

1 **Plant growth promotion in cereal and leguminous agricultural important plants: from**
2 **microorganism capacities to crop production**

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8

9 **Abstract**

10 Plant growth-promoting rhizobacteria (PGPR) are free-living bacteria which actively colonize
11 plant roots, exerting beneficial effects on plant development. The PGPR may (i) promote the
12 plant growth either by using their own metabolism (solubilising phosphates, producing
13 hormones or fixing nitrogen) or directly affecting the plant metabolism (increasing the uptake
14 of water and minerals), enhancing root development, increasing the enzymatic activity of the
15 plant or "helping" other beneficial microorganisms to enhance their action on the plants; (ii)
16 or may promote the plant growth by suppressing plant pathogens. These abilities are of great
17 agriculture importance in terms of improving soil fertility and crop yield, thus reducing the
18 negative impact of chemical fertilizers on the environment. The progress in the last decade in
19 using PGPR in a variety of plants (maize, rice, wheat, soybean and bean) along with their
20 mechanism of action are summarized and discussed here.

21

22 **Keywords:** PGPR; wheat; rice; maize; soybean; bean.

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1 **1. Introduction.**

2 During the past century, industrialization of agriculture has provoked a significant and
3 essential productivity increase, which has led to a greater amount of food available to the
4 general population. Along with this abundance the appearance of serious environmental and
5 social problems came with the package: problems that must be faced and solved in the not too
6 distant future. Nowadays, it is urgent to maintain that high productivity, but it is becoming
7 urgent to alter as little as possible the environment. Clearly we must then head for a more
8 environmentally sustainable agriculture while maintaining ecosystems and biodiversity. One
9 potential way to decrease negative environmental impact resulting from continued use of
10 chemical fertilizers, herbicides and pesticides is the use of Plant Growth-Promoting
11 Rhizobacteria (PGPR). This term was first defined by Kloepper and Schroth (1978) to
12 describe soil bacteria that colonize the rhizosphere of plants, growing in, on or around plant
13 tissues that stimulate plant growth by several mechanisms. Since that time, research activities
14 aimed at understanding how these bacteria perform their positive (or negative) effect have
15 steadily increased and many reports have been published on these microorganisms. Firstly,
16 screening of rhizobacteria for *in vitro* production of phytohormones (Cassán et al., 2009;
17 Hoyos-Carvajal et al., 2009; Rashedul et al.; 2009; Abbasi et al., 2011) such as auxins (Khalid
18 et al., 2004); siderophores (Filippi et al., 2011; Yu et al., 2011); phosphorous solubilisation
19 (Yasmin et al., 2004; Tajini et al., 2012; Krey et al. 2013), or nitrogen-fixing (Peix et al.,
20 2001, Riggs et al., 2001, Fischer et al., 2007) were used to isolate PGPR from the rhizosphere
21 and to screen for their growth-promoting activity in plants under axenic conditions. Once the
22 PGPR candidates had shown promising performances under controlled conditions, they were
23 then used as inoculants for plants cultivated under natural conditions in pots and/or field
24 trials. Application of PGPR in legumes has been mainly restricted to rhizobia manipulation
25 for studies on increase in legume growth and development, specifically by means of
26 nodulation and nitrogen fixation. Obviously, the main reason for that is because a broad range

1 of soil-borne rhizobia species can establish symbiosis with legumes (Cooper, 2008).
2 Therefore, rhizobia can be considered the best known beneficial plant associated bacteria and
3 the most important biofertilizer.

4 Benefits to plants from host-PGPR interactions (Fig. 1) have been shown to include
5 plant health and growth, suppress disease-causing microbes and accelerate nutrient
6 availability and assimilation (Mantelin and Touraine, 2004; Yang et al., 2009). These
7 beneficial effects on plants can be achieved by the direct interaction between PGPR and their
8 host plant and are also indirectly due to their antagonistic activity against plant pathogens.
9 Direct stimulation includes several mechanisms such as: producing 1-aminocyclopropane-1-
10 carboxylate (ACC)-deaminase to reduce ethylene levels in the roots of developing plants;
11 producing plant growth regulators like auxins, gibberellins, cytokins and certain volatiles;
12 symbiotic nitrogen fixation; solubilising mineral like phosphorus and other nutrients, etc.
13 Indirect stimulation is related to biocontrol, by mean of antagonistic activity against
14 phytopathogenic microorganisms inducing plant systemic resistance responses, interfering in
15 the bacterial Quorum Sensing (QS) systems, etc.

16 Some reports show PGPR may use more than one of these mechanisms for
17 accomplishing plant growth enhancement (Bashan and Holguin, 1997; Ahmad et al., 2008).
18 An excellent review about these bacteria has been published recently (Bhattacharyya and Jha,
19 2012).

20 Different PGPR can be administered to crops in some formulations that are
21 commercially available (Lucy et al., 2004) and, recently, the popularity of microbial
22 inoculants has substantially increased, facilitated by extensive and systematic research that
23 has enhanced effectiveness and consistency (Berg, 2009; Thakore, 2006). Microbial
24 inoculants include three major groups: (1) arbuscular mycorrhiza fungi (AMF), (2) PGPR,
25 and (3) symbiotic-nitrogen-fixing rhizobia (**Fig. 2**). The beneficial capacity of each group has
26 been studied separately (Dobbelaere et al., 2001; Barea et al., 2002; Murray, 2011, Verma et

1 al., 2010). Moreover, numerous studies are being conducted to evaluate plant growth effects
2 by applying different microbial combinations or consortia (Table 1), such as AMF-PGPR,
3 symbiotic-nitrogen-fixing rhizobia-PGPR or different PGPR (Singh and Kapoor, 1999;
4 Swarnalakshmi et al., 2013). However, understanding the mechanisms of plant growth
5 promotion is important in order to decide what type of microorganism is better to use with
6 which plant in a given situation.

7 Rhizosphere is the zone of soil surrounding a plant root where the biology and
8 chemistry of the soil are influenced by the roots (Lugtenberg and Kamilova, 2009). Root
9 exudates include amino acids, organic acids, carbohydrates, sugars, mucilage and proteins.
10 The ability of rhizobacteria to use organic acids as carbon sources correlates with rhizosphere
11 competence. Structure of the rhizobacterial community is determined by the plant species just
12 as differences in the composition and amounts of root exudates most likely affect the
13 microbial populations. Understanding how plant roots select soil microbes to form the
14 microbial community of the rhizosphere is an important scientific issue when considering the
15 use of rhizobacteria as plant growth promoters (Droque et al., 2012).

16 In this review, our focus is mainly on PGPR. We begin with a description of various
17 mechanisms used by these bacteria to enhance the plant growth and to increase agronomic
18 parameters. Then, the current progress of using PGPR on the most important worldwide
19 cereal crops such as maize, rice, and wheat, along with the ubiquitous legumes, principally
20 soybean and dry bean varieties, is summarized in the review and discussed.

21

22 **2. Mechanisms for the Plant Growth Promotion.**

23 *2.1. Biofertilization.*

24 Rhizobacteria that promote plant growth by improving the nutrient uptake of the plants
25 are termed biofertilizers. These bacteria have a role of improving the nutrient status of host
26 plants by means of nitrogen fixation, increasing the availability of nutrients in the

1 rhizosphere, promoting the root surface area, or enhancing beneficial symbiosis of the host.
2 Usually, growth promotion is due to a combination of these action modes (Fig. 3).

