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Plant Growth Promoting Rhizobacteria (PGPR): A Sustainable Agriculture to Rescue the Vegetation from the Effect of Biotic Stress: a Review

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Abstract: Many biotic agents such as bacteria, viruses, nematodes, arachnids, and weeds encounter the plants. These entities induce biotic stress in their hosts with the aid of disrupting normal metabolism, resulting in limited plant growth and causing plant mortality. As Arbuscular Mycorrhizal Fungi (AMF), plant-associated microbes can regulate physiological and molecular responses to cope with pathogenic biotic stress *via* enhanced antioxidant defense systems and mitigate oxidative stress. Several microbes can benefit plant growth and perform a similar role as pesticides and chemical fertilizers, acting as a biofertilizer and biopesticide. Plant growth-promoting rhizobacteria (PGPR) can expressively heighten plant growth and represent a mutually helpful plant-microbe interaction by facilitating the surroundings' nutrient uptake. The rhizobacteria such as *Bacillus sp*. can form spores that help them survive for a long period under harsh environmental conditions. PGPR can augment plant growth by introducing induced systemic resistance, antibiosis, and competitive omission and resisting the plants against biotic agents. *Bacillus subtilis* exhibits both a direct and indirect biocontrol mechanism to suppress disease and provide resistivity towards pathogenic pests caused by pathogens. These mechanisms assist the plant in its protection from the pathogenic onset. The present review discusses Plant Growth-Promoting Rhizobacteria's biocontrol potential and its role as a root colonizer. The associated biocontrol mechanisms of these PGPR to increase crop productivity under biotic stress conditions.

Keywords: stress; PGPR; AMF; bio-control mechanism; crops.

1. Introduction

Field pea (*Pisum sativum* L.) one of the most important annual legume crops. *Pisum sativum L.* is an annual food legume of the Fabaceae family (formerly known as the Leguminosae). Uttar Pradesh alone produces about 49 % of pea produced in India. Besides, Uttar Pradesh, Madhya Pradesh, Bihar, and Maharashtra are the major pea producing states *(DES, 2015-16)*. The production and its productivity are far below the potential; it is due to 'stress'. Stress refers to any external factor that negatively influences the metabolism, growth, productivity, and ultimately survival of the plants. Stress can be defined as any factor which harms plant growth and development [1]. Fungal diseases have gained importance for several decades as they cause huge loss of yield to the legumes. *Fusarium* spp. and *F. oxysporum* are the most important obstacles for the enhanced production of legumes [2], causing chlorosis or yellowing of leaf, wilting, and crop death. The causal organism is the *Erysiphe* species, an important fungus causing approximately 40% yield loss in legumes [3]. Powdery mildew is a common disease in pea. *Aphanomyces* is another type of fungal pathogen present in the soil causing root rot in leguminous plants. Currently, due to the use of many synthetic products such as mineral fertilizers, insecticides, fungicides, herbicides, etc., in agriculture, causing the community health problem. Thus, contaminating the groundwater and harvested products. So, it is urgent to find alternative agricultural practices. In this perspective, the use of bioresources such as Plant Growth-Promoting Rhizobacteria (PGPR) can benefit plant growth because of their considerable agronomic advantage. PGPR is a group of micro-organisms that actively colonize plant roots and promote plant growth and yield. They are important in managing plant growth because of their effects on soil conditions, nutrient availability, growth, and yields. PGPR can produce antibacterial and antifungal compounds, which can effectively oppose certain plant pathogens and pests [4,5]. PGPR indirectly mediates biological control by eliciting Induced Systemic Resistance (ISR) against many plant diseases [6]. Several different bacteria promote plant growth, including *Acetobacter* sp., *Azotobacter* sp., *Azospirillum* sp., *Pseudomonas* sp., and, *Bacillus* sp. Also, it was observed to lead to induced systemic resistance in the treated plant [7]. This study aims to understand the beneficial effect of these PGPR isolates on plant growth under biotic stress conditions.

2. Stress

Stress is defined as a phenomenon that limits crop growth, affects productivity, or destroys biomass [8]. Environmental stresses are of two types as (1) Biotic stress and (2) Abiotic stress. Abiotic stress includes drought, salinity, heat, flooding, cold, heavy metals exposure, nutrient deficiency, etc. Biotic stress in plants is caused by living organisms, especially bacteria, fungi, viruses, nematodes, insects, and weeds. These biotic agents directly deprive their host of their nutrients can lead to the death of plants. Biotic stress can cause deleterious effects because of pre and post-harvest losses. Many biotic stresses affect Photosystems and reduce the rate of photosynthesis per leaf area. Therefore to overcome the biotic and abiotic stress, various PGPRs perform an important mechanism (Table 1). Pea crops are highly prone to bacterial, viral, and fungal diseases.

