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Biological Control Potential of *Pseudomonas fluorescence* in Managing Plant Diseases: A Comprehensive Review

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ABSTRACT: *Pseudomonas fluorescens* is Plant Growth Promoting Rhizobacteria that aggressively colonize the root zone and promote plant growth are generally termed as Plant Growth Promoting Rhizobacteria (PGPR). *P. fluorescens* act as biocontrol agents as well as plant growth promoter as it produces different types of secondary metabolites likes iron chelating siderophores exoenzymes, phytohermones, antibiotic which helps to adopts the plants from various diseases and stressed conditions. It also induces systemic resistance. This review was carried on mechanisms of bio-control agent *Pseudomonas fluorescens* against plant pathogens, plant-growth-promoting qualities, plant-growth-promoting methods, antibiosis through production of antibiotics and secondary metabolites, act as competition for space and nutrients and the induction of systemic resistance by plant-growth-promoting rhizobacterium (PGPR) against several plant diseases and nematode pests. The article discusses the causes of induced systemic resistance to a variety of plant pathogens that cause bacterial, viral, and fungal illnesses as well as nematode pests.

Keywords: *Pseudomonas fluorescens,* PGPR, Inoculation, Siderophore.

INTRODUCTION

Increasing agricultural production is one of the biggest challenges we face in the twenty-first century. The environment has also been eroded by an increase in the overuse of chemical fertilizers and pesticides. In order to reduce crop damage brought on by plant pathogens, the biological control measure thus emerges as a nonhazardous tactic (Weller 1998; Cook *et al.,* 1995). Biologicals are readily available models that are an optional means of combating plant diseases. Research on the relationship between plants and pathogens has advanced significantly during the previous 20 years (Huang *et al.,* 2013).

According to Shurtleff and Averre (1997), "Biological control" or "biocontrol" refers to an organism's direct or indirect involvement in limiting the spread of a pathogen and lessening the severity of disease. Microbes associated with plants play a dual role in stress tolerance, both biotic and abiotic, in addition to stimulating plant development (Welbaum *et al.,* 2004; Jain, 2012). Worldwide, plant diseases are the main reason for yield loss (Alzandi and Naguib 2019). Utilizing biocontrol agents helps to reduce the use of chemicals while increasing the likelihood of disease resistance. The use of *Pseudomonas fluorescens* as a biocontrol agent and plant growth promoter necessitates a thorough understanding of how these bacteria interact with one another and function in the rhizosphere (Kloepper *et al.,* 1989; Gotz *et al.,* 2006; Panpatte *et al.,* 2016).

Among the reported genera of Gram-negative bacteria, the Pseudomonas genus is the most significant (Gomila *et al.,* 2015). According to (Palleroni, 2008), the Pseudomonas belongs to the Order Pseudomonadales and Family Pseudomonadaceae, which are motile rods with a Gram-negative reaction that do not sporulate and contain one or more polar flagella. The excellent plant growth-promoting rhizobacteria (PGPR) *Pseudomonads fluorescence* acts as a biocontrol agent for a variety of phytopathogens and pests. In addition to its extensive use in the agricultural sector, Fig. 1 (Silby *et al.,* 2011; Scales *et al.,* 2014) clearly illustrates its numerous uses in the medical, industrial, bioremediation, environmental, and commercial sectors. By supplying minor or major phytopathogens, these bacterial biocontrol agents promote plant growth by causing the production of growth-promoting metabolites like auxins and gibberellins (Salt 1979; Fravel 2005). This review discusses bacterial antagonist-controlled in various agricultural crops as well as effects of *Pseudomonas flourescens* on growth parameters.

Mechanisms of bio-control agent *Pseudomonas fluorescens* against plant pathogens. For biological control to be effective, antagonists must be able to successfully colonize the roots (Weller 1998; Parke 1990). They also produce some toxic secondary metabolites that are antagonistic (Defago and Haas

1990). By using a variety of mechanisms and producing a variety of metabolites, such as siderophores (Kloepper *et al.,* 1980; Leong, 1986; Schippers *et al.,* 1987), antibiotics (Fravel, 1988; Thamashow and Weller 1990; Keel *et al.,* 1992), and other compounds, these helpful rhizobacteria inhibit the growth of plant pathogens.