3 Plants can assimilate nitrogen (N), which is one of the principal plant nutrients, from
4 soil as nitrite, nitrate or ammonia. These forms of nitrogen are not abundant in most soils and
5 the chemical nitrogen fertilization employed in agriculture is frequently lost during rainfall or
6 by mineral leaching of these fertilizers. Atmospheric N₂-fixing bacteria such as *Rhizobium*
7 and *Bradyrhizobium* can establish symbiosis forming nodules on roots of leguminous plants
8 such as soybean, pea, peanut and alfalfa, in which they convert N₂ into ammonia, which can
9 be used by the plant as a nitrogen source (Murray, 2011). However, this process is practically
10 limited to legume crops. On the other hand, several non-symbiotic bacteria have been
11 identified as free-living N₂-fixers (*Azospirillum*, *Azoarcus*, *Azotobacter*, *Bacillus polymyxa*,
12 *Burkholderia*, *Gluconoacetobacter* or *Herbaspirillum*). These potential PGPR can fertilize
13 several important agronomic plants such as wheat (Boddey et al., 1986), sorghum (Stein et al.,
14 1997), maize (Garcia de Salamone et al., 1996), rice (Malik et al., 1997) or sugarcane
15 (Boddey et al., 2001). Inoculation of these PGPR species usually increases plant's dry weight,
16 flowering and grain production. However, the yield increase caused by inoculation of these
17 PGPR could often be attributed to an increase in root development, which allows better rates
18 of water and mineral uptake (Okon et al., 1998).

19 Another essential nutrient in plants is phosphorus (P). Although the large reserve of P
20 is in soils, most of it is not soluble, which cannot then be absorbed by plants, therefore
21 limiting the plant growth. Certain PGPR are able to solubilise P through acidification
22 (Richardson et al., 2009), chelation or enzymatically (Hameeda et al., 2008). Bacteria such as
23 *Azospirillum*, *Bacillus*, *Burkholderia*, *Erwinia*, *Pseudomonas*, *Rhizobium* or *Serratia* are
24 reported as phosphate solubilising bacteria (Sudhakar et al., 2000; Mehnaz and Lazarovits,
25 2006).

1 Furthermore, inoculation of PGPR can increase plant uptake of several other nutrients
2 such as Ca, K, Fe, Cu, Mn and Zn. This uptake usually occurs during acidification of the soil
3 rhizosphere via organic acid production or via stimulation of proton pump ATPase (Mantelin
4 and Touraine, 2004). In any case, the soil pH decrease improves solubilisation of these
5 nutrients.

6

7 *2.2. Rhizoremediation and Stress Control*

8 Numerous reports on potential PGPR that degrade soil pollutants have been published
9 (Fig. 3). The contribution of the rhizomicrobial population to degrading pollutants allows
10 plants to emerge as natural vegetation at a contaminated site. Studies focused on degradation
11 of compounds such as herbicides, pesticides and hazardous organic compounds have been
12 carried out, although those reports have provided little information on the microbial
13 population. A key step during rhizoremediation consists of the selection of pollutant-
14 degrading rhizobacteria that live in the rhizosphere and use the root exudates as an energy
15 source (Kuiper et al., 2001). These bacteria, besides degrading the pollutant compounds, often
16 directly assist rhizoremediation by producing hormones, fixing atmospheric nitrogen,
17 solubilising P or secreting siderophores (Denton, 2007). In the same way, consortia of
18 bacteria (Table 1) are found to be efficient since each partner can accomplish different parts
19 of the catabolic degradation route (Rahman et al., 2002).

20 When plants are exposed to stress conditions they respond increasing ethylene levels
21 that lead to an increase in cell and plant damage (Argueso et al., 2007). A high concentration
22 of ethylene can be harmful because it induces defoliation and other cellular processes that
23 may affect crop development (Desbrosses et al., 2009). Many PGPR destroy 1-
24 aminocyclopropane-1- carboxylate (ACC), a precursor of the ethylene, via production of the
25 enzyme ACC deaminase, which in turn facilitates plant growth and development by decreasing
26 plant ethylene levels. In addition, several forms of stress are relieved by ACC deaminase

1 producers, such as effects of phytopathogenic bacteria, and resistance to stress from
2 polyaromatic hydrocarbons, from Ca^{2+} and Ni^{2+} , and from salt and draught (Glick et al.,
3 2007).

4

5 2.3. *Phytostimulation.*

6 Diverse PGPR can alter root architecture and promote plant development due to their
7 ability to synthesize and exudates plant hormones like indole-3-acetic acid (IAA), gibberellins
8 (GAs), cytokinins and certain volatiles, hence they are termed phytostimulators (Bloemberg
9 and Lugtenberg, 2001), this capacity being bacterial strain specific (Boiero et al., 2007).

10 The PGPR stimulatory effect comes from a manipulation of the complex and balanced
11 network of plant hormones that directly are involved in growth or stimulation of the root
12 formation. For instance, the biosynthesis of IAA by various PGPR has been demonstrated to
13 enhance root proliferation (Dobbelaere et al., 1999; Khalid et al., 2004). Bacteria use this
14 phytohormone to interact with plants as part of their colonization strategy, including
15 phytostimulation and avoidance of basal plant defence mechanisms. Moreover, it has recently
16 been indicated that IAA can also be a bacterial signalling molecule and therefore can have a
17 direct effect on bacterial physiology (Spaepen et al., 2007).

18 In bacteria there is no known role for GAs, rather they seem to be secondary
19 metabolites that may play a role as signalling factors towards the host plant. In this way, there
20 are many studies where GA production by *Azospirillum* or *Bacillus sp.* induces growth
21 promotion in plants (Bottini et al., 2004; Piccoli et al., 1997; Gutiérrez-Mañero et al., 2001).

22 Involvement of PGPR cytokinins were observed in root initiation, cell division, cell
23 enlargement and increase in root surface area of crop plants through enhanced formation of
24 lateral and adventitious roots (Salamone et al., 2005; Werner et al. 2003). Some strains of
25 *Azotobacter spp.*, *Rhizobium spp.*, *Pantoea agglomerans*, *Rhodospirillum rubrum*,
26 *Pseudomonas fluorescens*, *B. subtilis*, and *Paenibacillus polymyxa* are reported to produce

1 cytokinins (Glick , 2012; Salamone et al., 2001). However, a detailed understanding of the
2 role of PGPR-synthesized cytokinins and how their production is regulated is not currently
3 available.

4 It has recently been reported that some rhizobacteria promote plant growth by
5 releasing volatile signals (Ping and Boland, 2004). The discovery of rhizobacterial-produced
6 volatile organic compounds (VOCs), like 2, 3-butanediol, acetoin, terpenes, jasmonates, etc.,
7 constitutes an important mechanism for the elicitation of plant growth by rhizobacteria. The
8 synthesis of bioactive VOCs seems to be a strain-specific phenomenon. The VOCs produced
9 by the rhizobacteria can act as signalling molecule to mediate plant–microbe interactions as
10 volatiles produced by PGPR colonizing roots are generated at sufficient concentrations to
11 trigger the plant responses (Ryu et al. 2003). However, more investigations into the volatile
12 components in plant-rhizobacteria system should follow.

13

14 *2.4. Biocontrol.*

15 Plant growth promotion can be achieved indirectly through biocontrol activity against
16 plant pathogens. Several ways of controlling bacterial pathogens have been described in
17 PGPR.

18

19 *2.4.1 Antagonism.*

20 Members of the bacterial genera *Bacillus*, *Pseudomonas*, *Serratia*, *Stenotrophomonas*,
21 and *Streptomyces* and the fungal genera *Ampelomyces*, *Coniothyrium*, and *Trichoderma* are
22 well-studied microorganisms with proven microbial influence on plant health. When testing
23 microbial isolates from plant-associated habitats, between 1 and 35% showed antagonistic
24 capacity to inhibit the growth of pathogens *in vitro* (Berg, 2009).

25 Mechanisms responsible for antagonistic activity include inhibition of the pathogen by
26 antibiotics, toxins and surface-active compounds (biosurfactants); competition for minerals,

1 nutrients, and colonisation sites; and a mechanism that develops production of extracellular
2 cell wall degrading enzymes such as chitinase and β -1,3-glucanase (Fig. 4) (Whipps, 2001;
3 Compant et al., 2005; Haas and Défago, 2005). Successful biological control on the basis of
4 plant-associated antagonists not only requires better knowledge of the complex regulation of
5 disease suppression by antagonists in response to biotic and abiotic factors, but also
6 knowledge of the dynamics and composition of plant-associated bacterial communities and
7 what triggers plant colonisation (Normander and Prosser, 2000).

