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Review On Pseudomonas Fluorescens: A Plant Growth Promoting Rhizobacteria

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Abstract

Plant growth-promoting rhizobacteria (PGPR) are a group of microorganisms that contributes to productivity through promotion of plant growth as well as triggering of induced systemic resistance (ISR). These group of bacteria are making an important contribution to biocontrol of pests and pathogens of plants by triggering defense of plant. Fluorescent Pseudomonas belongs to PGPR that plays a major role in the induced systemic resistance, biological control of pathogens and plant growth promotion as well. Antibiotics and Siderophores released by the bacteria suppress the phytopathogens could be of significant importance. Both mechanisms help in microbial antagonism and act as elicitor for induced resistance. These rhizobacteria might be useful in formulating new inoculants, offering an alternate of ecofriendly biological control plant diseases. In this review, the characteristics of P. fluorescens, plant-growth-promoting properties, mechanisms of plant growth promotion, and induction of systemic resistance against diseases, have been reviewed.

Keyword: Antibiotics, biocontrol, induced systemic resistance, Pseudomonas fluorescens, PGPR, Siderophores

Introduction

One of the major challenges of this 21st century is to increase the agricultural production. Increase in the overuse of chemical fertilizers and pesticides also eroded the environment. Therefore, environmentally sound plant protection methods must be our primary concern. Biological control thus comes out as a nonhazardous strategy to reduce crop damage caused by plant pathogens (Weller, 1998; Cook, et al., 1995). Biologicals are an elective strategy for battling plant pathogens, and are financially accessible models. In the past two decades, studies on plant-pathogen interaction have witnessed tremendous progress (Huang, et al.2013). Plant associated microbes not only stimulates the plant growth but also involved in biotic and abiotic stress tolerance (Welbaum, et al., 2004; Jain, 2012). Success of biocontrol by Pseudomonas is due to its ability to colonize the rhizospheres' zone and their persistence in the growing season. (Van-Loon et al., 1998).

Plant growth-promoting rhizobacteria (PGPR)

Pseudomonas fluorescens is a gram-negative, aerobic, ubiquitous organism present in agricultural soils and well adapted to grow in the rhizosphere. This rhizobacteria possesses many traits to act as biocontrol agent and to promote the plant growth ability. It rapidly utilizes the root exudates, colonizes and multiplies in the rhizosphere and sperm sphere environments. Plant growth-promoting rhizobacteria (PGPR) are the rhizosphere bacteria that can enhance plant growth by different mechanisms like siderophore production, biological nitrogen fixation, phosphate solubilization, quorum sensing (QS), inhibition of biofilm formation, rhizosphere engineering, phytohormone production, exhibiting antifungal activity, induction of systemic resistance, production of volatile organic compounds, interference with pathogen toxin production etc. The efficacy of rhizobacteria in the field of agriculture is largely increased as it replaces the use of chemical fertilizers. PGPR also contributes to biocontrol of such pathogens just by triggering defense. Growth promoting substances are secreted in large quantities by these rhizobacteria. Biological control is a potential non-chemical means for plant disease management by reducing the harmful effects of a pathogen. However, the effectiveness of PGPR-triggered plant defense depends on a variety of biotic/abiotic environmental and genetic factors. The rhizosphere is a nutrient-rich habitat and harbors a wide variety of fungal and bacterial entities that each can have neutral, beneficial or deleterious effects on the plant (Berendsen, et al., 2012). These organisms can improve growth of the plant by different mechanisms (Lugtenberg and Kamilova, 2009; Van der, 2009)

