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A review

Biological control by Plant Growth Promoting Rhizobacteria

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ABSTRACT

Plant Growth Promoter Rhizobacteria (PGPR) is soil bacteria that can live on, in or around plant tissue and promote plant growth by many mechanisms that include a biological control of plant pathogens. Indeed, PGPRs have a protective effect through several modes of action such as antagonism, competition, production of hydrolytic enzymes and biofilm formation. Moreover, the use of PGPRs as biocontrol agents is very harmonious with the environment and therefore represents a good alternative to the use of chemicals in agriculture. This review is presented as a general bibliographical synthesis on the different aspects of PGPRs and their biocontrol potential.

1. Introduction

Throughout the world, concern about plant diseases that can affect agriculture is becoming more and more serious due to severe crop damage [1]. Post-harvest diseases are a major cause of deterioration of unprocessed fruits and vegetables [47]. Economic losses are enormous [4]. In order to protect crops against plant pathogens and to meet the social and economic needs of the inhabitants, farmers have become dependent on chemicals as a method of crop protection [25]. These chemicals, such as pesticides, are an effective tool to solve these problems, but they have harmful consequences by rapid resistance of plant pathogens to antibiotics [58]. On the other hand, this leads to the creation of multi-resistant germs that spread in microbial populations, which generally attack agriculture and infect humans and animals when they consume these crops, in addition to several other damages to the environment and the ecological balance [58].

In view of the drawbacks of chemical remediation, the scientific community has turned to new control methods less harmful to the environment in order to ensure the sustainability of agriculture by increasing its profitability and safeguarding natural resources for future generations [24], and this has led to the use of antagonistic biological agents found in large numbers in the soil. In fact, the rhizosphere (the part of the soil that surrounds the roots) is an important ecological niche of microbial biodiversity, rich in nutrients due to plant root exudates, and which interacts between it and the roots of host plants [7]. Among these rhizospheric antagonistic agents, PGPRs (plant growth promoting rhizobacteria) are in the front line of attack. They have the capacity to effectively colonize host plant roots and whose overall effect is to promote their growth directly through soil biofertilization and phytostimulation through the production of phytohormones or indirectly through the improvement of stress tolerance and the control of phytopathogens, this phenomenon is commonly referred to as "biocontrol" [57].

The use of PGPR as a biocontrol agent is therefore a hot topic and has been the focus of recent work, as its use is considered the best alternative to chemical control [14]. Thus, biocontrol is based on the use of natural enemies to eliminate aggressors or phytopathogenic agents through

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several mechanisms such as antagonism, competition, biofilm formation, as well as the synthesis of hydrolytic enzymes [39].

In this perspective, our work focused on the main mechanisms of action attributed to PGPRs and their roles in the biocontrol of plant diseases.

2. General information

2.1. Rhizosphere

The bacteriologist and agronomist Lorenz Hiltner were first defined the term rhizosphere in 1904 [30] as a thin layer of soil where interactions between absorbent roots and microorganisms take place [9], with a composition changed by the metabolism and activity of the latter [44].

2.2. Rhizobacteria

According to Kloepper [33], rhizobacteria or rhizospheric bacteria are a specific community of soil bacteria that have the ability to colonize the rhizospheric soil, with the potential to reside in contact with plant roots at various stages of development and growth. Bacteria meeting this definition belong to different genera and species, of which the most studied are *Pseudomonas*, *Azospirillum*, *Agrobacterium* and *Bacillus* [38].

2.3. Plant Growth Promoting Rhizobacteria (PGPR)

Plant Growth Promoting Rhizobacteria (PGPR) is a rhizobacteria that has *the* ability to enhance plant growth directly or indirectly through the colonization of root systems [35]. This term was first used by Kloepper and Schroth in 1978 [34] to designate *Pseudomonas fluorescens* strains. Indeed, PGPRs include those that live freely, and those that form specific symbiotic relationships with plants [6].

2.4. Mechanisms of action of the PGPRs

PGPRs promote plant growth through several mechanisms, either directly or indirectly (Fig. 1).

