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Ecofriendly Approaches of Potential Microbial Bioagents in Management of Sheath Rot Disease in Rice Caused by *Sarocladium oryzae* (Sawada)

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Abstract: There is growing interest in the use of effective microbial bioformulations that might be useful in the development of ecologically sustainable biocontrol strategies for the management of several plant pathogens. Recent studies suggest that the combination of several bio control agents could be more effective in controlling plant pathogens than individual strains. The new microbial consortia of Plant Growth Promoting Rhizobacteria *Pseudomonas fluorescens* strains Pf1, TDK1, TV5 and *Bacillus subtilis* isolate TH10 was developed and tested for their bioefficacy against the sheath rot (*Sarocladium oryzae* (Sawada) diseases in rice. The microbial consortia (Pf1+TDK1+TV-5+TH 10) effectively reduced sheath rot disease incidence in rice compared to individual bioformulations and control treatments under glasshouse and field conditions. Further, the significant increase in growth parameters and yield were observed in rice plants treated with microbial consortia (Pf1+TDK1+TV5+TH10) compared to individual bioformulations and untreated control. The present study revealed the probable influence of antagonism and plant growth promotion by the mixture of microbial consortia in enhancing the disease resistance in rice plants against sheath rot disease. Plant Growth Promoting Rhizobacteria (PGPR) metabolism which might be useful for development of ecologically sustainable biocontrol strategy for the management of plant pathogens in sustainable manner.

Key words: Rice, bioformulations, plant growth-promoting rhizobacteria, *Pseudomonas fluorescens*, *Bacillus subtilis*, *Sarocladium oryzae*, sheath rot

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food for more than half of the world's population and approximately 90% of the world's rice is produced in Asia. The productivity of rice is threatened by a number of diseases attacking the crop from nursery to harvest and causing enormous yield loss.

Pests and diseases cause 35-40% annual yield loss in rice (Srinivasachary *et al*., 2002) and among the various diseases in rice, sheath rot pathogen (*Sarocladium oryzae* (Sawada) W. Gams and D. Hawksworth) have gained major importance because of their ability to reduce the yield considerably all over the world. The management of rice sheath rot disease has been almost exclusively based on the application of chemical pesticides. Many effective pesticides have been recommended against this disease, but not considered as a long-term solution because of concerns about pesticide residue risks, health and environmental hazards, expense, residue persistence and elimination of natural enemies. Furthermore, the non-availability of varieties resistant to this pathogen has aggravated the problem. Therefore, the need for alternative methods of control of sheath rot disease has become vital.

The use of Plant Growth-Promoting Rhizobacteria (PGPR) in the management of plant diseases (Saravanakumar *et al*., 2007, 2008) has been demonstrated in previous studies. PGPR have latent defence mechanisms that can be systemically activated on exposure of plants to stress or infection by pathogens. However, most of the approaches using biological control of disease have used a single organism. The application of a single biocontrol agent is not likely to be active in all ecological situations where it is applied or against all pathogens that attack the host plant. This partially accounts for the reported inconsistent performance of biocontrol preparations. Thus, more emphasis is laid on

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the combined use of two or more strains of microbes, which has turned out to be more successful than either of them alone, as reported by several researchers (Nandakumar *et al*., 2001b, Bharathi *et al*., 2004; Thilgavathi *et al*., 2007). Several literature have documented that the use of biocontrol agents in combination was more effective for management of plant diseases and pathogens compared to individual agents (Kim *et al*., 2008; Ganeshmoorthi *et al*., 2008; Latha *et al*., 2009). Recently Sundaramoorthy *et al*. (2012), Sundaramoorthy and Balabaskar (2012) reported the consortial application of PGPR strains showed better disease suppression when they were tested singly. For this background, the present study evaluated the effectiveness of combination of *Pseudomonas* strains and *Bacillus* isolate for their ability to promote plant growth and their effectiveness against sheath rot disease on rice under glasshouse and field conditions. In addition to the activity of defence enzymes due to the combination of microbial bioformulation treatment against sheath rot incidence.

