The Bioscan 15(1): 107-112, 2020
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
www.thebioscan.com

RECENT ADVANCES IN THE ROLE OF BACTERIAL ENDOPHYTES IN PLANT DISEASE MANAGEMENT

SANA BASHIR, EFATH SHAHNAZ*, SABA BANDAY, ZAHOOR A. BHAT AND MISBAH MUZAFFAR
Division of Plant Pathology, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, Shalimar - 190 025, Jammu & Kashmir, INDIA
e-mail: efaths@gmail.com

KEYWORDS
Endophytes
Plant diseases
Nematodes
Plant pathogenic bacteria

Received on :
11.11.2019

Accepted on :
24.01.2020

***Corresponding author**

ABSTRACT
Since times immemorial people have feared plant diseases due to the widespread destruction they caused directly or indirectly. Renaissance ushered in a new era of questioning everything resulting in the germ theory of disease and subsequently disease management with chemicals. However, with the surge in the environment consciousness and global climate change, research in plant pathology has seen a shift in research focus from chemical to biological management. Endophytes have played their role well but research has been limited, with only five per cent of the endophytes been effectively screened for their disease management properties. Endophytic bacteria live within the tissues of the plant but unlike plant pathogens do not cause harm to the plants invaded. Roots are considered to be the points of invasion for potential endophytes from soil to the roots and generally higher populations of endophytes are present in the below ground parts as compared to the above ground parts. Endophytes can colonise the same tissues as phytopathogens and hence act as biocontrol agents. A number of mechanisms are employed by the endophytes for disease management. Various researchers have reported the use of endophytes for the management of wilts, rots and damping off, blights and leaf spots, powdery mildews, rusts, downy mildews, basal rots and various post harvest fungal diseases. Diseases caused by nematodes and plant pathogenic bacteria can also be managed by the use of endophytes. The present paper reviews the recent research in the field of endophytes for the benefit of researchers and scholars.

INTRODUCTION

Agricultural augmentation since the twentieth century has been greatly attained through the use of farm machineries, high-yielding varieties, vigorous tillage, irrigation, fertilizers and pesticides (Foley *et al*., 2005). This is well illustrated by the global use of fertilizers that has increased from approximately 27 to 170 million nutrient tonnes over the past 50 years (Heffer, 2013). However, continuous use of fertilizers over a long period leads to deleterious effects on the soil. Accordingly, environmentally safe approaches have to be implemented to maintain sustainable agricultural production to overcome threats that lead to yield loss, including unfavourable environmental conditions to plants, as well as biotic stress induced by plant pathogens and pests. A viable alternative is the use of endophytic bacteria for the management of plant diseases (Jha *et al*., 2013). Bacterial endophytes have been defined as bacteria that colonize the internal tissues without any deleterious effects on the host (Schulz and Boyle, 2006). Of the well over 3, 00,000 plant species that exist on the earth, very few endophytes have been described (Strobel *et al*., 2004). Therefore, there are enormous prospects of upbringing beneficial endophytes from the diverse genera inhabiting different ecosystems.

Bacteria may live in soils, rhizosphere, rhizoplane or phyllosphere, and may establish symbiotic relations with plants (Smith and Goodman, 1999). Unlike phytopathogens, endophytic bacteria do not cause any symptoms on host plants, and their occurrence is not related to the morphological changes that appear in plant tissues such as formation of root-nodule by symbionts. Endophytes colonize all plant parts, in between the spaces of the cell walls and vascular bundles of plant roots, stems and leaves, tissues or flowers, fruits and seeds (Trognitz, 2014). Population dynamics of endophyte bacteria may vary from 10^0 to 10^9 bacteria per gram of plant tissue (Chen *et al*., 1995). Generally, higher endophytic populations are found in below ground parts as compared to above ground tissues (Reinhold-Hurek and Hurek, 2011). Further, roots are considered as point of invasion of the potential endophytes from soil to the host plant. Strong union amid host plant and endophytes is mediated through the action of secondary metabolites produced by the microorganisms and the host cells (Brader *et al*., 2014). Bacterial endophytes may colonize the same plant tissue as plant pathogens, and consequently can act as biocontrol agents (Berg *et al*., 2005). There are innumerable reports of endophytic bacteria having the capability to manage phytopathogens (Krishnamurthy and Gnanamanickam, 1997), insects (Azevedo *et al*., 2000) and nematodes (Hallmann *et al*., 1995).