The resource base in the rhizosphere is more complex (Lynch and Whipps, 1991; Loper, et al., 1984) and accordingly, the composition of the microorganisms of rhizosphere undergoes a dynamic change. Among the microbes in rhizosphere, the bacteria have received much attention. P. fluorescens have been shown as potential biocontrol agent which suppress plant diseases. P. fluorescens known to enhances plant growth and reduces severity of many fungal diseases (Hoffland, et al., 1996, Wei et al., 1996). Specific strains of Pseudomonas fluorescens and P. putida group were shown to colonize the growing roots and also cause statistically significant yield increases (Schroth and Hancock, 1982). This effect is due to the production of many secondary metabolites including siderophores, antibiotics and hydrogen cyanide (O'Sullivan and O'Gara, 1992). They are Fluorescent Pseudomonas which are significant groups of plant growth-promoting rhizobacteria reported to protect plants by evolving varied mechanisms such as competition, antagonism and systemic resistance (Kloepper, 1980, Harman, et al., 2004; Van Loon, et al., 1998; Vinale et al. 2008 and Marx, 2004). P. fluorescens and its other related species may act directly on the growth and physiological as well as nutritional status of plant they colonize. Pseudomonas fluorescens belongs to saprophytic nonpathogenic bacteria that colonize soil, water and plant surface environments. It is a gram negative, rod-shaped bacterium. It secretes a soluble greenish fluorescent pigment called fluorescein, particularly under conditions of low iron availability. Pseudomonas fluorescens has simple nutritional requirements and grows well in mineral salts media supplemented with the carbon sources (Palleroni, 1984). Pseudomonas spp. are known to produce plant hormones like cytokinins, indole-acetic acid (IAA), gibberellins and inhibitors of ethylene production, which helps in increasing the absorptive surface of roots for proper uptake of nutrients and water (Nihorimbere, et al. 2011). P. fluorescens with ACC deaminase activity (Blaha, et al., 2006) could be important for biological control as it diminishes the plant aminocyclopropane-1- carboxylic acid deaminase (ACC) left for ethylene synthesis (Glick, 2005). In the past three decades, numerous strains of fluorescent Pseudomonas have been isolated from the rhizospheric soil and from roots of the plant by several workers and their biocontrol activity against soil-borne and foliar pathogens were reported (Vivekananthan et al., 2004). The genes that were conserved among the different Pseudomonas species have provided some clues to the common characteristics of Pseudomonas, such as rhizosphere competence traits (nutrient catabolism and transport, resistance to various environmental stresses and rhizosphere colonization). Genetic changes accelerate the commercialization of PGPR as biological control agents, which could further contribute to sustainable development of agriculture (Shen, et al. 2013).

Mechanisms of bio-control agent Pseudomonas fluorescens against plant pathogens

Antagonists must have the ability to colonize the roots effectively for successful biological control (Weller, 1988; Parke, 1990) They also produces certain antagonistic secondary metabolites (Defago and Haas, 1990). These beneficial rhizobacteria suppress the growth of plant pathogens by a variety of mechanisms and production of different metabolites that include siderophores (Kloepper, et al., 1980; Leong, 1986; Schippers, et al., 1987), antibiotics (Fravel, 1988; Thamashow and Weller, 1990; Keel, et al.,1992), volatile substances such as cyanide (Voisard et al., 1989) or induced systemic resistance or ISR (van Loon et al., 1998), parasitism and lysis (Ordentich, et al., 1987; Campbell and Ephgrave, 1983).

Competition for Nutrients and Root Niches

Nutrients secreted in the rhizosphere by plants are utilized by the soil microorganism. The surface surrounding rhizosphere act as carbon sinks (Rovira, 1969) and provides many important nutrients such as H^+, water, enzymes, free oxygen ion, antimicrobials vitamins, plant growth regulators, mucilage etc. Plant roots attracts microorganisms, including pathogens, thereby creating competition for the nutrients and niches. Fluorescent Pseudomonas adapt themselves to such condition and thus become competitive with pathogens. Flagellar movement are guided through chemotactic responses and reach up to root surfaces through movement provided by flagella (De Weert, et al., 2002). P. fluorescensWCS417r strain colonizes of roots of tomato endophytically (Duijff, et al., 1998). The ability of PGPRs of colonizing the roots is related to their secretion of a a site-specific recombinase (Dekkers, et al. 1998). Bacterial lipopolysaccharides can contribute to root colonization. The O-antigenic side chain of P. fluorescens PCL1205 has been found to be involved in tomato root colonization (Dekkers, et al., 1998). Endophytic P. fluorescens strain ALEB 7B significantly inhibited the growth of Athelia rolfsii strain SY4 by secretion of lytic exo-enzymes and antibiotics (Zhou, et al., 2014).