MATERIALS AND METHODS

***Pseudomonas* strains:** Rhizosphere soil samples were collected from different agro-ecosystems of Tamil Nadu, India (2011). The fluorescent pseudomonad strains were isolated from rhizosphere soil samples using the serial dilution technique in Kings' B (KB) medium (peptone 20 g; $MgSO_4$ 1.5 g; K_2HPO_4 1.5 g; glycerol 10 mL; agar 20 g and distilled water 1 l). The strains of *Pseudo-monas* sp., were identified according to the description given in Bergey's manual for systematic bacteriology (Krieg and Holt 1984). These isolates were maintained at -80°C with 50% glycerol. *P. fluorescens* strain Pf1 was obtained from the Culture Collection Section, Department of Plant Pathology, Centre for Plant Protection Studies (CPPS), Tamil Nadu Agricultural University (TNAU), Coimbatore, India.

Compatibility among bacterial strains: *Pseudomonas* strains were tested for their compatibility among each other following the method of Fukui *et al*. (1994). The compatibility was determined for fluorescent *Pseudomonad* strains using KB medium. Bacterial strains were streaked horizontally and vertically to each other and incubated at 16°C. Compatibility was tested by the overgrowth or inhibition of *Fluorescent pseudomonad* strains and observations were made over a period of 72 h.

Antagonistic activities of PGPR against sheath rot pathogen (*S. oryzae*) under *in vitro* condition: Several biocontrol strains were selected during the previous screening studies and demonstrated a good potential against *S. oryzae* by using dual culture plate techniques by keeping pathogen at one end and streaking bacterial strain at the other end (Nandakumar *et al*., 2001a, b).

Efficacy of bio formulations against sheath rot diseases in rice under glass house conditions: Glass house experiment was conducted with three replications on to test the efficacy of bioformulations against sheath rot disease. The following treatments were used in the glass house experiments:

- T_1 Pf1
- T_2 TDK 1
- T_3 TV 5
- T_4 TH 10 (*Bacillus*)
- T_5 Pf1+TDK1+PY15
- T_6 Pf1+TV 5+TH 10
- T_7 TDK 1+TV 5+TH 10
- T_8 Pf1+TDK1+PY15+TV5
- T_9 Pf1+TDK1+TV5+TH 10
- T_{10} Carbendazim (1 g L^{-1})
- T_{11} Control

Field experiment: Field trial was conducted with three replications on to test the efficacy of bioformulations against major diseases. A randomized block design was used in the experiments with plot size of 5×4 m^2. Production practices were followed as recommended by Tamil Nadu Agricultural University, Coimbatore, India with blanket recommendation, N 150, P_2O_5 50, K_2O 50 kg ha^{-1} and spacing 20×10 m. The treatments were followed same as used in the glass house experiments.

Statistical analysis: The data were statistically analyzed (Gomez and Gomez, 1984) and the treatment means were compared by Duncan's Multiple Range Test (DMRT). The package used for analysis was IRRI-Stat version 92-a developed by International Rice Research Institute Biometrics Units, The Philippines.

RESULTS

Microbial consortia containing mixture of fluorescent pseudomonad strains and *Bacillus* were tested against sheath rot diseases in rice under *in vitro*, glass house and field conditions, the results are presented below.

Antagonistic activity of PGPR against sheath rot pathogen (*S. oryzae*) under *in vitro* condition: The antagonist individual strains effectively inhibited the mycelial growth of *S. oryzae* (48 h after incubation) and no over growth were observed even after 7 days (Fig. 1).

Efficacy of PGPR formulations against sheath rot in rice under glass house conditions: Microbial consortia which showed significantly higher vigour index and inhibition over the *S. oryzae* were selected and screened against sheath rot disease under glass house conditions. Fluorescent pseudomonad bacterial strains viz., Pf1, TDK1, TV5 and TH10 individually and in combination were tested for their efficacy against *S. oryzae* under pot culture conditions along with the carbendazim as chemical check (Table 1).