The endophytic bacteria contribute in plant disease management by (i) assisting in nutrient availability and uptake (ii) enhancing stress tolerance and (iii) providing disease resistance (Ryan *et al*., 2008; Hamilton *et al*., 2012). They are correlated with the enhanced plant growth by the production of hormones that increase accessibility of nutrients, such as nitrogen, potassium and phosphorus (Glick *et al*., 2012). Induced disease resistance activities are allied with the abilities to produce secondary metabolites, such as antibiotics or chitinase enzymes, which can inhibit growth of plant pathogens (Wang *et al.,* 2014; Pieterse *et al.*, 2014). Endophytic bacteria can also promote seedling emergence and stimulate plant growth (Chanway, 1997) under stress conditions (Bent and Chanway 1998).

The recent research on the role of endophytes in the management of different diseases is reviewed under the following heads:

Fusarium wilts

Nandhini *et al.* (2012) tested endophytic bacteria isolated from root, stem, leaves and fruits for their antagonistic activity against *Fusarium* wilt disease in tomato. All the isolates belonged to four bacterial genera viz., *Bacillus*, *Pseudomonas*, *Klebsiella* and *Citrobacter*. The results revealed that only 50% of the isolates exhibited strong antagonistic activity against tomato wilt pathogen. Sundaramoorthy *et al.* (2012) found that a consortium of rhizospheric and phyllospheric bacterial strains (*P. fluorescens* (Pf1) and *B. subtilis* (EPCO16 and EPC5) strains) reduced *Fusarium* wilt incidence in chilli by 17-30% compared to control. Six endophytic and four rhizospheric bacterial isolates obtained from root and corm tissues of banana plants reduced the incidence of *Fusarium* wilt of banana (Thangavelu and Muthukathan, 2015).

Rots and damping-off

Of the seventy one endophytic bacterial strains isolated from cotton, 40 strains protected cotton plants from *R. solani* infection (Chen *et al.*, 1995). Benhamou *et al.* (1998) revealed seed bacterization (*Serratia plymuthica*) of cucumber protected the seedlings from infection by damping-off. Cucumber seeds treated with endophytic bacterium *S. plymuthica* reduced the incidence of damping-off (Benhamou *et al.,* 2000). Bhowmik *et al.* (2002) reported that seed treatment with endophytic bacterium (PR 8) reduced the incidence of damping-off disease of cotton. On the other hand, Anith *et al.,* (2003) isolated a strain PN-026 from underground shoot portions of rooted cuttings of black pepper and tested it against foot rot of pepper. The results revealed that strain PN-026 was efficient in reducing *Phytophthoracapsici*, the causal agent of severe infestation of foot rot disease. Muthukumar (2008) tested nine endophytic bacterial isolates obtained from chilli plants, some of them (isolated from stem and root) exhibited high inhibition of *P. aphanidermatum* (51.4, 41.7 and 40.0%) causing chilli damping-off. The maximum inhibition on the mycelial growth of *R. bataticola* was in chickpea by *P. fluorescens* strains PFBC-25 and 26 (Khan and Gangopadhyay, 2008). Bacterial endophytes (46 strains) were obtained from amaranthus and tested against *R. solani* by dual culture technique. Among these, six bacteria exhibited highest mycelial growth inhibition of *R. solani* (Uppala *et al.,* 2009). About 67 bacterial endophytes were isolated from cassava; they were subjected to 16S rRNA sequencing and FAME analysis. The bacterial profile revealed that 25% of endophytic isolates belonged to the genus *Bacillus*. Among these, the isolate *B. pumilus* MAIIIM4a showed a strong inhibitory activity against *R. solani*, *P. aphanidermatum* and *S. rolfsii* (Pereira de Melo *et al.*, 2009). In Kashmir root and collar rots of apple are frequently surfacing feature in orchards owing to the shift of paddy land into apple orchards. Use of endophytes can prove to be promising approach to manage them but till now no bacterial endophyte has been evaluated against it. However, mycorrhizal evaluation has revealed the presence of some potential antagonist against *Dematophora* sp. and *Pythium sp.* causing root rot and collar rot of apple in Kashmir. (Banday *et al.*, 2008a; Banday *et al.*, 2008b and Dar *et al.*, 2009).