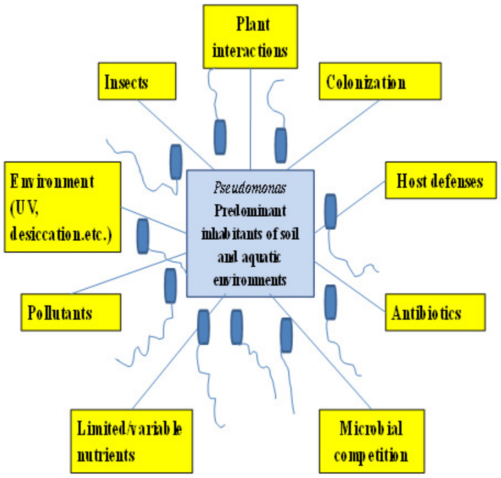

Fig. 1. Multidimensional use of *Pseudomonas* spp. in various sectors highlighting its versatility as a successful colonizer due to its various functional abilities (Source: Silby *et al.,* 2011; Scales *et al.,* 2014).

A *Pseudomonas fluorescens's* biological control mechanism, a wide variety of rhizosphere microorganisms have been described, examined, and studied recently for their potential to act as biocontrol agents against soil-borne phyto pathogens. By producing antibiotics, a variety of enzymes, side rophores, and occasionally by inducing systemic resistance that stimulates general defense in the host plants, microorganisms can limit or reduce the damage caused by phyto pathogens. Additionally, it has been discovered that the microbes serve as pathogens' competitors for vital nutrients and ecological niches (Panpatte *et al.,* 2016). The fluorescent Pseudomonas exerts its bio-controlling effects by using the following mechanisms:

Antibiosis through production of Antibiotics and secondary metabolites. Since they are simple to isolate from the soil, bacterial bio-control agents have been found to produce antibiotics and are crucial in the management of a variety of plant diseases. Numerous variables, including pH, temperature, and the concentrations of various metal ions, particularly zinc $Zn2^{+}$, can have an impact on the production of antibiotics (Duffy and Defago 1997). The potential to control soil- and seed-borne pathogenic fungi, as well as oomycetes, has drawn attention to some fluorescent pseudomonad strains (Keel *et al.,* 1992; Keel *et al.*, 1996).

Fewer *Pseudomonas* spp. biocontrol strains produce diffusible or/and volatile antibiotics that can inhibit pathogens in vitro than effective biocontrol strains (Haas *et al*., 2002). The peculiar ability of fluorescent pseudomonas to synthesize a variety of antibiotics helps to maintain plant pathogens and boosts the organism's own vigor (Mazzola *et al.,* 1992; Gaur *et al.,* 2004). However, strain-to-strain variations are also seen to exist (Raaijmakers *et al.,* 2002). A number of these antibiotics have broad-spectrum activity. Secondary metabolite development is greatly aided by the moderate rate of bacterial growth in the rhizosphere (Haas and Defago 2005).

Table 1: Volatile antibiotics released by *Pseudomonas fluorescens* that are effective against diseases.

***Pseudomonas Fluorescens* strain**	**Component**	**Pathogen/Disease controlled**	**References**
P. fluorescens LBUM636	Phenazine-1 carboxylic acid	Late blight of potato *Phytophthora infestans*	Morrison *et al.* (2016)
P. fluorescens Pf1	HCN, siderophore, pyocyanin, fluorescin	Coleus root rot *M. phaseolina*	Vanitha and Ramjegathesh (2014)
P. fluorescens Q2-87	DAPG	*P. syringae* pv. *tomato* in *Arabidopsis*	Vincent *et al.* (1991)
P. fluorescens CHA0	Pyoluteorin	Tomato crown and root rot disease	Keel *et al.* (1992)
P. fluorescens Pf-5	Pyoluteorin, pyrrolnitrin DAPG	*R. solani* and *Pythium ultimum* damping off of cotton	Howell *et al.* (1980)

Competition for space and nutrients. The plants are the main source of nutrients for the soil microbes, which rely heavily on it. The surface of the rhizosphere acts as an extraordinary carbon sink and collects a wide range of nutrients, including water, hydrogen ions, iron, oxygen, enzymes, vitamins, and other significant secondary metabolites. Because the root contains a lot of nutrients, the various types of microorganisms it draws into it compete with one another for nutrients and space.