8

9 2.4.2. Systemic Response Induction.

10 Induced systemic resistance (ISR) and systemic acquired resistance (SAR), which are
11 part of plants systemic resistance responses, are activated by certain microorganism molecules
12 referred to as elicitors. The ISR is the phenomenon in which the interaction of some bacteria
13 with the plant root results in plant resistance to some pathogenic bacteria, viruses and fungi
14 (Lugtenberg and Kamilova, 2009). ISR is triggered by non-pathogenic microorganisms and
15 starts in the root, extending to the shoot, (Fig. 4) (Ramos-Solano et al., 2008). This defence
16 response is dependent on ethylene and jasmonic acid signalling in the plant (van Loon, 2007).
17 In contrast, SAR is typically activated by necrotic pathogenic bacteria and the molecule that
18 plays a key role is salicylic acid (SA). However, both ISR and SAR can overlap in some
19 cases. In fact, López-Baena et al. (2009) showed that the absence of “nodulation outer
20 proteins” from *Sinorhizobium fredii* HH103, secreted across the type III secretion system,
21 provoked a higher induction of SA dependent *PRI* gene with respect to the wild type despite
22 this microorganism being a soybean symbiotic bacterium.

23 Elicitors are the molecules that induce the ISR defence responses. Cell wall
24 polysaccharides are the most described biotic elicitors, along with flagella, salicylic acid,
25 cyclic lipopeptides, siderophores, antibiotics, the signal molecule AHL or volatile compounds
26 (Shuhegge et al., 2006; van Loon, 2007; Ramos Solano et al., 2008; Berg, 2009).

1 ISR has been reported as one of the mechanisms by which PGPR reduces plant disease
2 modulating the physical and biochemical properties of host plants (Pieterse et al., 2002). The
3 first studies about this process were carried out by van Peer et al. (1991). They inoculated
4 non- pathogenic *Pseudomonas* spp. on roots and observed the trigger of a plant-mediated
5 resistance response in above-ground plant parts. Since then, the ISR elicitation by PGPR as a
6 biocontrol method has been studied in many plant species such as bean, tomato, tobacco,
7 radish, cucumber and carnation (van Loon et al., 1998). Obviously, the easy handling of the
8 *Arabidopsis thaliana* plant is being the main model for PGPR-elicited ISR studies (Ruy et al.,
9 2004). ISR is characterized by a specificity relationship between plant and PGPR species. In
10 fact, a PGPR that produces ISR in one plant species may not do it in another. Several strains
11 from *Pseudomonas*, *Bacillus* and *Azospirillum* genera are the mayor group of PGPR that have
12 been described eliciting ISR response. There are other species included in the symbiotic group
13 of rhizobacteria that are used in coinoculations with different PGPR and can be involved in
14 ISR (Elbadry et al., 2006). However, the metabolic pathway involved in this process is poorly
15 studied (Ramos Solano et al., 2008).

16

17 2.4.3. Interference with Quorum Sensing System.

18 Many bacteria regulate their gene expression in response to changes in their
19 population density in a process called QS, which involves communication between cells
20 mediated by small diffusible signal molecules termed autoinducers (Fuqua et al., 1994). N-
21 acyl-homoserine-lactones (AHLs) are the most common autoinducer molecules; they regulate
22 the expression of genes implied in the production of the virulence factor or biofilm formation
23 in several plant pathogens (Quiñones et al., 2005). Many plants are able to produce molecules
24 which specifically interfere in the QS systems of plant associated bacteria and, in any case,
25 depending on the bacterium being detected as a pathogen or as a beneficial microorganism the
26 molecule enhances or inhibits the phenotypes regulated by QS (Fig. 4) (Pérez-Montaña et al.,

1 2013). Furthermore, several bacteria produce acylase (*Ralstonia*) or lactonase (*Bacillus*)
2 enzymes that degrade the AHL molecules (Fig. 4) (Dong et al., 2002; Lin et al., 2003). For all
3 these reasons, bacteria able to interfere in the QS systems may be potentially used against
4 bacterial pathogens. In fact, the virulence of *Erwinia carotovora*, whose virulence factors are
5 regulated by QS, is attenuated in the presence of the lactonase enzyme produced by *Bacillus*
6 (Dong et al., 2002).

7

8 2.4.4. Competence for iron and heavy metals.

9 Iron is an essential nutrient for virtually all forms of life. However, in most aerobic
10 microbial habitats, Fe^{2+} is oxidized to Fe^{3+} , forming insoluble compounds that are unavailable
11 to microorganisms. In those circumstances, some bacteria and mycorrhizal fungi produce
12 low-molecular mass iron chelators with high affinity for iron termed siderophores (Miethke
13 and Marahiel, 2007; Machuca et al., 2007). These molecules act as solubilizing agents for iron
14 from minerals or organic compounds under conditions of iron limitation. Siderophores,
15 generally form 1:1 complexes with Fe^{3+} , which are then taken up by the cell membrane of
16 bacteria, where the Fe^{3+} is reduced to Fe^{2+} and released from the siderophore into the cell
17 (Boukhalfa and Crumbliss, 2002).

18 PGPR have been demonstrated as enhancing the plant-growth producing very efficient
19 extracellular siderophores which allow control of several plant diseases by depriving the
20 pathogen of iron nutrition, thus resulting in increased crop yield (O'Sullivan and O'Gara,
21 1992). In addition to iron, siderophores can also form stable complexes with other metals that
22 are of environmental concern, such as Al, Cd, Cu, Ga, In, Pb and Zn (Schalk et al., 2011).
23 Braud et al. (2009) have shown that the presence of heavy metals induces bacterial
24 siderophore production. Paradoxically, plants grown in metal-contaminated soils are often
25 iron deficient and the bacteria may help plants to obtain sufficient iron (Burd et al., 2000).
26 Microbial siderophores are used as metal chelating agents that regulate the availability of iron

1 in plant rhizosphere. This in turn helps plants to alleviate the toxicity of metals as reported for
2 arsenic uptake by several plants (Wang et al. 2007). Siderophores producing microbes that
3 inhabit the rhizosphere soils are believed to play an important role in heavy metal
4 phytoextraction. Recent studies also suggested that rhizosphere/seed inoculation with
5 beneficial microbes helps plants to alleviate heavy metal stress through enhancing the
6 activities of antioxidant enzymes. Mycorrhizal fungi can also affect physiological and
7 biochemical basis of plant tolerance to heavy metals by changing the antioxidant enzyme
8 activities. So, to understand how plant-associated siderophore producing microbes influence
9 heavy metal mobilization and its uptake by plants in multi metal-polluted soils is critical
10 information (Rajkumar et al., 2012).

11

12 **3. Use of PGPR on Plants**

13 According to the FAO (<http://faostat3.fao.org>), after sugarcane the next three first
14 crops in terms of production (million tonnes) in the world are the cereal maize (*Zea mays*),
15 rice (*Oryza sativa*) and wheat (*Triticum aestivum* L.). The global production of maize in the
16 year 2011 was more than 883 MT. In 2050, it is estimated that the demand for maize in the
17 developing countries will double (Rosegrant et al., 2009). In 2011, global production of rice
18 was almost 723 MT. Rice exhibits wide adaptability to different environments, which makes
19 it the most widespread crop in the world. It can grow in drought conditions or in shallow
20 water (up to 50 cm of water), and in a wide range of latitudes and up to 3000 m altitude. For
21 this reason, it is considered a strategic crop for food security in the world by the FAO. With
22 regards to wheat, global production of this cereal was almost 704 MT in 2011. Wheat
23 represents a major renewable resource for food, feed, and industrial raw material and it is the
24 most widely grown worldwide crop. Although during the last century, wheat has undergone a
25 spectacular yield increase, annual yield increase began to slow down in 1995 and is now
26 stagnating in nearly every country (Reynolds et al., 2009). A clear link has been established

1 between this stagnation and the increasing frequency of interfering climatic factors such as
2 spring drought during stem elongation, heat stress around flowering time and during grain
3 filling out since 1995 (Brisson et al., 2010, Lobell et al., 2011). During that same time period
4 world population increased from 5.8 billion to 6.6 billion and is expected to surpass 9 billion
5 by 2050. The demand for wheat in the developing world is projected to increase 60% by 2050
6 while climate change is expected to affect production negatively by 29% in the same areas
7 (Dixon et al., 2009).