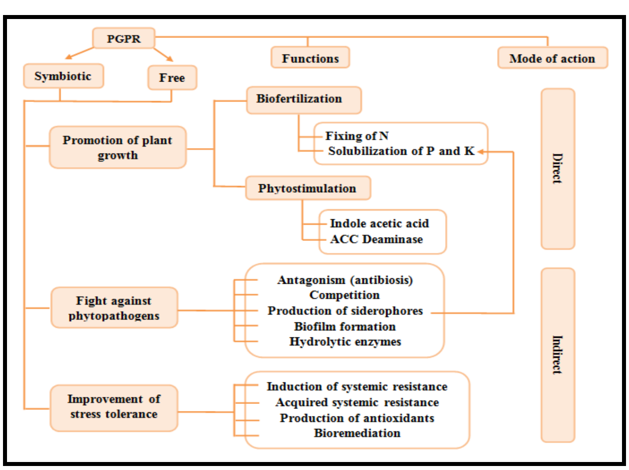

Fig 1. Schematic diagram representing the forms, functions and modes of action of PGPRs [5].

2.4.1. Biofertilization

The aim of biofertilizers is the improvement of plant nutrition through biological processes, two of the most relevant of which are:

(1) The biological fixation of atmospheric nitrogen by reducing it to ammonia through a complex enzyme system mainly nitrogenase [32].

(2) The phosphate-solubilizing microorganisms (PSM), which are characterized by their ability to solubilize precipitated forms of phosphorus and include a wide range of symbiotic and non-symbiotic organisms [40].

2.4.2. Phytostimulation

Phytostimulation is a hormonal stimulation of the plant through the availability of the latter or their precursor by PGPR. We will quote as examples: (1) the production of Acetic Indole Acid (AIA) by some PGPR of the genus *Pseudomonas*, *Bacillus*, *Azospirillum brasilense*, *Rhizobium*, *Enterobacter*, *Xantomonas*, *Alcaligenes piechaudii*, *Agrobacterium spp.*, *Rhizobium leguminosarum*, and *Comamonas acidovorans spp*. [27, 63]. (2) PGPRs, which possess the enzyme Aminocyclopropane-1-carboxylate (ACC) deaminase, facilitate plant growth and development by lowering ethylene levels, inducing salt tolerance and reducing drought stress in plants [46, 7].

3. PGPR as biological control agents

3.1. Biological control

Biological control, also known as "biocontrol", is the deliberate use of the biological capabilities (natural mechanisms of action and/or interactions) of a beneficial species to reduce the development of another harmful species [62]. The need for natural, ecologically sustainable, environment-friendly and non-toxic alternatives to chemicals is increasingly being sought, and is leading to the consideration of using PGPRs as biocontrol agents because of the strength that they give to the rhizosphere to deal with threats that target plant roots, in addition to contributing to restoring biodiversity in agro-ecosystems [2].

3.2. Potential of PGPRs in biocontrol

Biocontrol can be as effective in controlling plant pathogenic diseases (Table 01) as the use of chemical fungicides [17]. For example, the *Pseudomonas fluorescens* strain can reduce red pepper plant crown rot disease caused by the fungus *Sclerotium rolfsii* by 78% [56]. Also, *Gliocladum vireus* and *Burkholderia cepacia* have been used to reduce tomato diseases caused by *Sclerotium rolfsii, Pythium ultimum, Rhizoctonia solani* and *Fusarium oxysporum f. sp. Lycopersici* [41].

The particularity of PGPRs, by having a wide range of modes of action and their ability to adapt to the rhizosphere, contribute to biocontrol becoming more sustainable than chemicals. Thus, the use of PGPRs is considered an alternative route to the use of chemicals [12], [8]. In addition, several biocontrol products (Table 02) are marketed and used worldwide [20, 18].

Table 1. Example of biocontrol microorganisms used against plant pathogens [18].

Biocontrol agent	Target Plant Pathogens	Mechanism(s) of action
Bacillus subtilis *Bacillus licheniformis* P40	*Fusarium spp. Erwinia carotovora ssp. Atroseptica* and *Erwinia carotovora ssp.carotovora*	Antibiosis Hydrolytic enzymes Competition
Pseudomonas spp. DF-41 and PA-2	*Sclerotinia Sclerotiorum*	Antibiosis
Streptomyces sp. Di-944	*Rhizoctonia solani*	Antibiosis
Streptomyces sp. 93	*Pythium, Aphanomyces, Phytophtora, Rhizoctonia* and *Fusarium* spp.	Antibiosis
Pseudomonas aeruginosa	*Aspergillus flavus, Aspergillus niger, Rhizoctonia bataticola, Rhizoctonia solani, Sclerotium rolfsii* and *Puccinia arachidis*	Antibiosis Competition
Streptomyces diastatochromogenes PonSSII	*Streptomyces scabies*	Antibiosis Competition
Pseudomonas spp.	*Gaeumannomyces graminis var. tritici, Pseudomonas tolaasii, Fusarium oxysporum f.* sp. *Lini* and *Erwinia amylovora*	Antibiosis Competition
Pseudomonas fluorescens *Pseudomonas putida*	*Pectobacterium carotovorum subsp, atrosepticum* and *Pectobacterium carotovorum subsp.carotovorum*	Hydrolytic enzymes Competition Antibiosis Induced Resistance System
Trichoderma spp.	Several phytopathogenic fungi	Antibiosis Competition
Serratia plymuthica A30	*Dickeya solani*	Antibiosis