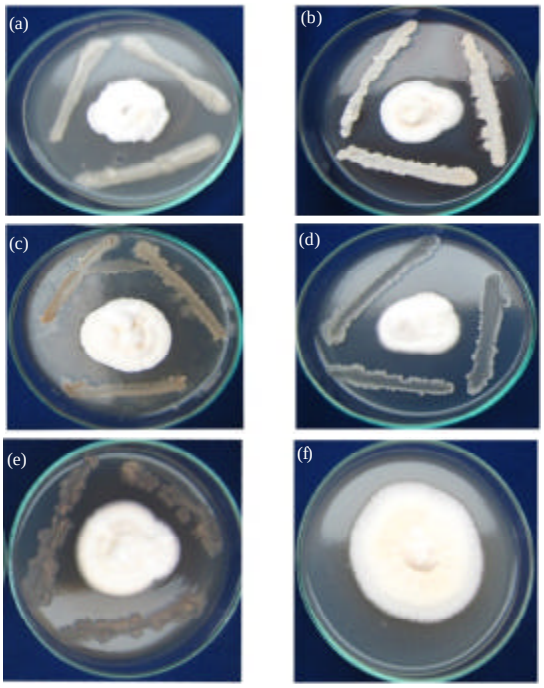

Fig.1(a-f): Efficacy of antagonistic activity of plant growth promoting rhizobacteria (PGPR) strains against sheath rot pathogen (*S. oryzae*) under *in vitro* condition, Pf1: *Pseudomonas fluorescens* strain 1, Py15: Pondicherry strain 15, TDK1-Thadiyankudisai strain 1, TV5: Thanjavur strain 5 and TH10: Thoothukudi strain 10

Effect of microbial bioformulations on incidence of sheath rot disease in rice under field conditions: Among the various combinations of bioformulations used, Pf1, TDK1, TV5 and TH10 treatment recorded with less mean disease index of 3.00 of *S. oryzae* which was significantly different from untreated control recording the mean disease index of 15.57 of *S. oryzae* from this experiment (Table 2). Pf1, TDK1, TV5 and TH10 treatment recorded the highest yield of 7716.7 kg ha^{-1}, which is significantly different from all other treatments including chemical treatment. Lowest yield of 4850.0 kg ha^{-1} was recorded from untreated control plots (Table 3).

DISCUSSION

Extensive and indiscriminate use of pesticides has resulted into several problems like development of resistance in pathogens, food contamination by toxic residue, adverse effect on parasitoids and high cost (Solunke and Deshpande, 1991). At this juncture popularization of biopesticides will be an effective solution to save environment. The development of biocontrol strategies involving a mixture of microbials is an emerging area in crop protection to reduce the damage caused by plant diseases on economically important crops. In the present study, the combination of *Pseudomonas* strains (Pf1, TDK1, TV5) and Bacillus isolate (TH10) was evaluated against sheath rot disease on rice. Furthermore, the compatibility study between the *Pseudomonas* strains Pf1 TDK1, TV5 and TH10 showed that they are compatible with each other. This compatible interaction has permitted the combination of the

Table 1: Efficacy of bioformulations containing mixture of plant growth promoting rhizobacteria (pgpr) strains on lesion size, chaffiness and percent disease index of sheath rot in rice under glass house conditions

