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Review Paper

Pseudomonads: Potential Biocontrol agents of Rice Diseases

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Abstract

Biocontrol mechanism to suppress fungal and bacterial pathogens of rice cropby Pseudomonas sp. *generally involves the production of antibiotics, siderophores, volatile compounds, hydrocyanic acid (HCN), enzymes and phytohormones. Rice is the staple food of over half of the world population. Diseases are the most important factors that affect rice production causing annual yield losses. Biological control is an eco-friendly, cost effective and sustainable alternative method in disease management.*

Keywords: Biocontrol, fungal and bacterial pathogen, Pseudomonas.

Introduction

Sustainable agriculture depends on the use of chemical fungicides, pesticides, herbicides and fertilizers. Repeated use of these chemicals is causing severe concern from the health and environmental point of view. In view of these the development of biologically based control method of diseases is now viewed not only asan eco-friendly but also sustainable agriculture. Research on biological control of rice diseases started mainly in the 1980. It is mainly concentrated on the identification, evaluation and formulation of potential biocontrol agents for deployment.Rice (*Oryza sativa* L.) is the most widely cultivated food crop in the world. Global rice production was 468.1M.T (million tons) during the year 2010 and it rose to a record 480 M.T in 2011. According to Agriculture ministry, India harvested a record 103.41 M.T of rice in the 2011-2012 crop years (July-June) as against 95.98M.Tin the previous year[1]. More than 90% of rice produced in Asia,where China and India being the lead producer[2]. Diseases are the significant limiting factors that affect rice production causing annual yield losses conservatively estimated 5%[3]. More than 70 diseases are caused by fungi,bacteria, viruses or nematodes on rice among which rice blast (*Magnaporthe grisea*) is the most serious one[4].

Table-1
List of rice diseases: (Fungal and Bacterial)[5,6]

FUNGAL	
Aggregate sheath spot *Ceratobasidium oryzae-sativae* Gunnel and Webster (anamorph: *Rhizoctonia oryzae-sativae* (Sawada) Mordue	Narrow brown leaf spot *Cercospora janseana* (Racib) O.Const. = *C.oryzae Miyake* (telemorph: *Sphaerulina oryzina* K.Hara)
Black kernel *Curvularia lunata* (Wakk) Boedijn (telemorph: *Cochliobolus lunatus*R. R.Nelson &Haasis)	Peckey rice (Kernel spotting) Damage by many fungi including *Cochliobolus miyabeanus* (Ito and Kuribayashi) Drechs. ex Dastur, *Curvularia* sp., *Fusarium* sp. *Microdochium oryzae* (Hashioka and Yokogi) Samuels and I.C. Halett, *Sarocladium oryzae* (Sawada) W. Gams and D. Hawksworth
Blast (leaf, neck [rotten neck], nodal and collar *Pyricularia grisea* Sacc. = *P.oryzae* Cavara (teleomorph: *Magnaporthe grisea* (Hebert) Barr)	Root rots *Fusarium* sp. *Pythium* sp. *P.dissotocum* Drechs. *P.spinosum* Sawada
Brown spot *Cochliobolus miyabeanus* (Ito and Kuribayashi) Drechs. ex Dastur (anamorph: *Bipolaris oryzae* (Breda de	Seedling blight *Cochlio bolus miyabeanus* (Ito and Kuribayashi) Drechs.ex Dastur, *Curvularia spp.,Fusarium spp.,Rhizoctonia solani*

Haan)Shoemaker	Kuhn,*Sclerotium rolfsii* Sacc.(teleomorph: *Athelia rolfsii* (Curzi) Tu and Kimbrough)
Crown sheath rot *Gaeumannomyces graminis* (Sacc) Arx and D.Olivier	Sheath blight *Thanatephorus cucumeris* (A.B.Frank) Donk (anamorph: *Rhizoctonia solani* Kuhn)
Downy mildew *Sclerophthora macrospora* (Sacc) Thirumalachar *et al.*	Sheath spot Rhizoctonia oryzae Ryker and Gooch
Eye spot *Drechslera gigantea* (Heald and F.A.Wolf) Ito	Sheath rot *Sarocladium oryzae* (Sawada) W. Gams and D. Hawksworth=*Acrocylindrium oryzae* Sawada
False smut *Ustilaginoidea virens* (Cooke) Takah.	Stackburn (Alternaria leaf spot) *Alternaria padwickii* (Ganguli) M.B.Ellis
Kernel smut *Tilletia barclayana* (Bref.)Sacc. and Syd. in Sacc. =*Neovossia horrida* (Takah) Padwick and A. Khan	Stem rot *Magnaporthe salvinii* (Cattaneo) R. Krause and Webster (synamorphs: *Sclerotium oryzae* Cattaneo, *Nakataea sigmoidae* (Cavara) K.Hara)
Leaf smut *Entyloma oryzae* Syd. and P.Syd.	Water-mold(seed-rot and seedling disease) *Achlya conspicua* Coker *A.klebsiana* Pieters *Fusarium spp*. *Pythium spp.* *P.dissotocum* Drechs *P.spinosum* Sawada
Leaf scald *Microdochium oryzae* (Hashioka and Yokogi) Samuels and aI.C.Hallett= *Rhynchosporium oryzae* Hashioka & Yokogi	Black sheath spot *Curvularia fallax* B.D.Gao et al.
BACTERIAL	
Bacterial blight *Xanthomonas oryzae* pv. *Oryzae* (Ishiyama)Swings et al. =*X.campestris* pv.*oryzae* (Ishiyama) Dye	Grain rot *Pseudomonas glumae* Kurita and Tabei
Bacterial leaf streak *Xanthomonas oryzae* pv. *oryzicola*(Ishiyama) Swings et al.	Sheath brown rot *Pseudomonas fuscovaginae* (ex Tanii et al.) Miyajima et al.
Foot rot *Erwinia chrysanthemi* Burkholder et al.	