Table 1. Some antagonistic agents marketed as biological products for the treatment of certain plant pathogens [54, 26].

Product	Microorganisms	Diseases treated	Distributor
QA 10	*Ampelomyces quisqualis*	Mildious	Ecogen, USA
Binab T	*Trichoderma* spp.	Root rot, fusariosis	Bio innovation AB, New Zealand, USA
Biofox C Fusaclean	*Fusarium oxysporum* (non-pathogenic)	Fusariosis	S.I.A.P.A., USA
Bio-fungus	*Trichoderma harzianum*	Root rot, fusariosis	De Ceuster, USA, EU, New Zealand
Intercept	*Pseudomonas cepacian*	Root rot	Soil Technologies, USA
PSSOL	*Ralstonia solanacearum*	Root rot	Natural Plant Protection, France
Contans KONI	*Coniothyrium minitans*	Root rot	Prophyta Biologischer, Hungary, Germany
Polyversum	*Pythium oligandrum*	Root rot	Biopreparaty, Czech Republic
Primastop (Prestop Mix)	*Gliocladium catenulatum*	Root rot, fusariosis	Kemira Agro, Finland
Root Shield, Plant Shield, T-22 Planting	*Trichoderma harzianum-T22*	Root rot	Bioworks, USA, EU, New Zealand
Soil Gard	*Gliocladium virens* GL-21	Root rot	Therma Trrilogy, USA
Sporodex	*Pseudozyma flocculoza*	Mildew	Plant products, Canada
Trieco	*Trichoderma viride*	Root rot, fusariosis	Ecosens Laboratories, India
GBO3, MbI 600	*Bacillus subtilis*	Melting of seedlings	Horiculture, USA
Mycostop	*Streptomyces griseovoridis*	Fusariosis, melting of seedlings	Kemira Agro Oy, Helsinki, Finland

3.2. Modes of action of PGPRs in biocontrol

The modes of action of PGPRs as a biocontrol agent depend mainly on the microorganism used and the type of plant pathogen to which is applied [11]. In general, the main modes of biocontrol attributed to PGPRs to reduce soil-borne diseases are as follows*:*

3.2.1. Antagonism

Beneficial rhizobacteria that can secrete substances that inhibit the growth of phytopathogenic microorganisms are called antagonistic bacteria. Therefore, antagonism is the ability of one germ to inhibit the growth of another germ when they are in the same micro-biotope [7]. Similarly, it is expressed in the laboratory when they are grown together in the same Petri dish [7], and it often linked to the phenomenon of antibiosis [11]. Antibiotic production is one of the mechanisms used by PGPRs in the prevention of phytopathogenic attacks and in the suppression of biotic diseases [26]. Regarding the use of PGPRs as a biocontrol tool, both genera *Paenibacillus spp* and *Bacillus* are frequently documented [36].

3.2.2. Competition

Competition for space, nutrients or other environmental factors that become limiting to microbial growth is a biological mechanism used by PGPRs to repel or eliminate plant pathogens [55]. An effective competitive agent must be an intense colonizer capable of immediately and efficiently exploiting nutrients present at low concentrations in the soil or stopping their uptaken by other microorganisms [29]. For example, some strains can synthesize extracellular enzymes that led to use organic compounds as a source of energy and/or to degrade phytotoxins [43].

However, in some cases, a reduction in disease may be associated with significant root colonization by PGPRs, which reduces the number of habitable sites for plant pathogenic microorganisms and consequently their growth [47]. The density and intensity of rhizobacteria activity influenced this interaction between beneficial bacteria and phytopathogens [50].