Treatments	No. of discolored grains/panicle	No. of chaffy grains/panicle	Lesion No./ tiller	Lesion size (mm) Length	Lesion size (mm) width	No. of panicles infected/tiller	Percent disease index	Disease severity
Pf1	13.58^{b}	5.05^{bc}	3.72^{b}	13.10^{c}	4.16^{c}	1.34^{b}	33.30^{b}(35.24)	19.91^{b}(26.49)
TDK1	11.43^{c}	5.05^{bc}	3.10^{c}	12.70^{c}	3.84^{cd}	1.13^{c}	27.95^{c}(31.91)	12.11^{e}(20.36)
TV 5(*Pseudomonas*)	11.20^{c}	4.97^{c}	3.02^{c}	16.10^{b}	4.95^{b}	1.09^{c}	25.56^{d}(30.36)	14.90^{c}(22.70)
TH 10 (*Bacillus*)	9.90^{d}	4.33^{d}	2.18^{e}	13.20^{c}	4.68^{b}	0.79^{e}	21.40^{f}(27.55)	20.13^{b}(26.65)
Pf1+PY15+TDK1	9.65^{d}	4.30^{d}	2.55^{d}	10.10^{de}	2.30^{f}	0.92^{d}	22.69^{e}(28.44)	11.28^{f}(19.62)
Pf1+TV5+TH10	9.44^{d}	4.30^{d}	2.01^{e}	11.60^{cd}	3.78^{cd}	0.79^{e}	18.78^{g}(25.67)	12.00^{e}(20.26)
TDK1+TV5+TH10	5.49^{e}	2.44^{e}	1.54^{f}	9.30^{e}	3.86^{cd}	0.56^{f}	15.07^{h}(22.83)	11.62^{ef}(19.92)
Pf1+PY-15+TDK1+TV5	9.52^{d}	4.33^{d}	2.25^{e}	10.20^{de}	2.22^{f}	0.81^{e}	20.99^{f}(27.26)	14.04^{d}(22.00)
Pf1+TDK1+TV5+TH10	4.64^{e}	2.36^{e}	0.70^{g}	10.90^{de}	3.59^{d}	0.25^{g}	12.08^{i}(20.33)	9.01^{h}(17.46)
Carbendazim (1 g L^{-1})	4.57^{e}	5.49^{b}	0.54^{g}	6.40^{f}	2.94^{e}	0.19^{g}	11.95^{i}(20.21)	9.97^{g}(18.40)
Untreated control	35.82^{a}	12.58^{a}	6.27^{a}	50.10^{a}	16.48^{a}	2.57^{a}	58.18^{a}(49.71)	51.27^{a}(45.72)

Pf1: *Pseudomonas fluorescens* strain 1, Py15: Pondicherry strain 15, TDK1: Thadiyankudisai strain 1, TV5: Thanjavur strain 5, TH10: Thoothukudi strain 10, Values are mean of three replications. Means in a column followed by same superscript letters are not significantly different according to Duncan's multiple range test at p = 0.05, The data in the parentheses are arcsine transformed values

Table 2: Efficacy of bioformulations containing mixture of Plant Growth Promoting Rhizobacteria (PGPR) strains on the incidence of sheath rot disease in rice under field conditions (Thanjavur)

Treatments	No. of discolored grains/panicle	No. of chaffy grains/panicle	Lesion No./ tiller	Lesion size (mm) Length	Lesion size (mm) width	No. of panicles infected/tiller	Percent disease index	Disease severity
Pf1	11.26^{c}	6.26^{c}	5.24^{c}	17.88^{c}	7.21^{c}	0.90^{d}	22.95^{c}(28.61)	20.14^{bc}(27.34)
TDK1	11.15^{c}	6.26^{c}	5.17^{c}	17.49^{c}	6.89^{c}	0.10^{h}	20.94^{d}(27.22)	18.30^{cd}(25.32)
TV 5 (*Pseudomonas)*	12.82^{b}	6.26c	5.77^{b}	19.16^{b}	7.98^{b}	1.20^{b}	27.44^{b}(31.58)	22.16^{b}(28.06)
TH 10 (*Bacillus)*	9.88^{d}	5.66^{d}	4.51^{e}	13.95^{d}	5.64^{d}	0.94^{cd}	17.21^{f}(24.50)	14.85^{e}(22.66)
Pf1+PY15+TDK1	9.97^{d}	5.63^{d}	4.77^{d}	14.24^{d}	5.99^{d}	0.98^{c}	18.53^{e}(25.49)	16.11^{de}(23.66)
Pf1+TV5+TH10	6.96^{e}	4.58^{e}	3.91^{f}	10.41^{e}	4.53^{e}	0.65^{e}	12.12^{g}(20.36)	10.29^{f}(18.711)
TDK1+TV5+TH10	7.12^{e}	4.46^{e}	3.47^{g}	10.12^{e}	4.510^{e}	0.47^{f}	11.05^{h}(19.41)	9.35^{fg}(17.79)
Pf1+PY-15+TDK1+TV5	7.05^{e}	4.24^{f}	3.91^{f}	10.41^{e}	4.53^{e}	0.65^{e}	12.12^{g}(20.36)	10.29^{f}(18.711)
Pf1+TDK1+TV5+TH10	6.34^{f}	4.01^{g}	2.98^{h}	9.04^{f}	4.25^{e}	0.36^{g}	9.61^{i}(18.05)	8.00^{g}(16.42)
Carbendazim (1 g L^{-1})	6.29^{f}	6.63^{b}	3.05^{h}	8.94^{f}	4.21^{e}	0.39^{g}	9.53^{i}(17.97)	7.73^{g}(16.13)
Control	28.94^{a}	12.59^{a}	7.95^{a}	54.03^{a}	19.91^{a}	2.98^{a}	47.62^{a}(43.63)	48.39^{a}(44.07)