By increasing competition for nutrients like carbon, nitrogen, oxygen, iron, or water, which hinders the ability of the fungal pathogens to disperse in the soil rhizosphere, fungal pathogens can be eliminated from the soil (Leong 1986; Loper and Buyer 1991). In these circumstances, *Pseudomonas fluorescens* can adapt and compete with the pathogens, reducing their chances of surviving (Rovira, 1969).

Therefore, it is important to evaluate the bacterium's capacity for colonizing roots, which in turn offers some defense against soil-borne pathogens. Root colonization is the process by which rhizobacteria introduced into seeds, vegetative plant parts, or soil are dispersed Iron limitation is an illustration of nutrient competition because iron is a growth factor for all organisms. In neutral and alkaline soils, there is an iron limitation. The ferrous ion can be used by *P. fluorescens* to produce siderophores. It gives an advantage over other phyto pathogens that lack effective systems for iron among roots growing in raw soil, multiply, and survive for a period of time in the presence of native soil macroflora, according to Weller *et al.* (2002).

binding and uptake. In comparison to their wild type parental strains, which were able to produce siderophores, siderophore deficient mutants were found to be less effective against phyto pathogens (Bakker *et al*., 1986).

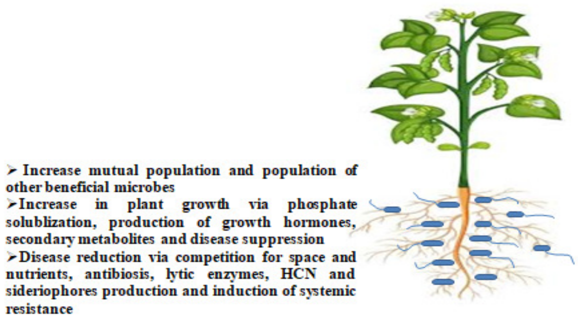

Fig. 2. *Pseudomonas fluorescens* adapting and competing with the pathogens, reducing their chances of surviving (Rovira, 1969) & Competition for space and nutrients.

Table 2: Induced systemic resistance determinants by various *Pseudomonas fluorescens* strain in different plants.

***Pseudomonas fluorescens* strain**	**Host plant**	**Pathogen/Disease controlled**	**Bacterial determinant**	**References**
P. putida WCS358 *Arabidopsis thaliana P. syringae pv. tomato*	*P. putida* WCS358 *Arabidopsis thaliana P. syringae pv. tomato*	*P. putida* WCS358 *Arabidopsis thaliana P. syringae pv. tomato*	Flagella	Meziane *et al.* (2005)
P. putida WCS358 Bean Tomato	Eucalyptus	Bacterial wilt	*Ralstonia solanacearum*	Leeman *et al.* (1995; (1996)
P. fluorescens P3 Tobacco	*P. fluorescens* P3 Tobacco	Tobacco necrosis virus(TNV)	Salicylic acid	Maurhofer *et al.* (1998)
P. putida BTP1	Bean *Botrytis cineria*	Bean *Botrytis cineria*	*N*-alkylated benzylamine derivative	Ongena *et al.* (2005)
P. aeruginosa 7NSK2	Tomato	*Botrytis cineria*	Pyocyanin Pyochelin	Audenaert *et al.* (2002)
P. aeruginosa PM12	Tomato	Fusarium wilt *Fusarium oxysporum* Schlecht. f. sp. *lycopersici*	3-hydroxy-5methoxy benzene methanol (HMB)	Fatima and Anjum (2017)

Induced Systemic Resistance. The host defense mechanism of the host plants is activated by biochemical changes caused by biocontrol agents, which confers resistance to pathogen infections (Nega, 2014; Upadhyay *et al*., 2021). Microbe associated molecular pattern (MAMP) refers to the stimulus produced by microorganisms; whereas pathogen associated molecular pattern (PAMP) refers to the stimulus produced by plants (Kohl *et al.,* 2019; Upadhyay *et al.,* 2021). According to (Van *et al.,* 1998), induced resistance is the improved defensive capacity that a plant develops in response to a specific biotic or chemical stimulus. ISR, also known as induced systemic resistance, is a generalized plant immune response that is triggered by beneficial plant bacteria that coexist with plant roots. According to research by (Nguyen *et al.,* 2020), *Pseudomonas* spp. have been shown to prime various plant species to produce ISR against different pathogens.