8 Soybean represents the most important legume included in human diet in many
9 countries, especially in developing nations. In fact, soybean and soy-products are the only
10 food available to people in some regions of the world (Bouchenak and Lamri-Senhadji, 2013).
11 Soybean seeds are a concentrated source of isoflavones that makes soybean a singular among
12 legumes. Moreover, soybeans are an excellent high quality protein source and are low in both
13 saturated fats and high in dietary fibre. Along the same lines, beans, in general, are especially
14 important for human diets mainly in developing countries because they provide an important
15 source of proteins, vitamins (folate), and minerals (Ca, Cu, Fe, Mg, Mn, Zn) (Broughton et
16 al., 2003). In first-world countries, the nutritional benefit of beans and their contribution to a
17 healthy human diet that combats diseases like cancer, diabetes, and heart disease, are
18 recognized by non-profit organizations that target human aliments (Hangen and Bennink,
19 2003). Annual production, including both dry and snap bean, exceeds 21 million (MT), which
20 represents more than half of the world's total legume food production.

21 Having these data in mind, it is clear there would be worthwhile benefits from the use
22 of PGPR as inoculants, which would constitute a biological alternative for sustainable
23 production of these crops. Table 1 shows some examples of the studies accomplished since
24 the year 2000 on PGPR applied individually or on consortia and the plants that are being dealt
25 with in this review. An exhaustive Table showing the majority of studies carried out on those

1 plants and the beneficial effects obtained on them are compiled in Supplementary data (**Table**
2 **S1**).

3

4 *3.1. Maize.*

5 Biofertilization is one of the uses of PGPR in maize. Many bacteria act like free-living
6 nitrogen-fixing PGPR such as *Burkholderia sp.*, *Azospirillum sp.*, *Azotobacter sp.*, *H.*
7 *seropedicae*, *Pseudomonas sp.* and *Bacillus sp.* (Riggs et al., 2001; Shaharoon et al., 2006;
8 Table S1). A strong increase in total plant and grain dry weight was obtained when maize
9 plants were inoculated with *Burkholderia cepacia*, *A. brasilense* and *H. seropedicae* in
10 individual experiments, in comparison to plants grown in soils without nitrogen (Riggs et al.,
11 2001). Krey et al., (2013) studied the effect of PGPR on phosphorus nutrition and they have
12 seen that field application of *P. fluorescens* DR54 on maize increased plant growth and soil P
13 pools. Since these effects were observed primarily during the P-deficient treatment, the
14 authors suggested the use of *P. fluorescens* DR54 on P poor soils and concluded that P
15 fertilizers and PGPR should be applied separately. Rosas et al., (2009) studied the promotion
16 effect of *P. aurantiaca* SR1 on maize and wheat in field treatments that included phosphorus
17 and nitrogen fertilization Both crops, when inoculated with the SR1 strain, presented
18 significant promoting effect in growth parameters and higher yields with lower fertilization
19 doses than conventionally applied.

20 Several reports suggest the role of the genera *Azospirillum*, *Achromobacter*,
21 *Burkholderia*, and *Arthrobacter* as phyto stimulator (Cassán et al., 2009). The positive effects
22 of these strains on shoot and root weight and nutrient uptake of maize plants show the
23 beneficial role of these PGPR, which might be attributed to phytohormone production, e.g.
24 IAA, and other activities like phosphorus solubilisation, or even other non-evaluated PGPR
25 traits that stimulate plant growth.

1 The bioprotective role of PGPR on maize crops has also been studied. The toxigenic
2 fungus *Fusarium* is one of the major genera associated with maize. Some PGPR such as *B.*
3 *amyloliquefaciens* and *Microbacterium oleovorans* were able to protect maize against *F.*
4 *verticillioides* when applied in the form of seed coatings (Pereira et al., 2011). Interestingly,
5 some PGPR species have appeared to promote plant growth by acting as both biofertilizer and
6 as biocontrol agents. For instances, strains of *B. cepacia* have been observed with biocontrol
7 characteristics against *Fusarium* spp., while they can also stimulate growth of maize under
8 iron-poor conditions via siderophore production (Bevivino et al., 1998).

9 10 3.2. Rice.

11 The main limiting nutrient for rice crops is nitrogen (Ladha and Reddy, 2003), and
12 only one-third of the N applied as chemical fertilizer is directly used by rice plants (Buresh et
13 al., 2008). Thus, it becomes important to find alternatives to reduce and optimize the use of N
14 fertilizers applied to rice crops; numerous reports describe the use of diazotrophic bacteria due
15 to their ability to fix atmospheric nitrogen (Araújo et al., 2013; Divan-Baldani et al., 2000;
16 García de Salomone et al., 1996), in addition to their ability to solubilise inorganic phosphate
17 or to produce IAA. Most of these diazotrophic bacteria belong to the genus *Azospirillum*,
18 although the genera *Pseudomonas*, *Burkholderia* or *Herbaspirillum* are also frequently used
19 as biofertilizers. In most cases, the application of these PGPR in field experiments showed a
20 statistically significant increase in several crop production parameters like grain production,
21 root length, leaf length or plant weight (Araújo et al., 2013).

22 Many PGPR reports consider that phytostimulation is mainly due to phytohormone
23 production by the bacteria. Thus, the genus *Burkholderia* has shown to be the most
24 widespread rice growth promoting bacteria able to produce plant hormones. Moreover, others
25 genera such as *Azospirillum*, *Bacillus*, *Paenibacillus*, *Brevundimonas*, *Serratia*,
26 *Herbaspirillum*, *Xanthomonas*, etc. enhance rice growth by phytostimulation. Most of them

1 synthesize IAA, gibberellin and ethylene. Interestingly, other PGPR abilities like nitrogen
2 fixation, phosphate solubilisation or siderophores production are usually detected. The
3 application of these PGPR in greenhouse and/or field experiments showed, in most cases, a
4 statistically significant increase in seed germination, weight and length of the plant, which
5 means a better grain production efficiency (Rashedul et al., 2009).

6 More than 70 diseases affecting rice crops have been reported as causing estimated
7 yield losses of 5 to 30%, depending on the year, zone, rice cultivar, pathogen, etc. Resistant
8 cultivars and application of pesticides have been used to avoid these yield losses; however, it
9 should be mentioned that using resistant varieties has the limitation of being particularly
10 specific for a determined pathogen and the use of pesticides is both economically and
11 environmentally costly. The three main rice pathogens *X. oryzae pv. oryzae*, *Rhizoctonia*
12 *solani* and *Magnaporthe oryzae* are responsible for bacterial leaf blight, shealt blight and blast
13 on rice plants, respectively. Most of the studies on the use of PGPR in rice biocontrol are
14 focused on treatment and prevention of these diseases (Han et al., 2005). *Bacillus* and
15 *Pseudomonas* are the predominant PGPR genera used against those pathogens, due to their
16 antagonism against growth of several fungal and bacterial microorganisms. These PGPR
17 usually produce siderophores, antibiotics, quitinases and proteases, which could be
18 responsible for the antagonism against pathogens. The yield of disease control in greenhouse
19 and field experiments is satisfactory, reducing the severity of diseases up to 90 % depending
20 on the PGPR, pathogen and rice cultivar (Filipi et al., 2011).

21

22 3.3. Wheat.