Pf1: *Pseudomonas fluorescens* strain 1, Py15: Pondicherry strain 15, TDK1: Thadiyankudisai strain 1, TV5: Thanjavur strain 5, TH10: Thoothukudi strain 10, Values are mean of three replications. Means in a column followed by same superscript letters are not significantly different according to Duncan's multiple range test at p = 0.05. The data in the parentheses are arcsine transformed values

Table 3: Effect of bioformulations containing mixture of Plant Growth Promoting Rhizobacteria (PGPR) strains on the plant growth parameters in rice under field conditions (Thanjavur)

Treatments	No. of tillers /hill	Plant height (cm) 30 DAP*	Plant height (cm) 45 DAP	Plant height (cm) 60 DAP	Plant height (cm) 75 DAP	No. of panicles /hill	No. of grains/ panicle	Panicle length (cm)	1000 grain weight (g)	Yield (kg ha^{-1})
Pf1 `	18.33^{c}	56.57	88.67	99.62	102.22	8.53^{c}	175.57^{i}	21.60^{e}	21.11^{f}	6163.3^{h}
TDK1	19.00^{bc}	58.90	92.00	100.33	102.93	8.60^{bc}	182.78^{h}	22.00^{e}	21.82^{e}	6233.3^{g}
TV5 (*Pseudomonas)*	19.60^{b}	63.90	96.00	101.8	104.4	8.80^{bc}	201.95^{g}	22.67^{c}	22.50^{d}	6533.3^{e}
TH10 (*Bacillus)*	19.73^{b}	64.00	96.33	102.73	105.33	8.80^{bc}	212.37^{e}	22.67^{c}	23.23^{c}	6683.3^{d}
Pf1+PY15+TDK1	19.27^{bc}	61.23	93.33	101.43	103.73	8.67^{bc}	209.54^{f}	22.57^{d}	22.50^{d}	6300.0^{f}
Pf1+TV5+TH10	20.13^{b}	65.07	97.67	105.97	108.27	9.55^{ab}	228.65^{b}	23.30^{ab}	23.78^{ab}	7390.0^{b}
TDK1+TV5+TH10	20.13^{b}	64.57	96.67	105.1	107.4	9.33^{abc}	226.95^{c}	23.13^{ab}	23.64^{bc}	7466.7^{b}
Pf1+PY 15+TDK1+TV5	19.97^{b}	64.07	96.67	103.83	106.73	9.13^{abc}	216.30^{d}	23.00^{bc}	23.40^{bc}	7116.7^{c}
Pf1+TDK1+TV5+TH10	22.27^{a}	66.20	98.33	107.37	109.67	10.07^{a}	235.79^{a}	23.57^{a}	24.18^{a}	7716.7^{a}
Carbendazim (1g L^{-1})	13.27^{e}	55.90	88.00	94.37	97.27	8.47^{c}	168.85^{j}	20.80^{f}	21.11^{f}	5816.7^{i}
Control	16.53^{d}	48.23	76.33	82.43	85.33	6.83^{d}	138.07^{k}	15.33^{g}	18.20^{g}	4850.0^{j}

Pf1: *Pseudomonas fluorescens* strain 1, Py15: Pondicherry strain 15, TDK1: Thadiyankudisai strain 1, TV5: Thanjavur strain 5, TH10: Thoothukudi strain 10, *Days after planting (DAP), Values are mean of three replications. Means in a column followed by same superscript letters are not significantly different according to Duncan's multiple range test at p = 0.05