*Pseudomonas*isa genus of gammaproteobacteria belonging to the family Pseudomonadaceae and is gram negative rod shaped having one or more flagella, motile, non-spore forming aerobicsome strains also have anaerobic respiration with nitrate as the terminal electron acceptor and 58-69% GC content[7]. It is a very large and important family of gram negative bacteria and is chemoheterotrophic with versatile function predominantly present in soil. They have the ability to colonize rhizosphere of a wide variety of crops including cereals, pulses, oilseeds and vegetables[8,9] and can be used as plant growth promoters and biocontrol agents[10-12]. The genus Pseudomonas includes both fluorescent and non-fluorescent species. The fluorescent species produce water soluble yellow green pigments and fluorescence under low wave length UV radiation[13]. Although some Pseudomonads are well known plant pathogen (*Pseudomonas syringae)* but some members of this group are beneficial to plants. They are known to produce secondary metabolites like siderophores, antibiotics, HCN etc[14] and enzymes like proteases and gluconases[15,16] which made them the most promising group of plant growth promoting rhizobacteria involved in the biocontrol of plant diseases[17-19]. Bacterial antagonists have twin advantage of faster multiplication and higher rhizosphere competence hence *Pseudomonas fluorescens* has successfully used for biological control of several plant pathogens[20] and its application as biocontrol agents has drawn wide attention because of the production of secondary metabolites such as siderophores, antibiotics, volatile compounds, HCN, enzymes and phytohormones[21,22].

Table-2
Pseudomonas as a biocontrol agent for major rice diseases

Disease	Pathogen (Causal agent)	Biological control agent developed	Reference
Blast (Bl)	*Pyricularia oryzae (Telimorph: Magnaporthe grisea)*	*Pseudomonas fluuorescens*	23, 24,25
Sheath blight(ShB)	*Rhizoctonia solani (Telimorph:Thanetophorus cucumeris)*	*Pseudomonas fluuorescens Pseudomonasputida*	26,27,28, 29
Sheath-rot(Sh-R)	*Sarocladium oryzae*	*Pseudomonas fluuorescens*	30,31,32
Bacterial Blight (BB)	*Xanthomonas oryzae pv.oryzae*	*Pseudomonas fluuorescens*	33,34,35

Mechanism of Pathogen Suppression

Antibiotic mediated suppression: *Pseudomonas fluorescens* has a gene cluster that produces antibiotics including compounds such as 2, 4-diacetylphloroglucinol (DAPG), phenazine, pyrrolnitrin, pyoluteorin and biosurfactant antibiotics[36]. *Pseudomonas fluorescens* is uniquely capable of synthesizing many of these antibiotics not only to enhance its own fitness but also to help in the maintenance of soil health and bioprotection of crop from pathogens[37,38]. Strains of plant associated Pseudomonas *Pseudomonas fluorescens* produce DAPG and was detected by PCR–based screening method that used primers Phl2a and Phl2b and amplified 745-bp fragment characteristics of DAPG. HPLC, 1H NMR and IR analysis provided further evidence for its production and showed that compound (DAPG) suppress the growth of *Xanthomonas oryzae*pv. *Oryzae*a causal agent of the bacterial blight of rice in vitro assay suppress up to 59%-64% in net house and in vivoi.e.in field experiments[39,40]. *P.aeruginosa* (PUPa3) isolated from rhizospheric soil of rice produce Phenazine-1-Carboxamide (PCN) control rice disease caused by *Sarocladium oryzae* and *Rhizoctonia solani*[41]. Phenazine-1-Carboxylic acid (PCA) produced by *P.fluorescens* suppress the leaf and neck blast of rice[42]. *Sarocladium oryzae* (Sawada) the causative agent of rice sheath rot is highly sensitive to *P.fluorescens*due to the production of antibiotics[43-48].