23 As it has been mentioned on maize and rice, the use of PGPR for improving crop
24 production, thus reducing the need for chemical fertilizers, is becoming a frequent strategy for
25 sustainable agriculture. For example, inoculation of the wheat seed with ACC-deaminase
26 producer *P. fluorescens* strains allowed the diminishing of N, P and K fertilizer rates

1 (Shaharoon et al., 2008) and, in general, crops presented higher grain yields, harvest index
2 and protein content with lower fertilizer doses, along with PGPR, than those conventionally
3 applied (Rosas et al., 2009).

4 Significantly enhanced yields of wheat have been obtained when consortia of PGPR
5 and AMF were applied, particularly if they exhibit different and complementary abilities.
6 Singh and Kapoor (1999) studied the effect of inoculation with the vesicular-arbuscular
7 mycorrhizal fungus *Glomus* sp.88 and two phosphate (PO_4^{3-})-solubilising microorganisms
8 (PSM), *B. circulans* and *Cladosporium herbarum*, in the presence or absence of rock
9 phosphate in a natural P-deficient sandy soil on wheat crops. The significant increase in grain
10 and straw yields due to inoculation with the consortia could be attributed to a high absorption
11 of nutrients. The effects of the application of the consortia AMF and PGPR on wheat crops
12 were investigated in a two-year experiments in different agro-climate zones of India at seven
13 locations extending from the Himalayan foothills to the Indo-Gangetic and it was seen that
14 dual inoculation of this cereal increased crop yield, grain and soil quality and the nutrient
15 uptake of wheat. In addition, it was observed that yield responses to inoculants were highest at
16 locations with previous low yields (Mäder et al., 2011).

17 Different wheat pathogens play a direct role in the destruction of natural resources in
18 agriculture. Traditional use of chemical pesticides to suppress these pathogens is currently
19 under revision due to public concern about the impact on human health and on the
20 environment. For this reason, the interest in biological control has increased recently. Diverse
21 PGPR produce anti-fungal metabolites such as DAPG (Landa et al., 2006), siderophores and
22 secretion of lytic enzymes that may reduce the growth of phytopathogens present in the
23 rhizosphere (Compant et al., 2005). Mavrodi et al. (2012) have isolated new strains of
24 *Pseudomonas* from agricultural soils, river silt, and soils from herbarium specimens that show
25 the ability to reduce disease symptoms of both *R. solani* and *Pythium ultimum*, two wheat

1 soilborne fungal pathogens, correlated with growth promotion of wheat seedlings at the same
2 time.

3 Salinity is considered one of the major limitations on crop productivity and quality in
4 the world. Around 10% of world's cropland and as much as 27% of irrigated land may
5 already be affected by salinity. Upadhyay et al. (2012) investigated the effects of two salt-
6 tolerant PGPR (*B. subtilis* and *Arthobacter* sp.) on wheat plants under different salinity
7 regimes and the results obtained demonstrated alleviation of the salinity stress effects on
8 plants treated with bacteria, above all when a combined inoculation of both PGPR was used.
9 Wheat rhizobacterial community structure is highly dynamic and influenced by different
10 factors such as wheat cultivar lineages, plant's age, soil characteristics and agronomic
11 practises (Roesti et al., 2006). These factors most likely determine changes both in the
12 rhizobacterial community and in the bacteria used as bio-inoculants. For instance, Roesti et
13 al., (2006) employed a consortia formed by a PGPR *Pseudomonas* spp and an indigenous
14 AMF to study their effect on the bacterial community structure and wheat growth. The PGPR-
15 AMF consortia significantly modified the bacterial community structure, but the loss of
16 certain bacterial species may not change the functioning of the system because other bacterial
17 species can carry out the same function, a phenomenon defined as bacterial redundancy.
18 These authors also found that changes in soils due to invading species were more buffered in
19 soils rich in microorganisms than in poor soils.

20

21 3.4. Soybean.

22 Co-inoculation studies with rhizobia and PGPR are becoming a frequent practice in
23 the development of sustainable agriculture. These experiments are focused on the
24 improvement of soybean yield production by increasing the nitrogen fixed by rhizobia. PGPR
25 tested as co-inoculants with rhizobia include *B. subtilis*, *B. thurigiensis*, *A. brasiliense*, *S.*
26 *proteomaculans*, *S. liquefaciens* and *P. aureofaciens*, and the rhizobia strains always used

1 have been *B. japonicum*. From these reports the plant-growth promoting capacities of those
2 PGPR are not described, and, in fact, the mechanism in which the non-rhizobial-PGPR is
3 involved is poorly understood. In contrast, Cassán et al., (2009) use *A. brasiliense*, which
4 produces IAA, GA₃ and zeatin, is a clear example of phytostimulation. Some authors support
5 the idea that the role of the non-rhizobial-PGPR on co-inoculant experiments is to emphasize
6 the infectivity and increase competitiveness of the rhizobial strains (Bai et al., 2002a)

7 Other studies have only used non-rhizobial PGPR species to inoculate soybean, most
8 of them endophytes isolated from roots nodules, leaves and stems and are ubiquitous in plant
9 tissues. In spite of the importance of biofertilization, most of those works are focused on
10 biocontrol. Some genera, like *Bacillus*, *Paenibacillus* and *Pseudomonas* are actively being
11 used for this purpose against plant pathogens like *R. solani*, *R. bataticola* and *Colletotrichum*
12 (Senthilkumar et al., 2009). However, it has been argued whether these biocontrol agents act
13 as antagonists in the process, or they act as producers of ISR in the soybean. Furthermore,
14 arbuscular mycorrhizal fungi such as *G. etunicatum* and *G. macrocarpum* are used for
15 rhizoremediation for metals like manganese (Mn), which in excess in the soil is toxic to
16 soybean crops (Nogueira et al., 2007).

17

18 3.5. Bean.

19 As it has been addressed on this review, one of the main problems in the crop-field is
20 the lack of nitrogen. The symbiotic association legume-*Rhizobium* is known to be the most
21 efficient system for biological N₂-fixation, and there are experiments where the co-inoculation
22 with other bacteria can increase the nodule number and improve the dry weight of roots,
23 leaves and shoots. Bacteria such as *Pseudomonas* (Grimes and Mount, 1984) or *Azospirillum*
24 clearly enhanced nodulation and N₂ fixation of beans during symbiosis with a rhizobial strain
25 (Okon and Kapulnik, 1986; Tajini et al., 2012).

1 Concerning plant pathogens control, the fungus *Trichoderma* can carry out biocontrol
2 by reducing Fe³⁺ through siderophores, and the plants can take up chelated iron by reductases
3 on the plasma membrane (Altomare et al., 1999), in addition to binding Fe, these siderophores
4 can also bind Pb, Cr, Al and actinide ions (Renshaw et al., 2002). Moreover, there are PGPR
5 of the genera *Bacillus* or *Pseudomonas* with an important role in biocontrol of bean diseases
6 such as bacterial wilt caused by *Curtobacterium flaccumfaciens* pv. *flaccumfaciens*, or root-
7 rot caused by *R. solani* respectively (Martins et al., 2013; Neeraj, 2011). Some PGPR show
8 different abilities, for instance biocontrol and biofertilization, at the same time (Table S1).
9 Thus, inoculation with *B. cepacia* SAOCV2 promotes the growth of common beans by
10 several mechanisms such as P mobilisation, increasing 44% the plant P content; and
11 promoting also antagonism towards the pathogenic species of *Fusarium*. Moreover, this result
12 is correlated with a larger number of nodules leading to an increase in N₂ fixation, and
13 indicates that the inhibition of fungal growth enhances the bacterial community in the plant
14 rhizosphere, including rhizobia (Peix et al., 2001).