Table 2 lists a small number of fluorescent Pseudomonads that can cause the ISR response in plants to protect them from a variety of phytopathogen infections (Van Wees *et al.,* 1997; Kamilova *et al.,* 2005). After such a response, immunized plants exhibit defense responses that are quicker and stronger when a pathogen attacks, resulting in an improved level of protection. ISR is a mode of action of plant growth promoting rhizobacteria (PGPR), primarily of the fluorescent Pseudomonads group that aids in the suppression of diseases by inducing ISR response in the plants, as independently discovered in 1991 by Van Peer and his research team in the Netherlands (Van Peer *et al.,* 1991).

Plants may develop defense mechanisms in response to flagellum, a protein found in bacterial flagella. Flagella's role in ISR in Arabidopsis thaliana was investigated for *P. putida* strain WCS358 and it was discovered that it induced an ISR response against *P.*

Syringae tomato. According to Gomez-Gomez and Boller (2000); Zipfel *et al.* (2004); Meziane *et al.* (2005), the mutant of WCS358 that was devoid of flagella was also responsible for inducing ISR. This suggests that the mutant may have also contained other determinants that can trigger ISR in the Arabidopsis thaliana plant.

LPS from the inradish, *P. fluorescens* WCS374 strain was crucial in the ISR against the pathogen *F. oxysporum* that causes Fusarium wilt. Radish seeds were treated with strain WCS374 as a seed treatment, which reduced Fusarium wilt by an average of 42% and increased yield by an average of 45%. A study that applied isolated LPS along with the use of mutant strains that were deficient in their LPS's O-antigenic side chain offered additional proof of the involvement of LPS in ISR.

Application of LPS helped in triggering ISR in the radish plant, which helped in the significant reduction of fusarium wilt of radish (Leeman *et al.,* 1995). The mutants lacking O-antigen were unable to elicit ISR response in radish for reduction of disease incidence. In a different study on bean and tomato plants, the WCS358 strain mutant lacking the O-antigen was unable to activate the ISR in bean and tomato plants, whereas application of LPS was successful in doing so (Meziane *et al.,* 2005). The *Pseudobactin siderophore* of *P. putida* WCS358 strain was in charge of ISR in the management of bacterial wilt in eucalyptus. In contrast to the mutant lacking the pseudobactin siderophore, penetration of leaves with the bacterium WCS358 or purified pseudobactin was beneficial in reducing bacterial wilt by inducing ISR response in eucalyptus (Ran *et al.,* 2005).

Additionally, purified pseudobactin of WCS374 was found in another study to induce ISR in radish against the pathogen that causes Fusarium wilt, whereas pseudobacterium isolated from other strains was ineffective (Leeman *et al.,* 1996). When grown in the field under conditions of low iron availability, *P. putida* BTP1 is observed to induce ISR in beans to fend off *Botrytis cineria.* Nalkylated benzylamine derivative was the substance that caused the ISR response in beans to be triggered in response to *Botrytis cineria*; however, its mode of action appears to involve lipoxygenase pathway stimulation (Ongena *et al.,* 2002; Ongena *et al.,* 2004; Ongena *et al.,* 2005). Pyochelin and pyocyanin's combined action caused *P. aeruginosa* 7NSK2 to cause ISR in tomato against *Botrytis cineria*.

Pyochelin and pyocyanin together significantly suppressed *B. cineria*, indicating that both compounds are necessary for inducing ISR in mutants of 7NSK2 lacking either one of them (Audenaert *et al.,* 2002). Salicylic acid synthesis genes were extracted from the *P. aeruginosa* strain PAO1 and expressed in the *P. fluorescens* strain P3, which does not produce salicylic acid but was able to increase the ISR in tobacco against TNV (tobacco necrosis virus), indicating that salicylic acid can also induce the ISR response in tobacco against TNV (Maurhofer *et al.,* 1998). *P. aeruginosa* strain PM12 was discovered to produce the potential elicitor 3-hydroxy-5-methoxy benzene methanol (HMB), which aided in the induction of ISR in tomato plants against the pathogen responsible for Fusarium wilt.