HCN mediated suppression: Hydrocyanic acid production plays a major role in suppression of the growth of phytopathogen. HCN inhibits the electron transport thereby the energy supply to the cell is disrupted leading to the death of the organism. It inhibits the proper functioning of enzymes and natural receptors by reversible mechanism of inhibition[49]. It is also known to inhibit the action of cytochrome oxidase[50]. HCN is a volatile compound which on interaction with fungi can easily degrade its cell wall[51,52] presented evidence that HCN is involved in biological control by *Pseudomonas fluorescens* strain CHAO. HCN production by *Pseudomonas* isolated from Potato and wheat rhizosphere[53]. Plant associated *Pseudomonas fluorescens* produce HCN, a broad-spectrum antimicrobial compound involved in the biological control of root diseases where HCN synthase is encoded by three biosynthetic genes hcnA, hcnB and hcnC[54].

Siderophores mediated suppression: Siderophores are iron binding extracellular compound with low molecular weight and high affinity for ferric iron that are secreted by microorganisms to take up iron from the environment[55]. The ability of sequester iron provides a competitive advantage to microorganisms. Siderophore chelate ferric ions with a high specific activity and serves as vehicles for the transport of ferric iron in to the microbial cell[56]. Transport of iron in to the cell is mediated by a membrane receptor that specifically recognizes ferric-siderophore complex[57]. Since iron is an essential element and a cofactor in various oxidoreductive enzymatic reaction binding of this element to siderophore create an artificial deficiency in the soil and their mode of action in suppression of disease were thought to be solely based on competition for iron with the pathogen[58,59]. Fluorescent Pseudomonads are characterized by the production of yellow-green pigments termed pyoverdines which fluoresce under UV light and function as siderophores[60]. The role of siderophores produced by fluorescent Pseudomonas in plant growth promotion was first reported by Kloepper J.W. and Schroth M.N.[61] and was later reported to be implicated in the suppression of plant pathogens[62,63]. Competition for iron between pathogens and siderophores of fluorescent pseudomonas has been implicated in the biocontrol of wilt diseases caused by *Fusarium oxyporum*[64,65]. Pyoverdines chelate iron in the rhizosphere and deprive pathogens of iron which is required for (Pseudobactin and ferrooxamine B) that chelate the scarcely available iron and thereby prevent pathogens from acquiring iron[66]. Siderophore production by plant growth promoting fluorescent *Pseudomonas* sp.RB13 was effective against several fungal and bacterial pathogens[67]. Siderophore mutant of fluorescent Pseudomonas have been used to elucidate the role of siderophores in biocontrol. Mutants were obtained by exposure to UV[68]. NTG and Tn5 transposon mutagenesis[69-71] were compared with their wild types with respect to the suppression of diseases. The wild type strains were more effective in suppressing the diseases than Sid-mutants.Similarly the wild strain of *Pseudomonas putida* significantly suppressed chlamydospore of *Fusarium oxysporum*[72] whereas the sid mutant fails to do so.Several strains of siderophore producing *P.fluorescens* have been shown to inhibit *Fusarium oxysporum, Rhizoctonia solani* and *Acrocladium oryzae*[73]. Siderophores produced by Pseudomonas showed good antifungal activity against plant deletorius fungi, viz. *Aspergillus niger, A.flavus, A.oryzae, F.oxysporum* and *Sclerotium rolfsii*[74]. The iron concentration in soil was lowered by the addition of an iron chelator[75]. Fluorescent pseudomonas when grown on casamino acid medium under iron deficiency trihydroxamate type pyoviridines forming hexadentate ligands with Fe^{3+} ions were found and these siderophores were antagonistic to fungal pathogens like *Fusarium oxysporum .Alternaria* and *Colletotrichum capsici*[76]. Recently,the pseudobactin siderophore of *P.fluorescens* WCS374r was found to be an important determinant of ISR against blast disease of rice[77].

Enzymes and phytohormones mediated suppression: Chitinase, P-1,3 gluconase and cellulase are especially important fungus controlling enzymes due to their ability to degrade the fungal cell wall components such as chitin,P1,3 glucan and glucosidic bonds[78-80]. *Pseudomonas fluorescens* produce chitinase which involved in lysis and fragmentation of fungal cell wall and suppression of phytopathogenic fungi[81]. Chitinase excreting microorganisms have been reported as efficient biocontrol agents[82-84]. Fluorescent Pseudomonas produce plant growth promoting hormones and enzymes which suppress the growth of phytopathogenic fungi[85,86]. *Pseudomonas fluorescens* (AUPF25) produce protease, IAA and siderophore showed inhibition of mycellial growth of *Pyricularia oryzae* a causal organisms of blast disease of rice[87] .