Blights and leaf spot

Foliar application with *Pseudomonas* spp. induced disease resistance in rice against sheath blight pathogen. In spite of the absence of this bacterium on plant surfaces, its presence in the internal stem led to suppression of disease (Krishnamurthy and Gnanamanickam 1997). Endobacterium *B. subtilis*, isolated from xylem fluid of chestnuts, suppressed the growth of chestnut blight pathogen, *Cryphonectria parasitica* under *in vitro* conditions. The same bacterium reduced the lesion areas on stems, when applied three days prior to challenge inoculation (Wilhelm *et al.*, 1998). The endophytes *viz., Bacillus circulance* and *Serratia marcescense* supplemented with chitin inhibited the conidial germination of early and late tikka leaf spot in groundnut (Kishore *et al.*, 2005). Four endophytic bacteria (OS-9, OS-10, OS-11 and OS-12) were isolated from healthy leaves of *Ocimum sanctum* and tested against five plant pathogens namely *R. solani*, *S. rolfsii*, *F. solani*, *A. solani* and *C. lindemuthianum*. Of these, the bacterial strain OS-9 was highly inhibitory to the growth of *R. solani*, *A. solani*, *F. solani* and *C. lindemuthianum* while OS-11 alone was found antagonistic to *A. solani* (Kalraa *et al.*, 2010). The culture filtrate of endophytic bacteria CE-6 exhibited the highest inhibition on the mycelial growth of *Cercospora* (61.3%) *in vitro* (Hima *et al.*, 2013).

Powdery mildew

Recently (Gao *et al.*, 2015), isolated 14 endophytic bacterial strains from wheat leaves and tested them against *Blumeria graminis* f.sp. *tritici* causing wheat powdery mildew disease. The results revealed that *B. subtilis* strain (E1R-j) significantly reduced per cent disease index by 90.97% in pot culture under greenhouse conditions.

Rust

The endophytic bacteria were isolated from leaves and branches of *Coffea arabica* and *Coffea robusta* and tested against leaf rust pathogen *Hemileiava statrix* by detached leaf and leaf disc method. The bacterial isolates TG4-Ia (*Bacillus lentimorbus* Dutky) and TF9-Ia (*Bacillus cereus* Frank & Frank) exhibited highest growth inhibition against coffee rust pathogen (Shiomi *et al.*, 2006). Endophytic bacteria E1R-j, isolated from wheat leaves, showed strong inhibitory effect on wheat stripe rust in both greenhouse and field conditions (Li *et al.,* 2013).

Downy mildew

Sixty different endophytic bacterial isolates belonging to different genera were isolated from root and stem tissues of five medicinal plants (*Cymbopogan citratus*, *Azadirachta indica*, *Phyllanthus emblica*, *Boerhaavia diffusa* and *Boerhaavia repens*)and two agricultural crops (*Pisum sativum* and *Sorghum bicolor*) and one weed plant (*Parthenium hysterophorus*) and were tested against pearl millet downy mildew disease. The pearl millet seeds treated with endophytic bacteria *P. fluorescens* ISR 34 and *Bacillus sp.* ISR 37 recorded greater control of downy mildew disease by 68 and 63%, respectively. The endophytic bacterial strains not only reduced the disease incidence but also increased the plant growth by induced systemic resistance (Chandrashekhara *et al.,* 2007).