So, potential bacterial determinants in the induction of ISR response in plants include siderophores, lipopolysaccharides, salicylic acid, pyochelin, pyocyanin, and other cell envelope components like flagella (Audenaert *et al.,* 2002).

CONCLUSIONS

In the last few years, significant progress has been made in our understanding of how *Pseudomonads fluorescens* colonizes roots and the various ways in which it can suppress soil-borne phytopathogens. In the 21st century, remarkable progress has been made in the biotechnology of *P. fluorescens* as a biocontrol agent for the defense of crops. Chemical pesticides do not need assistance for proper establishment in the soil rhizosphere, while biocontrol agents do even after application.

Therefore, in order to ensure biocontrol, it is important to consider the biocontrol agent's quality as well as how it competes with other pathogens. Future applications for *P. fluorescens* as a biocontrol agent and a plant growth promoter in sustainable management techniques are extremely promising. The main drawbacks of *P. fluorescens* in biocontrol are its short shelf life and inconsistent performance in different environments, both of which can be improved by future research efforts.

FUTURE SCOPE

Eco-friendly practices must be used in the management of agricultural practices in the current environment. The health and productivity of the soil have been threatened by anthropogenic activities. Chemicals like pesticides, insecticides, and fertilizers should not be used indiscriminately because they harm the environment and ecological balance. Our reliance on the use of chemicals in agriculture has grown too much.

In order to maintain the health of the soil and the ecological balance, we must change to sustainable farming practices. We must take into account the use of biocontrol agents for managing disease and promoting plant growth in order to practice sustainable agriculture. A PGPR that can aid in both plant growth and the control of various plant diseases is pseudomonas fluorescens. Since many years ago, it has been used in agriculture as a biofertilizer and a biocontrol agent. It has enormous potential for supplying nutrients to plants, controlling various phytopathogens, bioremediation, etc.

As a result, it has enormous potential as a substitute for agrochemicals because it is less expensive, more effective, environmentally friendly, and a good PGPR for increasing crop yield. In addition to this, it lowers input costs and pollution. Future prospects could include simple methods for reproducing organisms, extensions to shelf life, the discovery of potential biocontrol strains, and increased knowledge of the genetic, proteomic, and transcriptional up- and down-regulation that are crucial to plants' defense against a variety of biotic and abiotic stresses.

REFERENCES

Alzandi, A. A. and Naguib, D. M. (2019). *Pseudomonas fluorescens* metabolites as biopriming agent for systemic resistance induction in tomato against Fusarium wilt. *Rhizosphere, 11*, 100168.

Audenaert, K., Pattery, T., Cornelis, P. and Höfte, M. (2002). Induction of systemic resistance to Botrytis cinerea in tomato by *Pseudomonas aeruginosa* 7NSK2: role of salicylic acid, pyochelin, and pyocyanin. *Molecular Plant-Microbe Interactions*, *15*(11), 1147-1156.

Bakker, P. A. H. M., Lamers, J. G., Bakker, A. W., Marugg, J. D., Weisbeek, P. J. and Schippers, B. (1986). The role of siderophores in potato tuber yield increase by *Pseudomonas putida* in a short rotation of potato. *Netherlands Journal of Plant Pathology*, *92*(6), 249-256.

Cook, R. J., Thomashow, L. S. and Weller, D. M. (1995). Molecular mechanisms of defense by rhizobacteria against root disease. *Proceedings of the National Academy of Sciences of the United States of America, 92*(10), 4197-4201.

Defago, G. and Haas, D. (1990). Pseudomonads as antagonists of soil borne plant pathogens: mode of action and genetic analysis. *Soil Biology and Biochemistry, 6,* 249, 291.

Duffy, B. K. and Defago, G. (1997). Zinc improves biocontrol of *Fusarium* crown and root rot of tomato by *Pseudomonas fluorescens* and represses the production of pathogen metabolites inhibitory to bacterial antibiotic biosynthesis. *Phytopathology*, *87*(12), 1250-1257.

Fatima, S. and Anjum, T. (2017). Identification of a potential ISR determinant from *Pseudomonas aeruginosa* PM12 against *Fusarium* wilt in tomato. *Frontiers inplant science*, *8*, 848.

Fravel, D. R. (1988) Role of antibiosis in the biocontrol of plant diseases. Annu. Rev. *Phytopathol, 26*, 75-91.