Conclusion

Chemical pesticides harm the environment and host-plant resistant,which is based on a single gene,may not be durable in the field leading to frequent resistance breakdowns.It is imperative to develop environment-friendly and sustainable control strategies.Biological control is an ecology-conscious, cost effective and sustainable alternative method in disease management. As reported by many researchers that Pseudomonas produce different antibiotics which suppress the rice disease causing pathogens it is important to find out these antibiotics are active against other diseases of rice or not. There is need to investigate the function of HCN, Siderophores ,enzymes and phytohormones produced by Pseudomonads in rhizospheric soil of rice field and their biocontrol against rice diseases as these are the most important compounds which inhibits the rice disease causing pathogens.

References

1. Rice Production, World rice output rises to record 480 million tonnes in 2011, The Economic Times, New Delhi, India, June 6 **(2012)**
2. Kumar K.V.K., Reddy M.S., Kloepper J.W., Lawrence K.S., Zhou X.G., Groth D.E., Zhang S., Sudhakara Rao R.,Wang Q., Raju M.R.B., Krishnam Raju S., Fernando W.G.D., Sudini H., Du B. and Miller M.E., Commercial Potential of Microbial Inoculants for Sheath Blight Management and Yield Enhancement of Rice, In: Bacteria in Agrobiology : Crop Ecosystem,Maheshwari D.K. (Ed), 237-264 doi: 10.1007/978-3-642-18357-7-9 **(2011)**
3. Song F. and Goodman R.M., Molecular biology of disease resistance in rice, *Physiol.Mol.Plant Pathol.*, **59**, 1-11 **(2001)**
4. Manandhar H.K., Lyngs Jorgensen H.J., Mathur S.B. and Smedegaard-Peterson V., Suppression of rice blast by preinoculation with avirulent *Pyricularia oryzae* and the nonrice pathogen*Bipolaris sorokiniana*, *Phytopathol.*, **88**, 735-739 **(1998)**
5. Hollier C.A., Groth D.E., Rush M.C.,Webster R.K. and Collators, Diseases of Rice (*Oryza sativa* L.), Common names of plant diseases, *The American Phytopathological Society,* www.apsnet.org, last update April 7**(1993)**
6. Gao B.D., Huang W. and Xia H., A New Rice Disease, Black Sheath Spot, Caused by *Curvularia fallax* in China, *The American Phytopathological Society*, **96(8)**, 1224.2 **(2012)**, doi.org:10.1094/PDIS-01-12-0021-PDN **(2012)**
7. Palleroni N.J., The road to the taxonomy of Pseudomonas, In Pseudomonas : Genomics and Molecular Biology, Cornelis P.(Ed), Caister Academic Press,1-18 **(2008)**
8. Johri B.N., Rao C.V.S. and Goel R., Fluorescent pseudomonas in plant disease management. In: Biotechnological Approaches in Soil Microorganisms for Sustainable Crop Production, Dadarwal R.(Ed),Scientific publishers, Jodhpur, 193-221**(1997)**
9. Megha Y.J., Alagawadi A.R. and Krishnaraj P.U., Multiple Beneficial Functions of Fluorescent Pseudomonads of Western Ghats of Uttar Kannada District, *Karnataka J.Agric.Sci.,* **20(2)**, 305-309 **(2007)**
10. Reinhold-Hurek B., Hurek T., Gillis M., Hoste B., Vancanneyt M., Kersters K. and Peley J., *Azoarcus* gen.nov., nitrogen-fixing proteobacteria associated with roots of Kallar grass (*Leptochloafusca* (L.) Kunth) and description of two species,*Azoarcus indigens* sp.nov. and *Azoarcus communis* sp. nov*., Int. J. Syst. Bacteriol.*, **43**,573-584 **(1993)**
11. Betelho G.R., Guimaraes V., De Bonis M., Fonseca M.E.F., Hagler A.N. and Hagler L.C.M., Ecology of plant growth promoting strain of *Pseudomonas fluorescens* colonizing the maize endosphere in tropical soil, *World J.Microbiol.Biotechnol.,* **14**, 499-504 **(1998)**
12. Naureen Z., Yasmin S., Hameed S., Malik K.A. and Hafeez F.Y.,Characterization of screening of plant growth promoting bacteria isolated from maize grown in Pakistani and Indonesian soil., *J.Basic Microbiol.,***45**, 447-459 **(2005)**
13. Holt J.G., Krieg N.R., Sneath P.H.A., Staley J.T. and Williams S.T.,Genus Pseudomonas,In: Bergey's manual of determinative bacteriology, Holt J.G., Krieg N.R., Sneath P.H.A., Staley J.T. and Williams S.T.(Eds),Williams & Wilkins, 93-94 **(1994)**
14. Sindhu S.S., Suneja S. and Dadarwal K.R., Plant growth promoting rhizobacteria and their role in crop productivity. In: Biotechnological Approaches in soil microorganisms for sustainable crop production, Dadarwal R.(Ed), Scientific publishers, Jodhpur, 149-191 **(1997)**