3.2.3. Biofilm formation

Biofilms are structurally complex aggregates of microbial cells attached to a surface and surrounded by an extracellular polymer matrix [57]. PGPRs have a very strong capacity to attach to the plant root system when they form a biofilm [22]. Biofilms have the power to provide significant protection against external aggression and stress, as they act as a protective barrier that prevents the penetration of plant pathogens, releasing a wide range of enzymes, and reducing microbial competition [28]. The best studied examples of PGPRs that form biofilms with plants are presented in Table 03.

Table. 3. Examples of PGPRs involved in biocontrol through biofilm formation.

Bacteria	**Features**	**References**
Azorhizobium caulinodans	*Rice root colonization.*	*[60]*
Azorhizobium brasilense	*Root colonization of wheat.*	*[31]*
Acinetobacter calcoaceticus P23	*Root colonization of duckweed.*	*[65]*
Bacillus amyloliquefaciens S499	*Root colonization of tomato, corn and Arabidopsis thaliana.*	*[19]*
Bacillus polymyxa	*Cucumber root colonization.*	*[66]*
Cyanobacteria spp	*Improvement of biofilm formation of mixed species with Rhizobium, Azotobacter and Pseudomonas spp.*	*[51]*
Klebsiella pneumoniae	*Root colonization of wheat.*	*[23]*
Pantoea agglomerans	*Root colonization of chickpeas and wheat.*	*[10, 4]*
Rhizobium leguminosarum bv. viciae 3841	*Root colonization of various legumes.*	*[61, 64]*
Rhizobium (Sinorhizobium) sp. strain NGR234	*Root colonization of various legumes and competitive colonization in the cowpea rhizosphere.*	*[37]*

3.2.4. Hydrolytic enzymes

The synthesis of hydrolytic enzymes is one of the essential biocontrol mechanisms used by PGPRs against telluric plant pathogens [52]. These strains play a major role in decomposing organic matter in ecosystems and thus protecting plants from environmental stresses [45]. PGPRs can produce certain enzymes, such as amylase [53], chitinase [21], phosphatase [15], protease [16], urease [68], cellulase and lipase [52].

3.2.5. Improvement of stress resistance

The action of PGPRs can improve plant's resistance against pathogens. It is mainly due to two signalling pathways (Figure 02):

✓The Acquired Systemic Resistance (ASR) whose signal molecule is salicylic acid. It acts by increasing the production of salicylic acid during a microbial infection at the site of contamination as well as in the whole plant. In some plant/pathogen models, salicylic acid, brought exogenously by fluorescent *Pseudomonas*, conferred protection against pathogens [42].

✓Induced Systemic Resistance (ISR): Some PGPRs can stimulate the induced response mechanisms in the plant and lead the whole plant to a state of resistance called Induced Systemic Resistance (ISR) [49, 59].

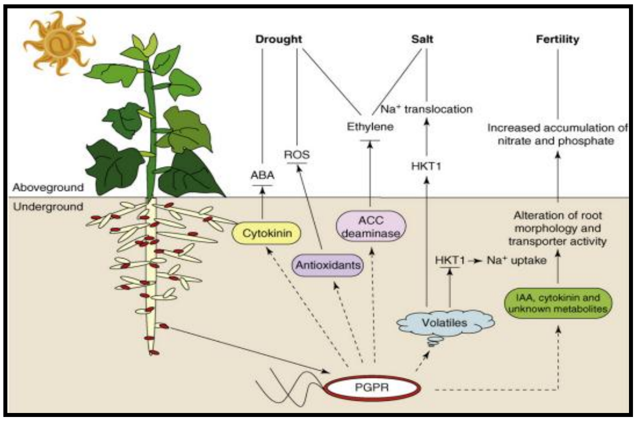

Fig. 2. Roles of PGPRs in promoting plant growth under stress conditions (ABA: abscisic acid; ACC: 1-aminocyclopropane-1-carboxylate; HKT1: high-affinity K+ transporter 1; IAA: indole acetic acid; IST: induced systemic tolerance; PGPR: plant growth promoting rhizobacteria; ROS: reactive oxygen species) [67].

4. Conclusion

The potential of PGPRs in biocontrol is well established, and their use is proving to be a promising strategy for chemical pesticides. In the present review, the phytoprotective effects of certain PGPRs suggest the possibility of the direct inclusion of these microorganisms in programs for the prevention and control of microbial infections of plants, particularly in agriculture.

Conflict of Interest

The authors declare that they have no conflict of interest

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