Fravel, D. R. (2005). Commercialization and implementation of biocontrol. *Annual Review of Phytopathology*, *43*, 337-359.

Gaur, R., Shani, N., Kawaljeet, Johri, B. N., Rossi, P., and Aragno, M. (2004). Diacetylphloroglucinol-producing pseudomonads do not influence AM fungi in wheat rhizosphere. *Current Science*, *86*(3), 453-457.

Gomez-Gomez, L. and Boller, T. (2000). FLS2: an LRR receptor–like kinase involved in the perception of the bacterial elicitor flagellin in Arabidopsis. *Molecularcell*, *5*(6), 1003-1011.

Gomila, M., Peña, A., Mulet, M., Lalucat, J. and García-Valdes, E. (2015). Phylogenomics and systematics in *Pseudomonas*. *Frontiers in microbiology*, *6,* 214.

Gotz, M., Gomes, N. C., Dratwinski, A., Costa, R., Berg, G., Peixoto, R., Mendonça-Hagler, L. and Smalla, K. (2006). Survival of gfp-tagged antagonistic bacteria in the rhizosphere of tomato plants and their effects on the indigenous bacterial community. *FEMS Microbiology Ecology*, *56*(2), 207-218.

Howell, C. R. and Stipanovic, R. D. (1980). Suppression of Pythium ultimum-induced damping-off of cotton seedlings by *Pseudomonas fluorescens* and its antibiotic, pyoluteorin. *Phytopathology*, *70*(8), 712-715.

Haas, D. and Defago, G. (2005). Biological control of soilborne pathogens by fluorescent pseudomonads. *Naturereviews microbiology*, *3*(4), 307-319.

Haas, D., Keel, C. and Reimmann, C. (2002). Signal transduction in plant-beneficial rhizobacteria with biocontrol properties. *Antonie van Leeuwenhoek*, *81*(1), 385-395.

Jain, A., Singh, A., Singh, S. and Singh, H. B. (2012). Microbial consortium-induced changes in oxidative stress markers in peplants challenged with *Sclerotinia sclerotiorum*.

Kamilova, F., Validov, S., Azarova, T., Mulders, I. and Lugtenberg, B. (2005). Enrichment for enhanced competitive plant root tip colonizers selects for a new class of bio control bacteria. *Environmental Microbiology*, *7*(11), 1809-1817.

Keel, C., Schnider, U., Maurhofer, M., Voisard, C., Laville, J. and Burger, U. (1992). Suppression of root diseases by Pseudomonas fluorescens CHA0 - importance of the bacterial secondary metabolite 2,4- diacetyl phloroglucinol. *Molecular Plant Microbe Interactions, 5*, 4-13.

Keel, C., Weller, D. M., Natsch, A., Défago, G., Cook, R.J. and Thomashow, L. S. (1996). Conservation of the 2, 4-diacetylphloroglucinol biosynthesis locus among fluorescent *Pseudomonas* strains from diverse geographic locations. *Applied and Environmental Microbiology*, *62*(2), 552-563.

Kloepper, J.W., Leong, J., Teintze, M. and Schroth, M.N. (1980). Enhanced plant growth by siderophores produced by plant growth-promoting rhizobacteria. *Nature*, 286(5776), 885-886.

Kloepper, J. W., Lifshitz, R. and Zablotowicz, R. M. (1989). Free-living bacterial inocula for enhancing crop productivity. *Trends in biotechnology*, *7*(2), 39-44.

Kohl, J., Kolnaar, J. and Ravensberg, W. J. (2019). Mode of action of microbial bio control agents against plant diseases: Relevance beyond efficancy. *Frontiers ofplant science*, *10*(845), 1-19.

Leeman, M., Den Ouden, F. M., Van Pelt, J. A., Dirkx, F. P. M., Steijl, H., Bakker, P. A. H. M. and Schippers, B. (1996). Iron availability affects induction of systemic resistance to *Fusarium* wilt of radish by *Pseudomonas fluorescens*. *Phytopathology*, *86*(2), 149-155.

Leeman, M., Van Pelt, J. A., Den Ouden, F. M., Heinsbroek, M., Bakker, P. A. H. M. and Schippers, B. (1995). Induction of systemic resistance against Fusarium wilt of radish by lipopolysaccharides of *Pseudomonas fluorescens*. *Phytopathology*, *85*(9), 1021-1027.