15. Jensen S.E., Phillippe L., Teng Tseng J., Stemke G.W. and Camphell J.N., Purification and characterization of extrecellular proteases produced by a clinical isolate and a laboratory strain of *Pseudomonas aeruginosa*, *Canadian Journal of Microbiology*, **26**, 77-86 **(1980)**

16. Hamamoto T., Kaneda M., Horikoshi K. and Kudo T., Characterization of a protease from a psychrotroph, *Pseudomonas fluorescens* 114, *Applied and Environmental Microbiology,***60**, 3878-3880 **(1994)**

17. Kloepper J.W., Leong J., Teintze M. and Schroth M.N., Pseudomonas siderophores: A mechanism explaining disease suppressive soils, *Current Microbiology*, **4**, 317-320 **(1980)**

18. Sulsow T.V. and Schroth M.N. Rhizobacteria of sugar beets: effects of seed application and root colonization on yield , *Phytopathol*., **72**, 199-206 **(1982)**

19. Gupta C.P., Dubey R.C., Kang S.C. and Maheshwari D.K., Antibiosis mediated necrotropic effect of *Pseudomonas* GRC2 against two fungal pathogens, *Current Science,* **81**, 91-94 **(2001)**

20. Ramamoorthy V., Raguchander T and Samiyappan R., Enhancing resistence of tomato and hot pepper to *Pythium* diseases by seed treatment with fluorescent pseudomonads, *European J.Pl.Pathol.,***108**, 429-442 **(2002)**

21. Weller D.M., Raaijmakers J.M., Mc. Spadden Gardener B.B. and Thomashow L.S., Microbial populations responsible for specific soil suppressiveness to plant pathpgens, *Annu.Rev. Phytopathol.*, **40**, 309-348 **(2002)**

22. Nagarajkumar M., Bhaskaran R. and Velazhahan R., Involvement of secondary metabolites and extracellular lytic enzymes produced by *Pseudomonas fluorescens* in inhibition of *Rhizoctonia solani,* the rice sheath blight pathogen, *Microbiology Research*, **159(1)**, 73-81**(2004)**

23. Gnanamanickam S.S. and Mew T.W., Biological control of blast disease of rice (*Oryza sativa* L.) with antagonistic bacteria and its mediation by a *Pseudomonas* antibiotic , *Annals of the Phytopathological Society of Japan* **58(1)**, 380-385 **(1992)**

24. Valasubramanian R., Biological control of rice blast with *Pseudomonas fluorescens* Migula: Role of antifungal antibiotics in disease suppression, Ph.D. dissertation, University of Madras **(2004)**

25. Kavitha S., Strategies for management of rice blast and sheath blight with bacterial biocontrol agents in combination with major genes for disease resistance , Ph.D. dissertation, University of Madras **(2002)**

26. Vasantha D.T., Malar V.R., Sakthivel N. and Gnanamanickam S.S., Biological control of sheath blight of rice in India with antagonistic bacteria, *Plant soil*, **119**, 325-330 **(1989)**

27. Thara K.V., Biological control of rice sheath blight by bacterial antagonists: Mechanisms of disease suppression, Ph. D. dissertation, University of Madras **(1994)**

28. Krishnamurty K. and Gnanamanickam S.S., Biological control of rice blast by *Pseudomonas fluorescens* strain 7-14: Evaluation of a marker gene and formulations, *Biological Control*, **13**, 158-165 **(1998)**

29. Kavitha S., Strategies for management of rice blast and sheath blight with bacterial biocontrol agents in combination with major genes for disease resistance , Ph.D. dissertation, University of Madras **(2002)**

30. Sakthivel N., Biological control of Sarocladium oryzae (Sawada) Gams & Hawksworth, sheath-rot pathogen of rice by bacterization with *Pseudomonas fluorescens* Migula, Ph.D.dissertation, University of Madras **(1987)**

31. Sakthivel N. and Gnanamanickam S.S., Evaluation of *Pseudomonas fluorescens* for suppression of sheath- rot disease and enhancement of grain yields in rice, *Oryza sativa* L.*, Applied and Environmental Microbiology,* **53**, 2056-2059 **(1987)**