Bacillus strain TH10 with *Pseudomonas* strains Pf1 TDK1, TV5 for the development of a new combination of microbial consortia and the design of a new strategy in the biological control of sheath rot disease on rice. Similarly, enhanced bioefficacy of bioformulations containing fungal and bacterial biocontrol agents has been reported for the management of root rot disease in mungbean (Thilgavathi *et al*., 2007). Several studies have documented that Pseudomonas, *B. subtilis* (CA32) and *Trichoderma harzianum* (RU01) significantly reduced the mycelial growth and conidial production of *F. solani* (Abeysingne 2007). Combination of biocontrol agents is a strategic approach to control the plant disease and pest (Nandakumar *et al*., 2001a; Saravanakumar *et al*., 2007). Furthermore, interactions among the bacterial strains may have synergistic effects that could induce ISR and promote the growth of the plants (Thilgavathi *et al*., 2007; Ganeshmoorthi *et al*., 2008; Latha *et al*., 2009). Several literature have documented that the use of biocontrol agents in combination was more effective for management of plant diseases and pathogens compared to individual agents. The results of the present study are in agreement with studies of Pierson and Weller 1994; Duffy and Weller, 1995; Domenech *et al*., 2006; Thilgavathi *et al*., 2007; Kim *et al*., 2008; Ganeshmoorthi *et al*., 2008; Latha *et al*., 2009).

Recently, Sundaramoorthy *et al*. (2012), Sundaramoorthy and Balabaskar (2012) reported that combination of *P. fluorescens* strain (Pf1) and *B. subtilis* strain (EPCO16) effectively inhibited the growth of the *F. solani* and *A. solani* in chilli and tomato plants respectively. The application of mixtures of microbes (Pf1, TDK1, TV5 and TH10) in the present study effectively reduced the incidence of sheath rot disease under glasshouse and field conditions. The characterisation of *P. fluorescens* strains Pf1 and TV5 indicated that they have indole-3acetic acid (IAA), 2,4-diacetylphloroglucinol (DAPG) and 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase activity . This could be responsible for the enhanced yield of rice plants under glasshouse and field conditions. It is assumed in the present study that *Pseudomonas* strains Pf1 TDK1, TV5 and TH10 in rice plants might help to weaken the pathogen. However, to advance further, there is a strong need for a

comprehensive understanding of the host plant physiology and metabolism, mainly in relation to jasmonic acid (JA), salicylic acid (SA) and ethylene-mediated pathways, by fluorescent pseudomonads, *Bacillus* and pathogens. No doubt, high-throughput molecular techniques in the coming years will help to develop effective microbial bioformulations that might be useful in the development of ecologically sustainable biocontrol strategies for the management of several plant pathogens in a sustainable manner.

CONCLUSION

Application of bio control agents, singly and in combination of PGPR strains was found to be effective in controlling the rice sheath blight disease. The present study clearly indicated that the microbial consortia (Pf1+TDK1+TV5+TH10) showed the greatest and most effective disease control and also enhance the yield parameter effects.

REFERENCES

Abeysingne, S., 2007. Biological control of *Fusarium solani* f. sp. phaseoli the causal agent of root rot of bean using Bacillus subtilis CA32 and *Trichoderma harzianum* RU01. Ruhuna J. Sci., 2: 82-88.

Bharathi, R., R. Vivekananthan, S. Harish, A. Ramanathan and R. Samiyappan, 2004. Rhizobacteria-based bio-formulations for the management of fruit rot infection in chillies. Crop Prot., 23: 835-843.

Domenech, J., M.S. Reddy, J.W. Kloepper, B. Ramos and J. Gutierrez-Manero, 2006. Combined application of the biological product LS213 with *Bacillus, Pseudomonas* or *Chryseobacterium* for growth promotion and biological control of soil-borne diseases in pepper and tomato. Bio. Control, 51: 245-258.

Duffy, B.K. and D.M. Weller, 1995. Use of *Gaeumannomyces graminis* var.graminis alone and in combination with fluorescent Pseudomonas spp. to suppress take-all of wheat. Plant Dis., 79: 907-911.

