibition of seed germination, decline of ascorbic acid content	[29,30]

The industrial outflow and municipal sewage that are rapidly discharged in the ecosystem cause pollution and interfere with the plant growth. Wastewater contains different pollutants such as pathogenic species, oxygen demanding wastes, heavy metals, pesticides, sewage sludge [31] and harmful microbes, organic chemicals and plant nutrients [32]. This sewage water increases agricultural productivity due to the presence of nutritive elements. However, the presence of heavy metals results in phytotoxicity which reduces cellular activities and retards plant growth [33-36]. Some studies revealed that waste water causes reduction in chlorophyll a and b and carotenoid content in rice. Also, higher concentration of municipal sewage water hampers seed germination [37].

Table 3: Pollutants in wastewater and their potential effects through agricultural use

Component	Criteria	Effects
Stable organics	Phenols, pesticides, chlorinated hydrocarbons	-Stay in the environment for a long time -Detrimental to the environment -Cause wastewater inapt for irrigation
Nutrients	N, P, K, etc	-High N concentration leads to nitrogen injury, prolonged vegetative growth, delayed reproduction and maturity -Excess N, and P can lead to eutrophication -Nitrogen leaching pollutes groundwater with serious health and environmental implications
Dissolved inorganic substances	TDS, EC, Na, Ca, Mg, Cl, and B	-Higher salinity and related adverse complications - Cause phytotoxicity -Effect permeability and soil structure
Heavy metals	Cd, Pb, Ni, Zn, As, Hg, etc	- Cause wastewater inapt for irrigation -Bioaccumulation in aquatic organisms (fish and planktons) -Harmful to plants and animals -Pervasive uptake by plants -Subsequent consumption by humans or animals -Bad health effects
Hydrogen ion concentration	pH	-Adverse effects on plant growth because of acidity or alkalinity
Residual chlorine in tertiary treated wastewater	Both free and combined chlorine	-Leaf tip burn -Contaminate ground water and surface water (cancer-causing effects of chlorides from when chlorine amalgamate with residual organic compounds) -Greenhouse effect
Suspended solids	Volatile compounds, suspended and colloidal impurities	-Deposition of sludge causing anaerobic conditions -Blocking of irrigation equipments and system like sprinklers
Biodegradable organics	BOD, COD	-Reduction of dissolved oxygen in surface water -Occurrence of septic conditions -Unstable habitat and environment -Detrimental to pond-breeding amphibians -Increases fish death rate -Build up humus
Pathogens	Virus, bacteria, helminth eggs, fecal coliforms etc.	-Cause various diseases

2. PGPR: the phyto-friendly soil microbes:

A narrow surface of soil bordering roots which is highly active is called rhizosphere where bacterial communities function through root activities [38]. The bacteria occupying the rhizosphere which are beneficial to plants are termed as Plant Growth Promoting Rhizobacteria or PGPR. From the past few years, the role of rhizobacteria has become very interesting in ecological systems as they impart benefits to the system. Many species of bacteria like, *Azospirillum*, *Azotobacter*, *Alcaligenes*, *Arthrobacter*, *Burkholderia*, *Bacillus*, *Enterobacter*, *Klebsiella*, *Pseudomona*, and *Serratia* have been shown to enhance plant growth by indirect and direct mechanisms [39-42].

Siderophores are low-molecular weight secondary metabolites with iron chelating capacity. Siderophores produced by some PGPR play an important role in bioremediation of heavy metals [43] and detoxification of heavy metal contamination [5]. The most frequently studied PGPR are *Azotobacter, Azospirillum, Bacillus, Enterobacter, Gluconacetobacter, Pseudomonas, Paenibacillus, Rhizobium, and Serratia* [44,45]. *Bacillus* is known to be highly adaptable and is an important PGPR having numerous physiological benefits [46]. In addition, Actinobacteria are well known for their potential to assemble secondary metabolites and plant growth regulators [47]. Apart from being biological controllers, Actinobacteria can also mobilize minerals and metals in various crops [47].

Furthermore, PGPR helps in the production of phytohormones naturally and reduce the application of chemical fertilizers. Biosynthesis of Indole-3-acetic acid (IAA) takes place in plant-associated bacteria. Interactions between plants and IAA producing bacteria have various implication on the plant such as phytostimulation and pathogenesis [48]. Bacteria use IAA to interact with different plants as a part of their colonization approach bypassing basal plant defense mechanisms [48]. Apart from these, some rhizobacteria occupy inner plant roots in close proximity and are known as root endophytes [49]. Endophytic bacteria are chief members of PGPR and are now considered to be more effective in comparison with rhizospheric bacteria [50]. Endophytes belong to various bacterial phyla such as *Acidobacteria, Actinobacteria, Ascomycota, Bacteriodetes, Basidiomycota, Deinococcus-Thermus, and Firmicute.*