32. Sakthivel N. and Gnanamanickam S.S., Incidence of different biovars of *Pseudomonas fluorescens* in flooded rice rhizospheres in India, *Agriculture, Ecosystems and Environment,* **25**, 287-298 **(1989)**

33. Vasudevan P., Isolation and characterization of *Bacillus* sp. from the rice rhizosphere and their role in biological control of bacterial blight of rice caused by *Xanthomonas oryzae* pv.*oryzae*.Ph.D. dissertation, University if Madras **(2002)**

34. Velusamy P. and Gnanamanickam S.S., Identification of 2,4-diacetylphloglucinol (DAPG) production by plant-associated bacteria and its role in suppression of rice bacterial blight in India, *Current Science*, **85**, 1270-1273 **(2003)**

35. Velusamy P., Immanuel J.E., Gnanamanickam S.S. and Thomashow L.S., Biological control of rice bacterial blight by plant-associated bacteria producing 2,4-diacetylphloroglucinol , *Canadian Journal of Microbiology*, **52**, 56-65 **(2006)**

36. Angayarkanni T., Kamalakannan A., Santhini E. and Predeepa D., Identification of biochemical markers for the selection of *Pseudomonas fluorescens* against *Pythium* spp. In: Asian Conference on Emerging Trends in Plant-Microbial Interactions, University of Madras, 295-303 **(2005)**

37. Mazzola M., Cook R.J., Thomashow L.S., Weller D.M. and Pierson L.S., Contribution of phenazine antibiotic biosynthesis to the ecological competence of fluorescent Pseudomonads in soil habitats, *Appl.Environ Microbiol*, **58**, 2616-2624 **(1992)**

38. Gaur R., Shani N., Kawaljeet, Johri B.N., Rossi P. and Aragno M., Diacetylphloroglucinol- producing

Pseudomonas do not influence AM fungi in wheat rhizosphere, *Current Science*, **86**, 453-457 **(2004)**

39. Vasudevan P., Kavitha S., Priyadarisini V.B., Babujee L. and Gnanamanickam S.S., Biological control of rice diseases, In: Biological control of crop diseases, Gnanamanickam S.S.(Ed), Marcel Dekker, New York,11-32 **(2002)**

40. Velusamy P., Immanuel J.E., Gnanamanickam S.S. and Thomashow L.S., Biological control of rice bacterial blight by plant-associated bacteria producing 2,4-diacetylphloroglucinol , *Canadian Journal of Microbiology*, **52**, 56-65 **(2006)**

41. Suneesh K., Biodiversity of fluorescent pseudomonads in soils of moist-decidous forests of Western Ghats of Uttara Kannada district, M.Sc. (Agri) Thesis, University of Agricultural Sciences, Dharwad **(2004)**

42. Balasubramanian R., Biological Control of rice blast: Role of antifungal antibiotic in disease suppression, Ph.D. dissertation, University of Madras, **(1994)**

43. Sakthivel N. and Gnanamanickam S.S., Evaluation of *Pseudomonas fluorescens* for suppression of sheath- rot disease and enhancement of grain yields in rice, *Oryza sativa* L., *Applied and Environmental Microbiology,* **53**, 2056-2059 **(1987)**

44. Tiwari P.K. and Thrimurthy V.S., Isolation and characterization of the *Pseudomonas fluorescens* from rhizosphere of different crops, *J. Mycol. Pl .Pathol.,***37,** 231-234 **(2007)**

45. Reddy K.R.N., Anita C.D. and Reddy M.S., Antifungal metabolites of *Pseudomonas fluorescens* isolated from rhizosphere of rice crop, *J.Mycol.Pl.Pathol.*, **37**(2), 280-284 **(2007)**

46. Upadhaya R.S. and Jayaswal R.E., *Pseudomonas cepacia* causes mycelial determination and inhibition of conidiation in phytopathogenic fungi, *Current Microbiology*, **24**, 181-187 **(1992)**

47. Reddy P.B. and Rao K.S., Biochemical and PCR-RAPD characterization of *Pseudomonas fluorescens* produced antifungal compounds inhibit the rice fungal pathogens in vitro, *Elecetronic J. of Envl., Agrl.andfood Chem.,* **8(10)**, 1062-1067 **(2009)**

48. Nathan P., Rathinum X., Kasi M., Abdul Rahman Z. and Subramanian S., A pilot study on the isolation and biochemical characterization of Pseudomonas from chemical intensive rice ecosystem, *African J. of Biotechnilogy*, **10(59)**,12653-12656 **(2011)**

49. Corbett J.R., Pesticide design, In: The Biochemical mode of action pesticides, Academic press Inc., London, 44-86 **(1974)**