Basal stem rot/ganoderma wilt/thanjavur wilt

An endophytic bacterium *Pseudomonas cepacia* (B3) and *Pseudomonas aeruginosa* (P3) isolated from root tissues of oil palm exhibited strong inhibition on the growth of *G. boninense*causing ganoderma wilt (Dikin *et al.,* 2003). Histological studies revealed that bacterial endophytes were confined to the vascular bundles of the roots taken from symptomless palms (Zaiton *et al.,* 2006). Total of 581 endophytic bacteria were isolated from root tissues of oil palm and tested against *Ganodermalucidum,* the wilt pathogen. Among these, three endophytic bacteria namely *Pseudomonas aeruginosa* GanoEB1, *Burkholderiacepacia* GanoEB2, and *Pseudomonas syringae* GanoEB3 were highly effective in inhibiting the mycelial growth of test pathogen. The results revealed that the isolate *P. aeruginosa* GanoEB1 was highly effective in controlling disease incidence of 13.3-26.7% compared to control (60%). (Ramli *et al.,* 2016)

Post harvest fungal diseases

A number of efforts have been made for using endophytic bacteria for the control of storage diseases. Endophytic bacteria were tested to control stone fruit rot pathogens *Monilinia laxa* and *Rhizopus stolonifer*. Twenty two bacterial strains were isolated from different fruits including red pepper, tomato, white plum, egg plant and zucchini. Of these 20 strains were able to control *M. laxa* in apricot and plum fruits. *R. stolonifer* was less susceptible to antagonistic bacteria than *M. laxa* and only one strain effectively controlled *R. stolonifer* (Pratella *et al.,* 1993). Endophytic bacteria (*B. subtilis*) isolated from stored apples have been used in the biocontrol of post harvest diseases of apple (Sholberg *et al.*, 1995). Further, an inhibitory compound acidic peptide produced by *B. subtilis*, was responsible for the inhibition of *Botrytis cinerea* but not to *Penicillium expansum* (Bechard *et al.,* 1998). The acidic peptide had a wide spectrum activity against Gram-negative bacteria. The endophytic bacterium *Bacillus thuringiensis* is capable of releasing volatile substances that lead to the inhibition of *Fusarium sambucinum* in potato tubers (Sadfi *et al.,* 2001). Two hundred and fifty eight endophytic bacteria were isolated from chilli leaves and screened against chilli fruit rot pathogen *Colletotrichum capsici* by fruit bioassay method. Of the endophytes tested, *B. megaterium* (ENB-86) recorded the highest suppression of lesion development in chilli fruits (59.66%). (Ramanujam *et al.,* 2012)

Nematode diseases

Endophytic bacteria have an additional advantage in control of phytoparasitic nematodes since the injuries produced by nematodes favour the entry of bacteria and colonize the root surface leading to their introduction into the root tissue (Khan, 1993). In cotton and tomato root knot nematode infection, peanut root knot and reniform nematode infection can be effectively controlled by using *B. subtilis* (Sikora, 1988). Seven endophytic bacteria *Aerococcusviridans*, *B. megaterium*, *B. subtilis*,*P. chlororaphis, P. vesicularis*, *S. marcescens* and *Sphingomonas paucimobilis* from cotton and cucumber plants were tested against cucumber root knot nematode. Seed bacterization with endophytic bacteria completely protected cucumber seedlings from *M. incognata* infection (Hallmann *et al.,* 1995). Culture filtrate of *P. fluorescens* strains CHA0 or CHA0/PME3424 were tested against tomato root knot nematode. The results revealed that the inoculum levels of 10^7, 10^8, 10^9cfu/g showed greater disease control under glasshouse conditions (Siddiqui and Shaukat, 2003). In another treatment, plants treated with culture filtrates of *B. subtilis*, *B. cereus* and *Arthrobotrys cladodes* reduced the soil population of *M. incognita* (Vetrivelkalai *et al.,* 2009).