2.1. Disease caused by Fusarium oxysporum on plants.

Fungal diseases have gained importance for several decades as they cause huge loss of yield to the legumes. Powdery mildew is a serious disease influencing pea crops. The causal organism is the *Erysiphe* species, a vital fungus causing approximately 40% yield loss in legumes [3]. Several fungi can cause diseases on plants, but the most worrying one is the *Fusarium oxysporum* (soil-borne fungus) which interact with plant tissue causing adverse effect. The pathogenic strains were further subdivided into races according to their cultivar specificity [19]. More than 150 *formae speciales* and races are presently described. The *F. oxysporum* host flora encircles some of the most estimable ornamental plants, such as *Chrysanthemum* spp. *Dianthus* spp., *Gerbera* spp., *Gladiolus* spp. and *Lilium* spp. [20,21].

Table 1. Potential role and mechanism of PGPR under Biotic and Abiotic stress tolerance.

S.No.	Pathogen	PGPR	Mechanism associated with the tolerance	Ref.
		Biotic Stress		
1.	Botrytis cinerea	*Bacillus subtilis* (PTA-271)	(i) Induced the oxidative burst. (ii) Accumulated the stress-related phytoalexin metabolites (trans-resveratrol and trans-ε-viniferin). (iii) Regulated the defense-related gene expression in shoot and root, including those with transcriptional factor functions (ACCsyn, GST, CHS, CHI), and PR proteins (PR1, PR2, PR3, PR5, and PR6).	[9]
		B. subtilis (BBG127, BBG131 Bs2504, and BBG125)	(i) By non-producing lipopeptides. (ii) Overproducing surfactin.	[10]
		Streptomyces anulatus S37	(i) Induced defenses modulated by Ca2+ signaling.	[11]
2.	Flavescence dorée phytoplasma	*Pseudomonas migulae* 8R6	(i) Production of 1-aminocyclopropane-1-carboxylate (ACC) deaminase enzyme helps the plant regulate the stress-related hormone ethylene level.	[12]
		Abiotic Stress		
3.	Salinity stress	*Bacillus amyloliquefaciens* SB-9	(i) By upregulating the melatonin biosynthesis and their intermediates, and downregulation of a serotonin N-acetyltransferase gene (SNAT) and grapevine tryptophan decarboxylase genes (TDCs). (ii) Reduction of reactive oxygen species (H2O2 and O2-) in roots.	[13]
4.	Drought stress	*P. fluorescens* Rt6M10 and *Bacillus licheniformis* Rt4M10	(i) Induced biosynthesis of monoterpenes and sesquiterpenes.	[14]
5.	Chilling	*B. phytofirmans* strain PsJN	(i) Increased stress-related metabolites such as aldehydes, malondialdehyde, phenolics, and proline). (ii) Enhanced the rate of photosynthesis and starch deposition. (iii) Induced the expression of the defense-related genes: StSy, PAL, Chit4c, Chit1b, Gluc, and LOX.	[15,16]
6.	Arsenic contamination	*Micrococcus luteus*, *B. licheniformis*, *P. fluorescens*	(i) Increased the antioxidant enzyme activity (APX-Ascorbate peroxidase; CAT-Catalase; and POX-Peroxidases). (ii) Reduced lipids peroxidation in a membrane (reduced malondialdehyde content) and damaged the photosystems in the presence of Arsenic.	[17]
7.	High temperature and drought stress	*Bioradis Gel:* mixture of five AMF fungi (*Septglomus deserticola, Funneliformis mosseae, Rhizoglomus intraradices, Rhizoglomus clarum,* and *Glomus aggregatum*), and a mixture of PGPR belonging to the *Bacillus* and *Paenibacillus* genera	(i) Under higher temperature and deficit irrigation, inoculated plants reached higher berry anthocyanins & some modifications in berry ABA catabolism.	[18]

2.2. Root colonization and bio-control activity.

The Rhizosphere is a thin layer of soil directly surrounding the root system [22]. Colonization of roots by *Bacillus subtilis* is beneficial to both the bacterium and the host plant. Approximately 27% of the fixed carbon produced by plants is secreted through root exudates. Its percentage can vary with different vegetation [23]. Biological control, utilizing beneficial microbes, is a tremendous method for limiting disease-causing microbes' detrimental impact on plant health and productivity, thereby enhancing agricultural productivity [24]. Some of the Bacillus species are recognized as safe bacteria as they produce a substance that is beneficial for crops [25]. They also produce endospores, which help the bacteria survive under harsh environmental conditions, allow for germination by different environmental cues, allow for long-term storage of the biocontrol agent, and reduce the formulation process's complexity [26].