Fukui, R., M.N. Schroth, M. Hendson and J.G. Hancock, 1994. Interaction between strains of Pseudomonads in sugar beet shermospheres and their relationship to pericarp colonization by *Pythium ultimum* in soil. Phytopathology, 84: 1322-1330.

Ganeshmoorthi, P., T. Anand, V. Prakasam, M. Bharani, N. Ragupathi and R. Samiyappan, 2008. Plant growth promoting rhizobacteria (PGPR) bioconsortia mediates induction of defense-related proteins against infection of root rot pathogen in mulberry plants. J. Plant Interact., 3: 233-244.

Gomez, K.A. and A.A. Gomez, 1984. A Statistical Procedure for Agricultural Research. John Wiley and Sons, New York.

Kim, Y.C, H. Jung, K.Y. Kim and S.K Park, 2008. An effective biocontrol bioformulation against Phytophthora blight of pepper using growth mixtures of combined chitinolytic bacteria under different field conditions. Eur. J. Plant Pathol., 120: 373-382.

Krieg, N.R. and J.G. Holt, 1984. Bergey's Manual of Systematic Bacteriology. Williams and Wilkins, Baltimore, MD., USA.

Latha, P., T. Anand, N. Ragupathi, V. Prakasam and R. Samiyappan, 2009. Antimicrobial activity of plant extracts and induction of systemic resistance in tomato plants by mixtures of PGPR strains and Zimmu leaf extract against *Alternaria solani*. Biol. Control., 50: 85-93.

Nandakumar, R., R. Viswanathan, S. Babu, J. Sheela, T. Raghuchander and R. Samiyappan, 2001a. A new bio-formulation containing plant growth promoting rhizobacterial mixture for the management of sheath blight and enhanced grain yield in rice. Biocontrol, 46: 493-510.

Nandakumar, R., S. Babu, R. Viswanathan, T. Raguchander and R. Samiyappan, 2001b. Induction of systemic resistance in rice against sheath blight disease by plant growth promoting rhizobacteria. Soil Biol. Biochem., 33: 603-612.

Pierson, E.A. and D.M. Weller, 1994. Use of mixture of fluorescent pseudomonas to suppress take-all and improve the growth of wheat. Phytopathology, 84: 940-947.

Saravanakumar, D., K. Muthumeena, N. Lavanya, S. Suresh, L. Rajendran, T. Raguchander and R. Samiyappan, 2007. *Pseudomonas* induced defence molecules in rice against leaffolder (*Cnephalocrocis medinalis*) pest. Pest Manag. Sci., 63: 714-721.

Saravanakumar, D., N. Lavanya, B. Muthumeena, T. Raguchander, S. Suresh and R. Samiyappan, 2008. *Pseudomonas fluorescens* mediated volatiles in rice plants enhancing natural enemy population against leaffolder (*Cnaphalocrocis medinalis*) pest. J. Appl. Entomol., 132: 469-479. 132: 469-479.

Solunke, B.R. and S.V. Deshpande, 1991. Studies on use of plant products for control of lemon butterfly larvae. J. Maharashtra Agric. Univ., 16: 302-303.

Srinivasachary, H. Shailaja, K. Girishkumar, H.E. Shashidhar and M.G. Vaishali, 2002. Identification of quantitative trait loci associated with sheath rot resistance (*Sarocladium oryzae*) and panicle exsertion in rice (*Oryza sativa* L.). Current Sci., 82: 133-135.

Sundaramoorthy, S. and P. Balabaskar, 2012. Consortial effect of endophytic and plant growth promoting rhizobacteria for the management of early blight of tomato incited by *Alternaria solani*. J. Plant Pathol. Microb., Vol. 3, No. 7.

Sundaramoorthy, S., T. Raguchander, N. Ragupathi and R. Samiyappan, 2012. Combinatorial effect of endophytic and plant growth promoting rhizobacteria against wilt disease of *Capsicum annum* L. caused by *Fusarium solani*. Biol. Control., 60: 59-67.

Thilgavathi, R., D. Saravanakumar, N. Ragupathy and R. Samiyappan, 2007. Integration of biocontrol agents for the management of dry root rot (*Macrophomina phaseolina*) disease in greengram. Phytopathol. Mediterr., 46: 157-167.