15

16 **4. Conclusions and perspective.**

17 This review has focused on a heterogeneous group of microorganisms that can be
18 found in the rhizosphere. They live in association with roots and stimulate the plant growth
19 and/or reduce the incidence of plant disease. Among the numerous PGP bacteria and fungus
20 described up to now, the bacteria *Azospirillum*, *Bacillus*, and *Pseudomonas*, and the fungus
21 *Glomus* are the genera more frequently mentioned on research reports. The important role that
22 PGPR play in agriculture can be clearly deduced from the extensive research published until
23 now. The exact mechanism by which PGPR accomplish the benefits on plants is not fully
24 understood, though it is becoming clear that all or some of the PGPR traits allow them to
25 greater or lesser extent to perform their effect(s). In addition to these traits, PGPR must be
26 rhizospheric competent, i.e. able to survive in the rhizospheric soil where the microbial

1 communities can be affected by a wide range of factors, such as soil characteristics, plant type
2 or agronomic practices which determine the presence or predominance of determined types of
3 bacteria. It would be very useful to match correctly the appropriate PGPR with the right plant
4 and environmental condition to achieve the best results on plant growth. In this sense, more
5 effort should be done on the development of good inoculant delivery systems that facilitate
6 the environmental persistence of the PGPR and this fact would allow diminishing the amount
7 of chemical fertilizers and pesticides used for enhance soil fertility and crop productivity.

8

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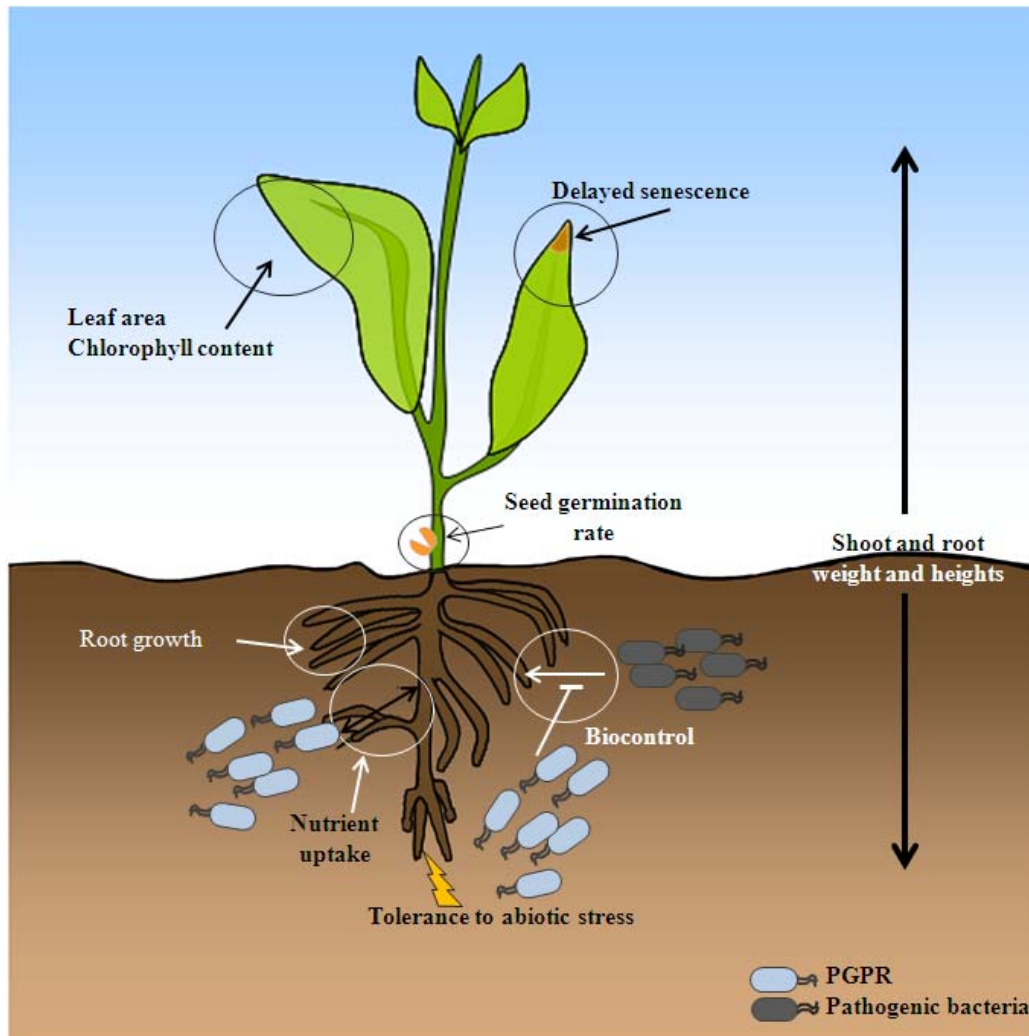
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1 **Legends to figures**

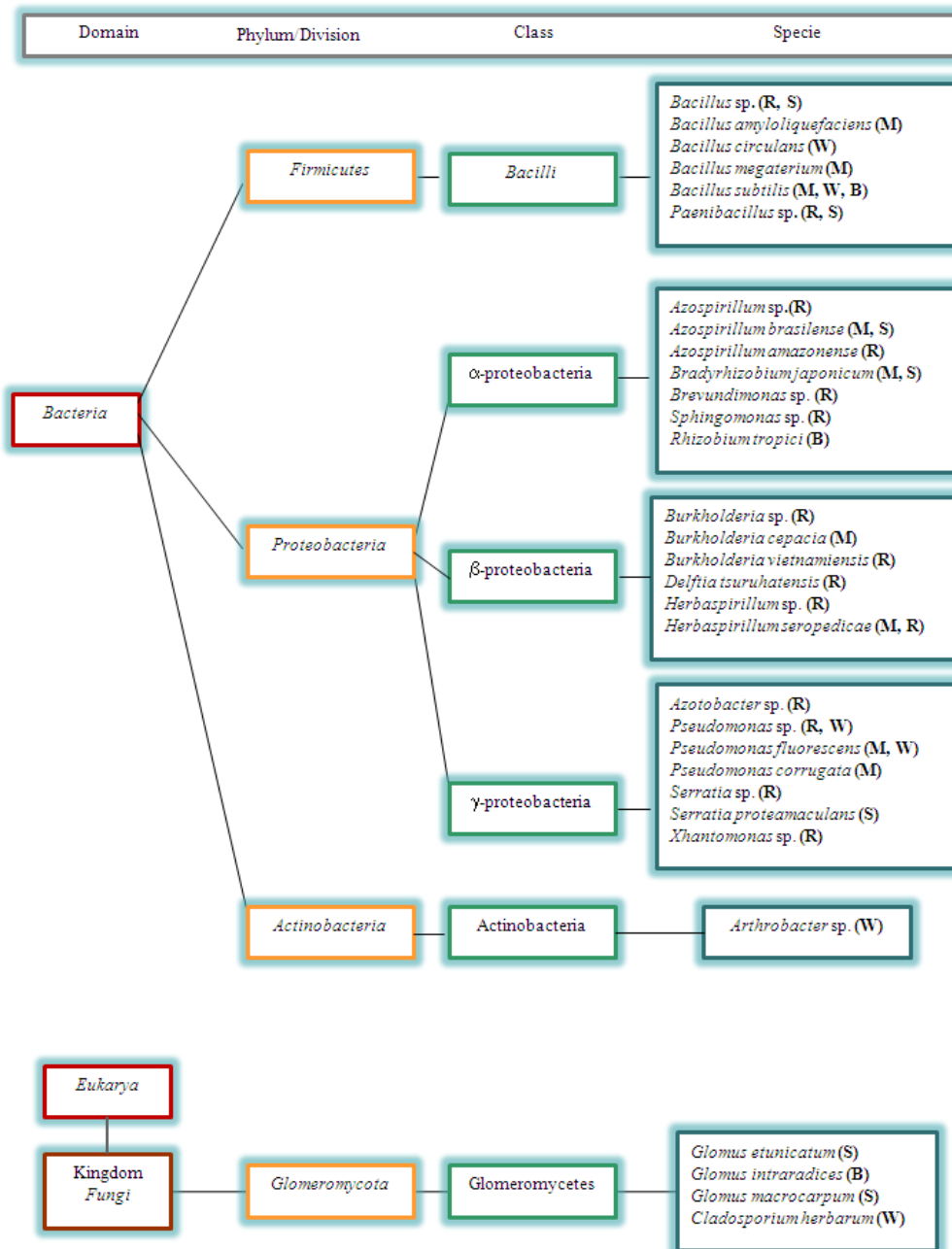
2 **Figure 1. Benefits to plants from host-PGPR interactions.** These benefits have been shown
 3 to include increase in seed germination rate, root growth, yield, leaf area, chlorophyll content,
 4 nutrient uptake, protein content, hydraulic activity, tolerance to abiotic stress, shoot and root
 5 weights and heights, bio-control, and delayed senescence.