Table 4: Benefits of plant growth promoting rhizobacteria inoculation in rice

Benefits of PGPR Inoculation to Plant	**PGPR**	**References**
Tolerance to salinity	*Azospirillum sp.*	[51]
Tolerance to biotic stress (biocontrol)	*Bacillus amyloliquefaciens,* *Streptomyces sp.*	[52,53]
Plant growth promotion	*Paenibacillus polymyxa*	[54]
Bio-stimulation by phytohormones production	*Azospirillum lipoferum,*	[55]
Bio-remediation of heavy metals and pollutants	*Bacillus sp., Pseudomonas sp, Bacilus cereus, Enterobacter sp.*	[56]

3. PGPR as stress alleviating agent in rice production:

Under high salt condition, plants show compromised leaf growth due to decrease water uptake, which restricts photosynthetic ability. 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase holding PGPR are present in different soils and offer promising bacterial inoculum for enhancement of plant growth under unfavourable conditions such as presence of heavy metals, phytopathogens, salinity, and drought. Inoculation of ACC deaminase carrying PGPR may support plant growth by removing deleterious effects of ethylene formed during salt stress [57]. For example, Cavite et al. [58] found that application of PGPR isolates with various growth promoting activities including ACC deaminase activity in combination with some recommended rate of inorganic fertilizers demonstrated improved growth and yield; implying that the use of chemical fertilizers can be substantially reduced by utilizing PGPR. A PGPR, *Bacillus amyloliquefaciens* was found to confer reistance against various abiotic stresses in rice [59].

Microbes alleviate toxicity of heavy metals by production of proteins, phytoantibiotics, acids and other chemicals [60]. The presence of beneficial microbes enhance plant growth and protect the plants from metal toxicity. For instance, *Pseudomonas putida* is an outstanding candidate for field application since it is tolerant to various heavy metals at elevated concentrations [61]. Bioremediation technique is now being employed to remove pollutants such as pesticides, polyarmatic hydrocarbons, heavy metals and other toxic wastage [62]. PGPR influenced bioremediation can be a very environmental friendly and cost effective technology for cleaning contaminated soils and simultaneously increasing crop productivity. A potent cadmium (Cd) resistant PGPR isolated from rice rhizosphere nearby a highly polluted area demonstrated substantial rice growth under Cd stress conditions [63]. *Bacillus cereus* also has the ability to alleviate Cd toxicity and improve phytoremediation activity in rice [64]. Similarly, PGPR inoculation can be effectively used to reduce Arsenic (As) contamination and improve rice yield in As-effected paddy fields [65].

4. Current constraints and future prospects

Eco-friendly and effective application of microbes and microbe-based products should be practised on large scale. However, without performing successful experiments in laboratories and under controlled plant growth conditions and without having appropriate knowledge on microbial efficiency, it is impossible to successfully transfer this techonology to the field. The first factor that stops farmers in applying microbe-based techniques is the dearth of practical evidence of their performance in the field. Secondly, relative to PGPR associated products, agro-chemicals in small amounts have effective and immediate action. This has limited the use of PGPR-based products. Thirdly, high fixed cost of bioproducts pose a great disadvantage. Since PGPR based products are new arrivals in the market, their prices will reduce only when they are distributed on a large scale. Another major challenge of using PGPR is their unpredictable behaviour in the field. It is hard to estimate an organism's reaction which is solely dependent on plant-microbe specificity. To address these issues and difficulties, more research in this area is required.

For safe and sustainable agricultural future, there is a need to produce sufficient amount of food crops concentrating on three main directions viz., disease resistance, stress tolerance, and high nutrient content. PGPR application can be an useful method for achieving this goal. The implementation of microbial traits in agricultural crop production can be used as continual strategy to eliminate the negative effects of climate change and global warming. There is a necessity to influence farmers to use bio-inoculants via acceptable and dependable products thereby gaining their faith in agrobiologicals. Large-scale use of microbial inoculants in agriculture can minimize the chemical load thereby reducing the risk of global warming. PGPR can play a pivotal role in improving crop productivity through various mechanisms viz., biofertilization, biocontrol, bioremediation and biofortification, and in the process achieve agricultural sustainability for a better tomorrow.

5. Conclusion

Various biotic and abiotic stresses pose serious threats to rice growth and yield. Expansion of agriculture services via an environmentally suitable approach is a key issue in the today's situation of expanding population and climate change. Farmers are still dependent on chemical fertilizers and explicit use of these harmful chemicals has only increased the problems. Plant growth promoting bacteria (PGPB) are useful because of their long-term stability and production of secondary metabolites, antagonistic activity, modulated defense mechanisms to resist heavy metals, wastewater and salinity stress. The considerable developments in recent years are noticeable in the area of plant-microbe interactions. PGPR strains showing enormous plant favouring activities are now known. Future development in the field of PGPR diversity, ability of colonization, mechanism of action, application and formulation could make this technology an authentic part of sustainable rice cultivation.

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