Bacterial diseases

B. subtilis, isolated from healthy chestnut trees showed strong antagonistic activity against *Cryphonectria parasitica,* the cause of chestnut blight (Wilhelm *et al.,* 1998). Five strains of *Pseudomonas* inhibited the growth of *X. axonopodis*pv. *malvacearum* and also increased cotton seed germination and seedling growth by 12.8% and 22.4 %, respectively (Mondal, 1999). The endophytic bacteria *B. amyloliquefaciens*, *B. subtilis* and *B. pumilus* produce several antibiotics (surfactin, iturin, bacillomucine, azalomycin F, surfactin, arthrobactin, surfactin, amphomycin, arthrobactin and valinomycin) which are highly inhibitory to the growth of *X. campestris*pv. *Campestris,* the cause of black rot of crucifers (Wulff *et al.*, 2002). The cotton seeds treated with the endophytic bacterium (Endo PR8) reducing cotyledonary infection with black arm of cotton (*X. campestris*pv. *malvacearum)* (Bhowmik *et al.*, 2002). The shoots dipped with endophytic bacterium before planting grapevine produced highest fresh weight of the shoots and roots, and quick growth with more lignin deposits (Barka *et al.,* 2002). Similarly, cotton seeds treated with bacterial endophyte (EPCO 102) showed increased plant vigour under *in vivo* conditions (Rajendran *et al.*, 2006). Foliar spraying and seed soaking with bacterial antagonist *Delftiatsuruhatensis* (strain HR4), isolated from root region of rice plants showed reduced bacterial blight infection in range of 7-32% (Han *et al.,* 2005). Under greenhouse conditions, endophytic*B. subtilis* strain Lu144 remarkably protected mulberry plants against *Ralstonia solanacearum* causing bacterial wilt disease (Ji *et al.*, 2008). Bacterial endophytes such as *Pantoea agglomerans*, *Pseudomonas sp*. and *Curtobacterium luteum* reduced the growth of *Erwinia carotovora* (Figueiredo *et al.*, 2009). Ninety three isolates of rhizobacteria were tested against *Xanthomonas axonopodis*pv. *malvacearum*. Of these, *B. subtilis* B49 recorded highest inhibition on the growth of pathogen *in vitro* and was highly effective in controlling bacterial blight of cotton under greenhouse and field conditions (Salaheddin *et al.*, 2010). Bacterial endophytes (*B. amyloliquefaciens* Bg-C31) isolated from *Bruguieragymnorhiza* was effective in controlling bacterial wilt of chilli under pot and field condition (Hu *et al.,* 2010). Endophytic bacterium, *B. subtilis* applied as seedling dip, soil and foliar application resulted in reduced the bacterial blight infection in rice under laboratory and field condition and it was found to increase the plant growth and yield (Nagendran *et al.*, 2013). *P. fluorescens* strain (PDY7) was highly effective in reducing the incidence of bacterial blight of rice under glass house and field condition (58.83 and 51.88%, respectively). This is mainly due to the production of antibiotics 2, 4-diacetylphloroglucinol (DAPG) (Velusamy *et al.,* 2013).

Twenty six bacterial strains were isolated from leaf, root and stem region of mangrove plant (*Rhizoporamucronata*). Among these, highest number of bacterial isolates were from leaf (38.5%) followed by root (34.5%) and stem (26.9%). Of these, five bacterial strains namely *Serratia*, *Bacillus*, *Pseudomonas*, *Micrococcus* and *Enterobacter* exhibited broad-spectrum of antagonistic activity against fungal and bacterial pathogen (Jose and Christy, 2013). Among the bacterial strains tested, strain MB04 and MB08 were highly inhibitory to the growth of *X. campestris* pv. *oryzae* causing rice bacterial blight (Yuliar, 2014). The endophytic bacteria isolated from tomato plants were tested against bacterial wilt pathogen. Of the isolates tested, only Ps1 and Ps8 could inhibit *R. solanacearum* in vitro using seed coat method. In *in vivo* test, 30 days old tomato seedlings, soaked with endophytic bacteria showed 8.07-9.19% disease suppression within 15-16 days incubation period (*Purnawati et al.,* 2014). Cotton seeds treated with endophytic bacteria strains *B. subtilis* UFLA285 recorded the lowest bacteria blight incidence of 26% (de Medeiros *et al.,* 2015). Four endophytic bacteria were isolated from potato stem tissue and tested against the growth of *Streptomyces scabies* in agar plate method. The results revealed that all the isolates were highly inhibitory to the growth of test pathogen (Flatley *et al.,* 2015).