Leong, J. (1986). Siderophores: their biochemistry and possible role in the biocontrol of plant pathogens. *Annu. Rev. Phytopathol, 24,*187-209.

Loper, J. E. and Buyer, J. S. (1991). Siderophores in microbial interactions on plant surfaces. *Mol. Plant-MicrobeInteract*, *4*(1), 5-13.

Maurhofer, M., Reimmann, C., Schmidli-Sacherer, P., Heeb, S., Haas, D. and Defago, G. (1998). Salicylic acid biosynthetic genes expressed in *Pseudomonas fluorescens* strain P3 improve the induction ofsystemic resistance in tobacco against tobacco necrosis virus. *Phytopathology*, *88*(7), 678-684.

Maurhofer, M., Reimmann, C., Schmidli-Sacherer, P., Heeb, S., Haas, D. and Défago, G. (1998). Salicylic acid biosynthetic genes expressed in *Pseudomonas fluorescens* strain P3 improve the induction of systemic resistance in tobacco against tobacco necrosis virus. *Phytopathology*, *88*(7), 678-684.

Mazzola, M., Cook, R. J., Thomashow, L.S., Weller, D. M. and Pierson, L. S. (1992). Contribution of phenazine antibiotic biosynthesis to the ecological competence of fluorescent pseudomonads in soil habitats. *Applied and environmental microbiology*, *58*(8), 2616-2624.

Meziane, H., Van Der Sluis, I., Van Loon, L. C., Höfte, M. and Bakker, P. A. (2005). Determinants of *Pseudomonas putida* WCS358 involved in inducing systemic resistance in plants. *Molecular Plant Pathology*, *6*(2), 177-185.

Morrison, C. K., Arseneault, T., Novinscak, A. and Filion, M. (2016). Phenazine-1-carboxylic acid production by *Pseudomonas fluorescens* LBUM636 alters *Phytophthora infestans* growth and late blight development. *Phytopathology*, *107*(3), 273-279.

Nega, A. (2014). Review on Concepts in Biological Control of Plant Pathogens. *Journal of Biology, Agriculture and Healthcare*, 4(10), 2224-3208.

Nguyen, N. H., Trotel-Aziz, P., Villaume, S., Rabenoelina, F., Schwarzenberg, A., Nguema-Ona, E., Clement, C., Baillieul, F. and Aziz, A. (2020). *Bacillus subtilis* and *Pseudomonas fluorescens* Trigger Common and Distinct Systemic Immune Responses in Arabidopsis thaliana Depending on the Pathogen Lifestyle. *Vaccines, 8*(3), 503.

Ongena, M., Duby, F., Rossignol, F., Fauconnier, M. L., Dommes, J. and Thonart, P. (2004). Stimulation of the lipoxygenase pathway is associated with systemic resistance induced in bean by a nonpathogenic *Pseudomonas* strain. *Molecular Plant-Microbe Interactions*, *17*(9), 1009-1018.

Ongena, M., Giger, A., Jacques, P., Dommes, J. and Thonart, P. (2002). Study of bacterial determinants involved in the induction of systemic resistance in bean by *Pseudomonas putida* BTP1. *European Journal of Plant Pathology*, *108*(3), 187-196.

Ongena, M., Jourdan, E., Schäfer, M., Kech, C. Budzikiewicz, H., Luxen, A. and Thonart, P. (2005). Isolation of an N-alkylated benzylamine derivative from *Pseudomonas putida* BTP1 as elicitor of induced systemic resistance in bean. *Molecular Plant-Microbe Interactions*, *18*(6), 562-569.

Palleroni, N. J. (2008). The road to the taxonomy of *Pseudomonas*. *Pseudomonas*. Genomics and molecular biology. *Norfolk: Caister Academic*, 1-18.

Panpatte, D. G., Jhala, Y. K., Shelat, H. N. and Vyas, R. V. (2016). *Pseudomonas fluorescens*: a promising biocontrol agent and PGPR for sustainable agriculture. In Microbial inoculants in sustainable agricultural productivity. Springer India Publishers, 257-270.

Raaijmakers, J. M., Vlami, M. and De Souza, J. T. (2002). Antibiotic production by bacterial biocontrol agents. *Antonie van leeuwenhoek*, *81*(1), 537-547.