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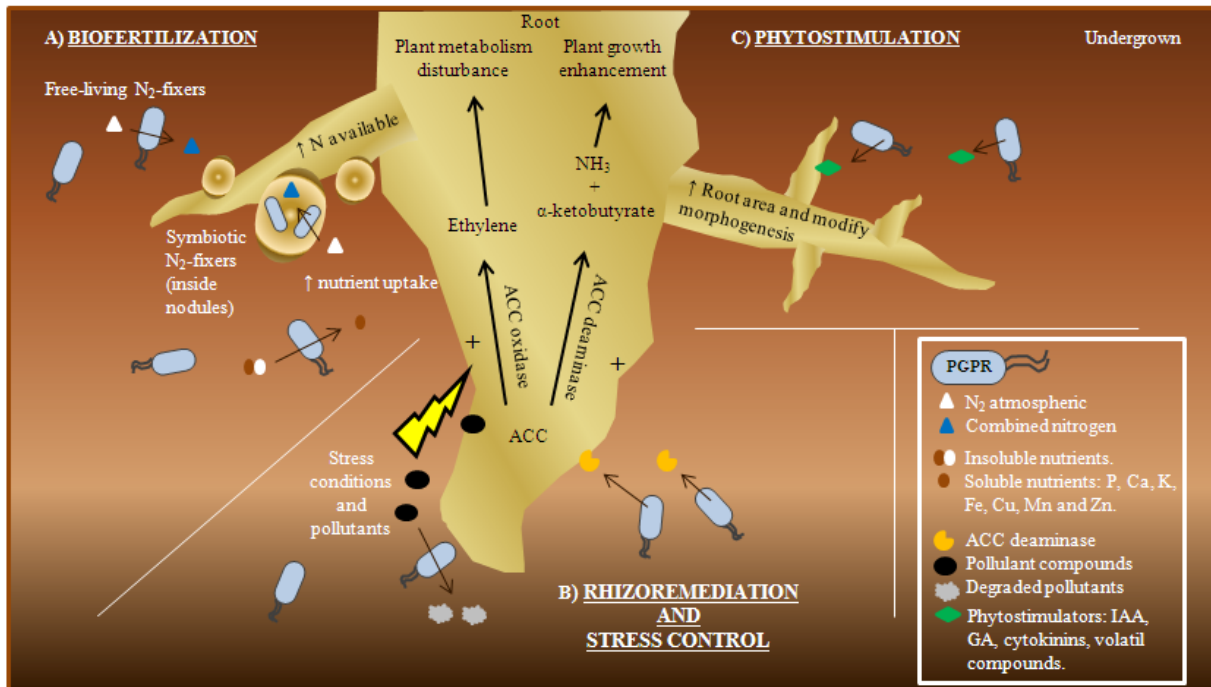
8 **Figure 2. PGPR most frequently studied, grouping according their phylogenetic**
 9 **classification.**



Plants where these microorganisms have been studied: M: maize, R: rice, W: wheat, S: soybean, B: bean

1
2
3 **Figure 3. Some forms of plant growth promotion.** A) BIOFERTILIZATION,
4 Rhizobacteria are able to promote plant growth by improving the nutrient uptake of plants.
5 Free-living and symbiotic atmospheric N₂-fixing bacteria are able to convert by means of
6 nitrogenase enzyme N₂ into ammonia, which can be used by the plant as a nitrogen source. B)
7 RHIZOREMEDIATION AND STRESS CONTROL, Plants exposed to stress conditions and
8 pollutants show an increase in the ethylene levels that lead to a metabolism disturbance and
9 plant damage. PGPR that contain the enzyme ACC-deaminase enhances plant growth and
10 development by decreasing plant ethylene levels. On the other hand, some PGPR are able to

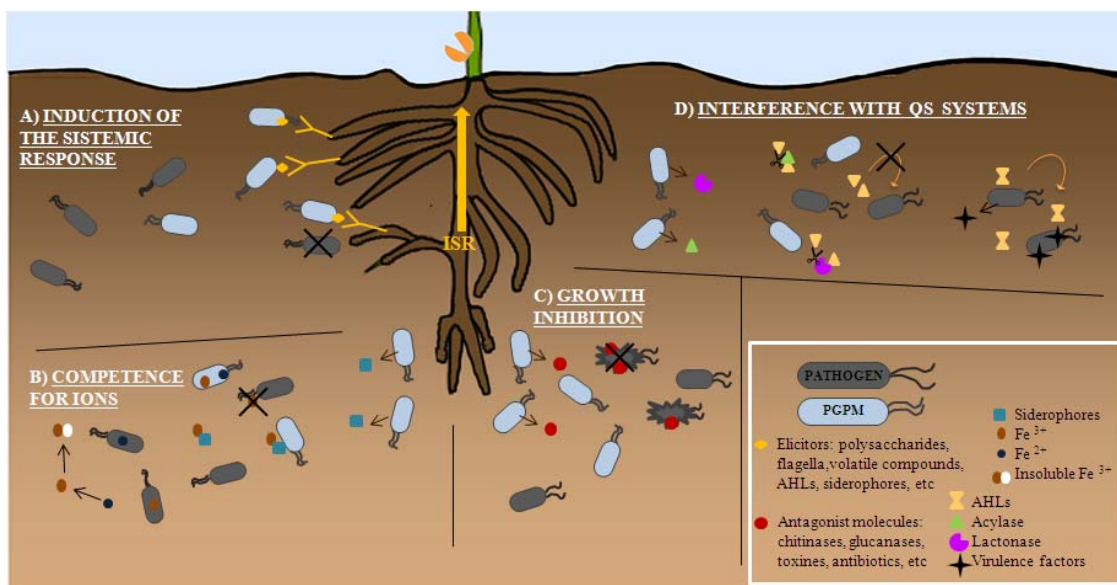
1 degrade or remove pollutants, avoiding the plant damage. C) PHYTOSTIMULATION,
 2 Production of substances like IAA, gibberellins, cytokinins and certain volatiles alter the root
 3 morphogenesis, proliferation and enhance plant mineral uptake and root exudation, which
 4 promote the plant growth.



5
 6
 7 **Figure 4. Some forms of PGPR antagonism against plant pathogens.** A) INDUCTION OF
 8 THE SISTEMIC RESPONSE, ISR is triggered by PGPR by means of molecules termed
 9 elicitors. This defence response is dependent on ethylene and jasmonic acid signalling in the
 10 plant and reduces plant disease modulating the physical and biochemical properties of host
 11 plants. B) COMPETENCE FOR IONS, In aerobic microbial habitats, Fe^{2+} is oxidized to Fe^{3+} ,
 12 which form insoluble compounds, making it unavailable to microorganisms. PGPR produce
 13 siderophores which form complexes with Fe^{3+} preventing insolubilization. In the membrane,
 14 this ion is reduced to Fe^{2+} and released into the cell. Therefore, cell pathogens would lack
 15 Fe^{2+} . C) GROWTH INHIBITION, Mechanisms responsible for antagonistic activity include
 16 inhibition of the pathogen by antibiotics, toxins, biosurfactants and by the production of
 17 extracellular cell wall degrading enzymes such as chitinase and β -1,3-glucanase. D)
 18 INTERFERENCE WITH QS SYSTEMS, QS is defined as a regulation of bacterial gene
 19 expression in response to changes in their population density, which is mediated by small
 20 diffusible signal molecules like AHLs. This system activates the synthesis of virulence factors
 21 such as biofilm formation, toxin and exopolysaccharide production, plasmid transfer and
 22 motility. Several bacteria produce acylase or lactonase, enzymes that degrade the AHL

1 molecules, thus avoiding the production of virulence factors, which are essential for the
 2 successful establishment of a pathogenic relationship with the eukaryotic hosts

3



4

1 Table1. Examples of cooperative interactions between consortia (different PGPR or bacteria and AM Fungi) tested on maize, rice, wheat, soybean and bean
2 crops.