REFERENCES

Barka, E. A., Gognies, S., Nowak, J. C., Audran, S. and Belarbi, A. 2002. Inhibitory effect of endophyte bacteria on *Botrytis cinerea* and its inuence to promote the grapevine growth. *Biological Control.* **24:** 135-142.

Bechard, J., Eastwell, K. C., Sholberg, P. L., Mazza, G. and Skura, B. 1998. Isolation and partial chemical characterization of an antimicrobial peptide produced by strain of *Bacillus subtilis. Journal of Agricultural and Food Chemistry.* **46:** 5355-5361.

Benhamou, N., Gagn, S., Le Quere, D. and Dehbi, L. 2000. Bacteria mediated induced resistance in cucumber: benecial effect of the endophytic bacterium *Serratiaplymuthica* on the protection against infection by *Pythium ultimum. The American Phytopathological Society.* **90:** 45-55.

Benhamou, N., Kloepper, J. W. and Tuzun, S. 1998. Induction of resistance against Fusarium wilt of tomato by combination of chitosan with an endophytic bacterial strain: ultrastructural and cytochemistry of the host response. *Planta.* **204:** 153-168.

Bhowmik, B., Singh, R. P., Jayaraman, J. and Verma, V. P. 2002. Population dynamics of cotton endophytic *Pseudomonas* their antagonism and protective action against the major pathogens of cotton. *Indian Phytopathology.* **55:** 124-132.

Chandrashekhara, S. N., Saligrama, A., Deepak, K.N., Amruthesh, N. P. and Shetty, H. S. 2007. Endophytic bacteria from different plant origin enhance growth and induce downy mildew resistance in Pearl Millet. *Asian Journal of Plant Pathology.* **1:** 1-11.

Chen, Y., Mei, R., Lu, S., Liu, L. and Kloepper, J. W. 1995. The use of increasing bacteria (YIB) as plant growth promoting rhizobacteria in chinese agriculture. In: Utkheade R (ed) Management of soil-borne diseases. M/S Kalyani publishers, New Delhi.

Compant, S., Duffy, B., Nowak, J., Clement, C. and Ebay, B. 2005. Use of plant growth promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects. *Applied and Environmental Microbiology.* **71:** 4951-4959.

Dar, G. H., Saba Banday, Beigh, M.A. and Fatima, N. 2009. Efficacy of biocontrol agents in improving plant growth and control of *Pythium* root rot in apple. *Plant Disease Research.* **24(2):** 142-145.

De Medeiros, FHVD., Souza, R. M. D., Ferro, H. M., Zanotto, E. and Machado, J. D. C. 2015. Screening of endospore-forming bacteria for cotton seed treatment against bacterial blight and damping-off. *Advances in Plants and Agricultural Research.* **2(4):** 56-61.

De Souza, J.T., Weller, D. M. and Raaijmakers. J. M. 2003. Frequency, diversity and activity of 2, 4-diacetylphloroglucinol producing fluorescent *Pseudomonas* spp. in Dutch take-all decline soils. *Phytopathology.* **93:** 54-63.

Dikin, A., Sijam, K., Zainal Abidin, M. A., Idris, A. S. 2003. Biological control of seed borne pathogen of oil palm, Schizopyllum commune Fr. with antagonistic bacteria. *International Jouranl of Agriculture and Biology.* **5:** 507-512.

Duffy, B. K. and Defago, G. 1999. Environmental factors modulating antibiotic and siderophore biosynthesis by *Pseudomonas fluorescens*biocontrol strains. *Applied and Environmental Microbiology.* **65:** 2429-2438.