50. Gehring P.J., Nolan R.J. and Watanabe P.G., Solvents, fumigants and related compounds, In: Handbook of pesticide Toxicology, Hayes W.J. and Laws E.R.(Eds), Academic press Inc.,San Diego,California, **2,** 646-649 **(1993)**

51. Fiddaman P. J. and Rossall S., The production of antifungal volatiles by *Bacillus subtilis*, *J.of Appl. Microbiol.,* **74**(**2**), 119-126 **(1993)**

52. Voisard C., Keel O., Haas P. and Defago G., Cyanide production by *Pseudomonas fluorescens* helps to suppress black root rot of tobacco under genobiotic condition, *European Microbiological J.,***8**,351-358 **(1989)**

53. Bakker A.W. and Schippers B., Microbial cyanide production in the rhizosphere in relation to potato yield reduction and *Pseudomonas* sp. mediated plant growth stimulation, *Soil Biology and Biochemistry*, **19**, 451-457 **(1987)**

54. Ramette A., Frapolli M., Defago G. and Moenne-Loccoz Y., Phylogeny of HCN synthase –encoding 'hcnbc' genes in biocontrol fluorescent pseudomonads and its relationship with host plant species and HCN synthesis ability, *Molecular Biology of Plant Microbe Interaction*, **16**, 525-535 **(2003)**

55. Hofte M., Classes of microbial siderophores, In: Iron Chelation in Plants and Soil Microorganisms, Borton L.L. and Hemmingings B.C. (Eds), Academic press, San Diego, Calif., 3-26 **(1993)**

56. Neilands J. B., Microbial iron compounds, *Annual Review of Biochemistry*, **50**, 715-731 **(1981)**

57. Hemming B.C., Siderophore receptors of root colonizing *Pseudomanas* sp., *Journal of Plant Nutrition*, **9**, 505-507 **(1986)**

58. Bakker P.A.H.M., Raajmakers J.M. and Schippers B., Role of iron in the suppression of bacterial plant pathogens by fluorescent pseudomonads, In : Iron chelation in plants and soil microorganisms, Barton L.L. and Schippers B.(Eds), Academic Press, San Diego, Calif., 269-282 **(1993)**

59. Duiff B.J., Giaininazzi-Pearson V. and Lemanceau P., Involvement of the outer membrane lipopolysaccharides in the endophytic colonization of tomato roots by biocontrol *Pseudomonas fluorescens* strain WCS417r, *New Phytol.,* **135**, 325-334 **(1997)**

60. Demange P., Wendenbaum S., Bateman A., Dell A., and Abdallah M.A., Bacterial siderophores: Structure and physicochemical properties of pyoveridines and related compounds, In : Iron transport in microbes, plants and animals, Winkleman G., Van Der Helm D. and Neilands J.B.(Eds), VCH Chemie, Weinheim, 167-187 **(1987)**

61. Kloepper J.W. and Schroth M.N., Relationship of in vitro antibiosis of plant growth promoting rhizobacteria to plant growth and the displacement of root microflora, **71**, 1020-1024 **(1981)**

62. Bakker P.A.H.M., Lamer J.G., Bakker A.W. and Schippers B., The role of siderophores in potato tuber yield increase by *Pseudomonas putida* in a short rotation of potato, *Netherlands J.of Pl.Pathol.*, **92,** 249-256 **(1986)**

63. Becker J.O. and Cook R.J., Role of siderophores in suppression of *Pythium* sp. and production of increased growth response of wheat by fluorescent pseudomonads, *Phytopathology*, **78**, 778-782 **(1988)**

64. Kloepper J.W., Leong J., Teintze M. and Schroth M.N., Pseudomonas siderophores: A mechanism explaining disease suppressive soils, *Current Microbiology*, **4**, 317-320 **(1980)**

65. Scher I.M. and Bakker R., Effect of *Pseudomonas putida* and a synthetic chelator on induction of soil suppressiveness of *Fusarium* wilt pathogens, *Phytopathology*, **72**,1567-1573 **(1980)**

66. Loper J.E. and Buyer J.S., Siderophores in microbial nteraction on plant surfaces, *Mol. Pl.Microbe Interact.,* **4**, 5-13 **(1991)**

67. Dileep Kumar B.S. and Dubey H.S., Siderophore production by a plant growth promoting fluorescent pseudomonad, RBT13, *Indian Journal of Microbiology,* **33**,61-65 **(1993)**

68. Kloepper J.W. and Schroth M.N., Relationship of in vitro antibiosis of plant growth promoting rhizobacteria to plant growth and the displacement of root microflora, **71**, 1020-1024 **(1981)**

69. Becker J.O. and Cook R.J., *Pythium* control by siderophore producing bacteria on roots of wheat, *Phypathology*, **74**, 806-807 **(1984)**