2.3. Synergistic interaction of Arbuscular Mycorrhizal Fungi (AMF) with Bacillus species stimulates plant growth.

Most of the *Bacillus* species directly stimulate plant growth through enhancement in the nutrient acquisition and stimulate the host plant's defense mechanisms before infection. They can also enhance plant growth by association with AMF [27]. The effect of PGPR *Bacillus polymyxa*, AMF *Glomus intraradices*, *Pseudomonas putida*, and *Azotobacter chroococcum* on *Stevia rebaudiana* was also studied [28]. The results confirmed elevated effects due to inoculants' dual compatible mixtures resulting from their strong synergistic relationship among themselves (Table 2) [29].

Table 2. Possible mode of action involved in bacterial–fungal interactions.

S.No.	Fungal partner	Associated bacteria	Mode of Action	References
1.	AM fungi	*Rhizobium leguminosarum; Azospirillum brasilense; Streptomyces sp.*	Physical attachment; electrostatic attraction; extracellular polymers; Change in pH; Production of volatile compounds (VOC)	[30–32]
2.	*Agaricus bisporus*	*Pseudomonas putida*	Removes the self-inhibiting compounds	[33]
3.	*Basidiomycetous fungi*	*Pseudomonads*	Fungal exudates	[34]
4.	*Tuber brochii*	*Pseudomonas fluorescens*	Chitinolytic weakening of spore wall	[35]
5.	*Lyophyllum karsten*	*Burkholderia terrae*	Through Biofilm formation	[34]

2.4. Induction of host resistance and plant growth.

B. subtilis is a species of PGPR that are known to activate plant host defense response (host resistance) against pathogens. *B. subtilis* is known to activate induced systemic resistance (ISR) in the hosts that they occupy, which increases host resistance to plant pathogens. The activation of ISR by *B. subtilis* is known to induce the synthesis of Jasmonic acid (JA), ethylene, and the (Non-Expressor of Pathogenesis-related genes 1) NPR1-regulatory gene in plants [36]. *Bacillus subtilis* help in enhancing the stress tolerance in the plant by inducing the expression of various stress-responsive genes, stress-related metabolites, and phytohormones. These defense responses are conferring the level of disease resistance against bacteria, viruses, and fungi throughout the plant [37]. Many PGPRs has led to increased disease resistance by lowering pathogenic infections.

2.5. Role of PGPR as a plant growth enhancer.

PGPR enhances plant growth due to specific traits [38]. PGPR enhances plant growth through direct and indirect mechanisms, which involve enhancing plant physiology and provide resistance to different phytopathogens through various modes and actions [39]. These include nutrient fixation, neutralizing biotic and abiotic stress, and producing Volatile Organic Compounds (VOCs) and enzymes to prevent disease. Many PGPRs can increase the antioxidants enzyme, thus preventing the plant cell from the oxidative burst [9, 40]. The antioxidant production due to fungus exposure was best studied in budding yeast (*Saccharomyces cerevisiae*), and oxidative information was reviewed in earlier details [41]. They are influenced by several biotic factors (plant genotypes, plant developmental stages, plant defense mechanisms, and other microbial communities). Many abiotic factors (soil composition, soil management, and climatic conditions) also influence these PGPRs [42].

3. Conclusions

The selection of bio inoculants as a PGPR manages the pathogen more effectively. This advancement adds sustainable control to controlling the pathogens and provides a defense mechanism by ISR. The recent plant-microbe interaction approaches have paved a protective role under biotic stress and show the biocontrol activity against pathogenic fungus. Further on, colonization and potential interactions also increase the efficiency of PGPB. Arbuscular Mycorrhizal Fungi (AMF) presence could modify root architecture, promote root growth, boost nutrient acquisition, and enhance plant growth performance. Hence, the selection of compatible microbial inoculums is an essential step before initiating any inoculation program and could help the recovery of pathogenic-degraded areas.

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Conflicts of Interest

The authors declare no conflict of interest.

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