Antibiosis

Antibiotics are low molecular-weight organic compounds of heterogeneous nature that are deleterious to the growth or metabolic activities of other microbes. The antibiotics are more effective in suppressing the growth of the pathogen in vitro as well as in situ. There are six classes of antibiotic compounds which are better associated with biocontrol of plant pathogens: Phenazines, pyoluteorin, cyclic lipopeptides, pyrrolnitrin, phloroglucinol and hydrogen cyanide (Haas and Defago, 2005). Pseudomonas being a potential biocontrol agent, shows competitive interactions with fungi, bacteria, protozoa and nematodes by producing lipopeptide bio-surfactants (de Bruijn et al., 2007; Raaijmakers, et al.,2010). The antibiotic 2, 4- diacetylphloroglucinol (DAPG) produced by Pseudomonas particularly has inhibitory action against zoospores of Pythium spp. (de souza, et al., 2003). Pseudomonas produces phenazine antibiotic, that shows antagonistic activity against Fusarium oxysporum and Gaeumannomyces gramini (ChinAwoeng et al., 2003). Antibiotic phenazine plays a vital role in mobilization of iron in soils at neutral soil pH, where iron is present in ferric form and this was proven experimentally with Pseudomonas chlororaphis PCL1391 strain isolated from rhizospheric zone of tomato (Hernandez et al., 2004; Haas and Defago, 2005). One or more genes that are responsible for biosynthesis of antibiotics have been manipulated, that shows the significance of production of antibiotic by bacterial antagonists. For example, mutant strains incapable of producing phloroglucinols (Keel, et al. 1992, Fenton, et al., 1992) and phenazines (Thomashow and Weller, 1988) have been shown to be equally capable of colonizing the rhizosphere but much less capable of suppressing soil borne root diseases than the corresponding wild-types. Phenazine and DAPG production by Pseudomonas putida WCS358r strains showed improved ability to suppress diseases in wheat (Glandorf et al., 2001; Bakker, et al., 2002).

Siderophore Production

Siderophores are iron-chelating compounds synthesized by Pseudomonas is a characteristic feature visible in some isolates from rhizosphere soils. Iron, being highly insoluble is an important micronutrient required by the microbes. A yellow-green halo can be observed in culture media with trace amounts of iron, which is fluorescent under ultraviolet light (Budzikiewicz, 1993). Iron binding ligands (siderophores) have a competitive advantage over other microorganisms. Affinity towards ferric iron depends on their structure, that is, phenolate/catecholate and hydroxymate -type structures, classified as either pseudobactins or pyoverdins (Weller et al. 2004). The ability of bacterial siderophores to suppress phytopathogens could be the significant agronomic importance (Beneduzi, et al. 2013). (Kloepper, et al., 1980) isolated first siderophore from B10 strain with the activity of disease suppression. A Tn5-induced siderophore-negative fluorescent Pseudomonas spp. strainWCS358 lost the ability to promote potato growth (Bakker, et al., 1986). Therefore, it stops the growth of harmful microbes by limiting iron availability (Loper and Buyer 1991). Interestingly, siderophore-mediated iron competition by P. fluorescens may also be useful to prevent growth of human pathogen Escherichia coli O157:H7 growing on food products (McKellar and Nelson, 2003).

HCN Production

Hydrogen cyanide (HCN) has been long known for disease suppression (Keel, et al., 1989). Fluorescent Pseudomonas produces HCN that plays a vital role in disease suppression (Laville, et al. 1992). Certain strains of fluorescent Pseudomonas are implicated for induction of resistance against diseases caused by fungi, such as Septoria tritici and Puccinia recondita f. sp. tritici on wheat (Flaishman, et al. 1996), Thielaviopsis basicola on tobacco (Laville, et al., 1992). The HCN production rate vary depending upon the species of crop may be due to difference in composition of amino acid of root exudates. HCN inhibits the terminal cytochrome c oxidases (Knowles, 1976). HCN also may have harmful effects on several plants (Schippers, et al., 1990; O'Sullivan and O'Gara, 1992). HCN-producing strains were exploited for biological control of weeds (Kremer and Souissi, 2001). HCN production by Pseudomonas spp. were known to have a negative effect on growth of lettuce and bean (Alstrom and Burns, 1989). (Siddiqui et al. 2006) reviewed the role of hydrogen cyanide in controlling tomato root knot disease. A close relationship is established between the bio-control activity of fluorescent Pseudomonas and the ability of their HCN production (Ellis, et al 2000) Positive correlations between in vitro HCN production and plant protection in the cucumber-Pythium ultimum and tomato-Fusarium oxysporum f. sp. radicis-lycopersici pathosystems (Ramatte et al. 2003).