3

Plant	Bacteria/Consortia ⁽¹⁾	PGPR abilities	Conditions	Results on plants	Reference
Maize					
	<i>Azospirillum brasilense</i> Az39 <i>Brayrhizobium japonicum</i> E109. (Individual and consortia experiments)	Phyostimulation	Growth chamber	Both strains, singly or in combination, showed the capacity to promote seed germination, nodule formation, and early development of corn and soybean seedlings.	Cassán et al., 2009
	<i>Serratia liqifaciens</i> , <i>Bacillus</i> sp. <i>Pseudomonas</i> sp. (Individual and consortia experiments)	Biofertilization (N) Biocontrol (Several root pathogens)	Greenhouse	Increase up to 14 % maize yield (dry weight) when they are inoculated as consortium respect to controls. In individual experiments, <i>S. liqifaciens</i> increase the dry weight of maize respect to controls more than 10%, <i>Bacillus</i> sp. more that 7% and <i>Pseudomonas</i> sp. more than 10 %.	Lalande et al., 1989
Rice					
	<i>P. fluorescens</i> Aur6 <i>Chryseobacterium balustinum</i> Aur9 (Individual and consortia experiments)	Biocontrol (<i>Magnaporthe grisea</i>) Salinity	Field	Three field experiments in different years. Each strain individually protects rice against rice blast, but the combination of both strains was the most effective treatment (reaching 50% of protection against disease). A relation between protection and increase in rice productivity and quality was found.	Lucas et al., 2009
Wheat					
	<i>Glomus</i> sp. 88, <i>B. circulans</i> and <i>Cladosporium herbarum</i> , (Individual and consortia experiments)	Biofertilization (P)	Pot experiment in greenhouse	The population of PO ₄ ³⁻ solubilizing microorganisms in the rhizosphere of wheat was larger in the treatments that were inoculated with the AMF fungus and Mussoorie rock phosphate.	Singh and Kapoor, 1999
	<i>Arthrobacter</i> sp. and <i>B. subtilis</i> (Individual and consortia experiments)	Stress controller (Salinity)	Pot experiment in greenhouse	Increases dry weight up to 26% when co-inoculated at 2 dS m ⁻¹ of salinity level and 40% when co-inoculated at 6 dS m ⁻¹ of salinity level.	Upadhyay et al., 2012

A natural AMF <i>P. jessenii</i> , <i>P. synxantha</i> (Individual and consortia experiments)	Biofertilization	Field	Dual inoculation of wheat with PGPR and AMF increased grain yield by 41% as compared to un-inoculated controls. Yield responses to the inoculants were highest at locations with previously low yields.	Mäder et al., 2011
<i>Providencia</i> sp. 2 strains of <i>Anabaena</i> sp. <i>Calothrix</i> sp. (consortia experiment)	Biofertilization	Growth chamber, greenhouse and field	Enhancement 18.6% protein content.	Rana et al., 2012
Soybean				
<i>S. proteamaculans</i> 1-102 <i>B. japonicum</i> 532C (Consortia experiments)	Biofertilization enhanced	Pot and pouch experiment in greenhouse	This assay is based on an inducible activator like a lipochitooligosaccharide (LCO) analogue which stimulates root nodule formation. Thus, addition of PGPR supernatant to <i>B. japonicum</i> inoculant increased nodule weight by 53,7% and plant weight by 31,2% under 25°C root zone temperature, that is at essentially the same level with co-inoculation of <i>B. japonicum</i> with the <i>S. proteamaculans</i> 1-102 culture.	Bai et al., 2002a
<i>S. proteamaculans</i> 1-102, <i>B. japonicum</i> (Consortia experiments) <i>S. liquefaciens</i> 2-68 <i>B. japonicum</i> (Consortia experiments)	Biofertilization enhanced	Field and greenhouse	The co-inoculation of PGPR at their optimal dose increased nodule number, plant dry weight and fixed nitrogen.	Bai et al., 2002b
<i>Bacillus subtilis</i> NEB4 and NEB5, <i>Bradyrhizobium japonicum</i> 532c (Consortia experiments) <i>Bacillus thuringiensis</i> NEB17, <i>Bradyrhizobium japonicum</i> 532c (Consortia experiments)	Biofertilization enhanced	Growth pouch experiment in greenhouse	Plants co-inoculated with these strains had significantly higher nodule and plants weights, and NEB5 and NEB17 seemed to increase nodule number per plant.	Bai et al., 2002c
<i>A. brasiliense</i> Az39 <i>B. japonicum</i> E109 (Consortia experiments)	Phytostimulation	Pot experiment in growth chamber	<i>A. brasiliense</i> Az39 and <i>B. japonicum</i> E109, singly or in combination, promoted seed germination, nodule formation, and early development of soybean seedlings.	Cassán et al., 2009

<i>Paenibacillus rhizosphaerae</i> TGX5E, <i>Glomus intraradices</i> (Consortia experiments) <i>P. favisporus</i> TG1R2, <i>G. intraradices</i> (Consortia experiments) <i>P. rhizosphaerae</i> TGX5E, <i>P. favisporus</i> TG1R2 <i>G. intraradices</i> (Consortia experiments)	Phytostimulation	Pot experiment in greenhouse	The frequency of mycorrhizal colonization and the extraradical mycelium increased significantly with time in plants inoculated with <i>G. intraradices</i> and both <i>Paenibacillus</i> strains. The highest dry biomass was found in soybean plants treated with <i>P. favisporus</i> , when this species was inoculated separately or in combination with <i>G. intraradices</i> .	Fernández-Bidondo et al., 2011
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Bean

<i>Rhizobium tropici</i> CIAT899 <i>A. brasilense</i> Cd (ATTCC 29729) (Consortia experiments) <i>R. etli</i> TAL182 <i>A. brasilense</i> Cd (ATTCC 29729) (Consortia experiments)	Biofertilization enhanced (N)	Growth chamber	Different results were obtained changing the concentration of <i>Rhizobium</i> and <i>Azospirillum</i> to inoculate the plants. Finally an increase in nodule number, nodule weight, root weight and shoot weight were observed when the concentration of both bacteria was 10 ⁵ and 10 ⁶ cfu/ml respectively.	Burdman et al., 1997
<i>R. tropici</i> CIAT899 <i>G. intraradices</i> (Consortia experiments)	Biofertilization enhanced (N and P)	Pot experiments in greenhouse	Plant growth parameters are enhanced as a consequence of improvement of 30-40% in the amount of P and 29-42% in N in the soil. An increase of 63-70% of nodule number, 40-43% in nodule mass, an enhancement of 23-24% shoot dry weight and 39-48% in root growth.	Tajini et al., 2012
<i>G. sinuosum</i> Gs <i>Gigaspora albida</i> Ga <i>P. fluorescens</i> (Consortia experiments)	Biofertilization (P and N) Biocontrol (<i>Rhizoctonia solani</i>)	Field	Coinoculation <i>G. sinuosum</i> + <i>P. fluorescens</i> + Mustard oil cake (MOC) and <i>G. albida</i> + <i>P. fluorescens</i> + Mustard oil cake (MOC) had an incidence disease of 12.35 and 12.72% respectively. Phosphor content was 2.26 and 2.23 mg/g dry tissue and nitrogen content was 3.42 and 3.26 mg/g dry tissue. Furthermore an increase of dry weight shoot, leaves and roots, and length of shoots and roots were observed.	Neeraj, 2011

1 ⁽¹⁾ Individual experiments mean that each bacterium has been tested separately and Consortia experiments mean that the microorganisms shown on
2 the table cells have been tested together.

3