70. Bakker P.A.H.M., Lamer J.G., Bakker A.W. and Schippers B., The role of siderophores in potato tuber yield increase by *Pseudomonas putida* in a short rotation of potato, *Netherlands Journal of Plant Pathology,* **91**, 249-256 **(1986)**

71. Loper J.E., Role of fluorescent siderophore production in biological control of *Pythium ultimum* by a *Pseudomonas fluorescens* strain, *Phytopathology*, **78**, 166-172

72. Simeoni L.A., Lindsay W.L. and Baker R., Critical iron levels associated with biological control of *Fusarium* wilt, *Phytopathology*, **77**, 1057-1061 **(1987)**

73. Sakthivel N., Sivamani E., Unnamalai N. and Gnanamanickam S.S., Plant growth promoting rhizobacteria in enhancing plant growth and suppressing plant pathogens, *Current Science*, **55**, 22-25 **(1986)**

74. Manwar A.V., Khandelwal S.R., Chaudhuri B.L., Meyer J.M. and Chincholkar S.B., Siderophore production by a marine *Pseudomonas aeruginosa* and its antagonistic action against phytopathogenic fungi, *Applied Biochem. Biotechnol.*, **118**, 243-252 **(2004)**

75. Siddiqui I.A. and Shaukat S.S., Resistance against the damping-off fungus *Rhizoctonia solani* systemically induced by the plant growth promoting rhizobacteria *Pseudomonas aeruginosa* (IE-6S+) and *P.fluorescens* (CHAO), *Journal of Phytopathology*, **150(8/9)**, 500-506 **(2002)**

76. Suryakala D., Maheshwari Devi P.V. and Lakshmi K.V., Chemical characterization and in vitro antibiosis of siderophores of rhizosphere fluorescent pseudomonads, *Indian Journal of Microbiology*, **44(2)**, 105-108 (**2004**)

77. De Vleesschauwer D., Bakker P.A.H.M., Djavaheri M., and Hofte M., *Pseudomonas fluorescens* WCS374r-induced systemic resistance in rice against *Magnaporthe oryzae* isbased on pseudobactin- mediated priming for a salicylic acid-repressible multifaceted defense response, *Plant physiol.*, **149**, 1996-1012 (**2008**)

78. Schroth M.N. and Hancock J.G., Selected topics in biological control, *Annual Rev. Microbiol*, **35**, 453-476 **(1981)**

79. Chet I., Trichoderma applications, mode of action and potential as a biocontrol agent of soil borne plant pathogenic fungi, In: Innovative approaches to plant diseases, Chet I.(Ed), Wiley,NewYork, 137-160 **(1987)**

80. Lorito M., Woo S.L., Ambrosia M.D., Harman G.E., Hayes C.K., Kubicek C.P. and Scala F., Synergistic Interaction between cell wall-degrading enzymes and membrane-affecting compounds, *Mol.Plant-Microbe Interact.,* **9**, 206-213 **(1996)**

81. Jaharamma M.,Badri Narayan K. and Sakthivel N., Genetic and Functional Diversity of Phosphate Solubilizing Fluorescent Pseudomonas and Their simultaneous Role in Promotion of Plant Growth and Soil Health, In: Genetic Diversity, Mahoney C.L.and Springer D.A.(Eds),Nova Science Publishers, Inc., **8**,1-18 **(2009)**

82. Sneh B., Use of rhizosphere chitinolytic bacteria for biological control of *Fusarium oxysporium, F.*sp.dianthi in carnation, *Phytopathol.,* **100**, 251-256 **(1981)**

83. Ordentlich A., Elad Y., Chet I., The role chitinase of *Serratia marcescens* in biocontrol of *Sclerotium rolfsii*, *Phytopathol.,***78**, 84-88 **(1988)**

84. Inber J. and Chet I., Evidence that chitinase produced by *Aeromonas caviae* is involved in the biological control of soil borne plant pathogens by this bacteria, *Soil Biol. Biochem.*, **23**, 973-978 **(1991)**

85. Antoun H. and Kloepper J.W., Plant growth promoting rhizobacteria , In: Encyclopedia of Genetics, Brenner S. and Miller J.F. (Eds), Academic Press, 1477-1480 **(2001)**

86. Albert F. and Anderson A.J., The effect of *Pseudomonas putida* colonization on root surface peroxidases, *Plant Physiol.*, **85**, 535-541(1987)

87. Shyamala L. and Sivakumaar P.K., Antifungal Activity of Rhizobacteria Isolated from Rice Rhizosphere Soil Against Rice Blast Fungus *Pyricularia oryzae*, *International Journal of Biological archives*, **3(3)**, 692-696 **(2012)**