Induced systemic resistance

Colonization of plant roots with some rhizobacteria also induces systemic resistance and thereby protecting the plants against wide array of pathogens. Development of ISR in response to an external agent makes plant immune. The mechanisms of ISR include (1) induction of cell wall reinforcement, (2) physiological tolerance, (3) growth promotion and (4) increase in production of defense enzymes, phytoalexins, proline, pathogenesis related proteins (PR) proteins, lignin deposition, antioxidants and modulation of phenols with antimicrobial and antioxidant properties (Jain, et al., 2012; Jain, et al., 2013; Jain, et al., 2015; Singh, 2014). P. aeruginosa suppressed oxalic acid production by S. sclerotiorum in pea plants alone or in combination with other microorganisms (Jain, et al., 2013). The involvement of ISR is studied in fluorescent Pseudomonas pathogen interaction (Bakker, et al., 2007). Antibiotics also plays vital role in inducing resistance in plants (Weller, et al., 2004). (Van Peer, et al., 1991) found that strain WCS417 of Pseudomonas induced resistance in carnation against wilt disease caused by Fusarium oxysporum f. sp. dianthi when the roots were inoculated with bacteria one week prior to stem inoculation with the pathogen. This strain was particularly isolated from the rhizosphere of wheat and also promoted the growth of several crops. Subsequently, these strains were shown to induce resistance in radish against F. oxysporum f. sp. raphani and other pathogens (Hoffland, et al., 1996). The O-antigenic side chain of the lipopolysaccharide of strain WCS374 and WCS417, appeared as determinant mainly responsible for induction of resistance (Leeman, et al., 1995). Pseudomonas spp. produce salicylic acid that plays a major role in SA-dependent signal transduction pathway under iron deficient conditions. Induced systemic resistance is broadly defined as activation of latent defense mechanisms in plants prior to attack of the pathogen. ISR is closely related with increased synthesis of few enzymes such as peroxidase (Langrimini and Rothstein, 1987), the accumulation of phytoalexins in the induced plant tissue (Van peer et al., 1991) and increased levels of certain acid soluble proteins (Zdor and Anderson, 1992). Seed bacterization of common bean with strain P. fluorescens S97 was reported to suppress the halo blight caused by P. syringe pv. phaseolicola through induced systemic resistance mechanism (Alstrom, 1991).

Quorum sensing (QS)

In bacteria, a major level of gene regulation involves cell-cell communication via the production of small signaling molecules. Many signal molecules that have been identified are involved in a form of regulation known as quorum sensing (QS), which allows bacteria to monitor their population density by responding to the extracellular concentration of the signal molecule they produce. This type of gene regulation is termed quorum sensing (Fuqua, et al., 1997). QS in P. fluorescens within spatially structured bacterial communities in the rhizosphere is found possible (Hense, et al., 2007). QS signaling is mainly affected by spatial distribution, cell density and mass transfer. Most common QS system is regulated by the N-acyl homoserine lactone-signaling molecules (AHLs) found mainly in gram-negative bacteria. Flagella and type IV pili mediate bacterial motility on semisolid surfaces in pseudomonads (Overhage, et al., 2008). Role of pyoverdine in bacterial motility as mutation in pvdQ which code for a cycle involved in pyoverdine biosynthesis made bacteria unable to show motility (Sio, et al., 2006).

Conclusion

Plant disease control, now become heavily dependent on fungicides to combat the wide variety of fungal diseases that threaten agricultural crops. The governments of many countries are increasingly aware of the drawbacks of many chemical pesticides, in terms of their effect on the environment, as well as on the growers and consumers of agricultural products. Studies aimed at replacing pesticides with environmentally safer methods are currently being conducted at many research centres. The heightened scientific interest in biological control of plant pathogens is partly a response to growing public concerns over chemical pesticides. Environmental concerns really have focused interest on the development of biological control agents as a safe alternative, eco-friendly management strategy for protection of the crops against pathogens. P. fluorescens is such a promising biocontrol agent against many plant pathogens. Many success reports by several scientists around the world have described different Pseudomonas strains able to significantly control a number of fungal, bacterial and nematode diseases in of several crops. However, the bacterial antagonism in combination with fungicides sometimes improved efficacy in controlling diseases. Besides disease control, treatments also improved seedling health and yields of crops. The present review contributes to future research programmes that aim to promote P. fluorescens as a potential bio-pesticide for augmentative biological control of many diseases as well as its diversified implications. However, a better understanding of the factors involved, the signalling interaction among antagonist, pathogen, soil and plants, are yet to be revealed to promote the biocontrol agents as wide applicable bio-pesticides in future.

The inconsistency in performance of these bio-control agents over time and space in comparison to chemical pesticides is a major impediment to their large-scale use in commercial agriculture. Thus, the use of biocontrol agents is being tried in a system where chemical fungicides provide a better and more economical result i.e., the bio-control agents are tried to fit in to a chemical paradigm (Harman, 2000) [30]. IAA, as IAA positively influences root growth and development, thereby enhancing nutrient uptake (Khalid, et al., 2004). Knowing that rhizospheric competence as a prerequisite of effective biological control, knowledge about cell-to-cell communication, root-microbe communication, microbe-microbe interaction, and genetic and environmental factors affecting growth will help in providing a better understanding of the mechanisms adopted.

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