Ramírez-Garcia, R., Gohil, N. and Singh, V. (2019). Recent advances, challenges, and opportunities in bioremediation of hazardous materials. In Phytomanagement of Polluted Sites. *Elsevier,* 517-568.

Ran, L. X., Li, Z. N., Wu, G. J., Van Loon, L. C. and Bakker, P. H. (2005). Induction of systemic resistance against bacterial wilt in *Eucalyptus urophylla* by *fluorescent Pseudomonas* spp. *European Journal of Plant Pathology*, *113*(1), 59-70.

Rovira, A. D. (1969). Plant root exudates. *The botanical review*, *35*(1), 35-57.

Salt, G. A. (1979). The increasing interest in minor pathogens. In: Schippers, B. and Gams, W. (Eds.) Soil borne plant pathogens. Academic Press, New York, 289-312.

Silby, M. W., Winstanley, C., Godfrey, S. A., Levy, S. B. and Jackson, R. W. (2011). *Pseudomonas* genomes: diverse and adaptable. *FEMS microbiology reviews*, *35*(4), 652-680.

Scales, B. S., Dickson, R. P., LiPuma, J. J. and Huffnagle, G. B. (2014). Microbiology, genomics, and clinical significance of the *Pseudomonas fluorescens* species complex, an unappreciated colonizer of humans. *Clinical microbiology reviews*, *27*(4), 927-948.

Schippers, B., Bakker, A. W. and Bakker, P. A. H. M. (1987). Interactions of deleterious and beneficial rhizosphere microorganisms and the effect of cropping practices. *Annual Review of phytopathology, 25*, 339-358.

Shurtleff, M. C. and Averre III, C. W. (1997). Glossary of plant-pathological terms. American Phytopathological Society (APS Press), USA, *137,* 371–372.

Thomashow, L. S. and Weller, D. M. (1990). Role of antibiotics and siderophores in biocontrol of take all disease of wheat. *Plant and Soil, 129*, 93-99.

Upadhyay, A. K., Bandi, S. R. and Maruthi, P. D. (2021). Bio Control Agents - Antagonistic Magicians against soil borne pathogens: *A Review. Biological Forum –An International Journal*, *13*(1), 232-242.

Vincent, M. N., Harrison, L. A., Brackin, J. M., Kovacevich, P. A., Mukerji, P., Weller, D. M. and Pierson, E. A. (1991). Genetic analysis of the antifungal activity of a soilborne *Pseudomonas aureofaciens* strain. *Applied and Environmental Microbiology*, *57*(10), 2928-2934.

Van Loon, L. C., Bakker, P. A. H. M. and Pieterse, C. M. J. (1998). Systemic resistance induced by rhizosphere bacteria. *Annual review of phytopathology*, *36*(1), 453-483.

Van Peer, R., Niemann, G. J. and Schippers, B. (1991). Induced resistance and phytoalexin accumulation in biological control of Fusarium wilt of carnation by *Pseudomonas* sp. strain WCS 417 r. *Phytopathology*, *81*(7), 728-734.

Van Wees, S. C., Pieterse, C. M., Trijssenaar, A., Van't Westende, Y. A., Hartog, F. and Van Loon, L. C. (1997). Differential induction of systemic resistance in Arabidopsis by bio control bacteria. *Molecular plant micro beinter actions*, *10*(6), 716-724.

Vanitha, S. and Ramjegathesh, R. (2014). Bio control potential of *Pseudomonas fluorescens* against coleus root rot disease. *Journal of Plant Pathology &Microbiology*, *5*(1), 1000216.

Weller, D. (1998). Biological control of soil borne plant pathogens in the rhizosphere with bacteria. *Annual Review of Phytopathology, 261,* 379-407.

Weller, D. M., Raaijmakers, J. M., Gardener, B. B. M. and Thomashow, L. S. (2002). Microbial populations responsible for specific soil suppressiveness to plant pathogens. *Annual review of phytopathology*, *40*(1), 309-348.

Welbaum, G. E., Sturz, A. V., Dong, Z. and Nowak, J. (2004). Managing soil microorganisms to improve productivity of agroecosystems. *Critical Reviews in Plant Sciences, 23*(2), 175-193.

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