Figueiredo, S., Poirel, L., Croize, J., Recule, C. and Nordmann, P. 2009. In vivo selection of reduced susceptibility to carbapenems in *Acinetobacterbaumannii* related to ISAba1-mediated over expression of the natural blaOXA-66 oxacillinase gene. *Antimicrobial Agents and Chemotherapy.* **53:** 2657-2659.

Flatley, A., Ogle, L., Noel, A., Fraley, E., Goodman, A. and Donna, B. 2015. Isolation of possible biocontrol endophytic bacteria from *Solanumtuberosum* effective against *Streptomyces scabies.* Poster Sessions 7.

Flores-Fargas, R. D. and O'Hara, G. W. 2006. Isolation and characterization of rhizosphere bacteria with potential for biological control of weeds in vineyards. *Journal of Applied Microbiology.* **100:** 946-954.

Foley, J. A., Defries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, I. C., Ramankutty, N and Snyder, P. K. 2005. Global consequences of land use. *Science.* **309:** 570-574.

G. and Smalla K. 2009. Plant species and soil type cooperatively shape the structure and function of microbial communities in the rhizosphere. *FEMS Microbiology Ecology.* **68:** 1-13.

Gaffney, T. D., Lam, S. T, Ligon, J. M, Gates, K., Frazelle, A., Dimaio, J., Hill, S., Goodwin, S., Torkewitz, N., Allshouse, A. M., Kempf, H. J. and Becker, J. O. 1994. Global regulation of expression of antifungal factors by a *Pseudomonas fluorescence* biological control strain. *Molecular Plant Microbe Interacteractions.* **7:** 455-463.

Gao, X., Yufei, G., Yunxia, H., Qingmei, H., Zhensheng, K. and Huang, H. L. 2015. Endophytic *Bacillus subtilis* strain E1R-J is a promising biocontrol agent for wheat powdery mildew. *Biomed Research International.* pp. 1-8.

Georgakopoulos, D., Hendson, M., Panopoulos, N. J. and Schroth, M. N. 1994. Cloning of a phenazine biosynthetic locus of *Pseudomonas aureofaciens* PGS12 and analysis of its expression in vitro with the ice nucleation reporter gene. *Applied Environment and Microbiology.* **60:** 2931-2938.

Glick, B. R., Cheng, Z., Czarny, J. and Duan, J. 2007. Promotion of plant growth by ACC deaminase containing soil bacteria. *European Journal of Plant Pathology.* **119:** 329-39.

Grover, M., Nain, L. and Saxena, A. K. 2009. Comparison between *Bacillus subtilis* RP24 and its antibiotic-defective mutants. *World Journal of Microbiology and Biotechnology.* **25:** 1329-1335.

Gunter, S. Miller, B., Troghitz, F. and Angela, S. 2014. Metabolic potential of endophytic bacteria. *Current Opinion in Biotechnology.* **27:** 30-37.

Haas, D. and Defago, G. 2005. Biological control of soil-borne pathogens by *fluorescens pseudomonads. Natra. Rev. Microb. doi*: 10.1038/nrmicro1129.

Hallmann, J., Kloepper, J. W., Rodriguez-Kabana, R. and Sikora, R. A. 1995. Endophytic rhizobacteria as antagonists of *Meloidogyne incognita* on cucumber. *Phytopathology.* **85:**1136.

Han, J., Sun, L., Dong, X., Cai, Z., Sun, X., Yang, H., Wang, Y. and Song, W. 2005. Characterization of a novel plant growth-promoting bacteria strain *Delftiats uruhatensis* HR4 both as a diazotroph and a potential biocontrol agent against various plant pathogens. *Systematic and Applied Microbiology.* **28:** 66-76.

Heffer, P. 2013. Assessment of fertilizer use by crop at the global level, 2010-2010/11. 1-9.

Hima, V. M., Surendra, V., Ramana Reddy, K., Eswara Reddy, N. P., Bhaskar Reddy, B. V. and Chowdappa, P. 2013. Leaf endophyte for the management of early leaf spot of groundnut. *Indian Journal of Plant Pathology.* **41:** 147-151.

Hu, H. Q., Le, X. S. and He, H. 2010. Characterization of an antimicrobial material from a newly isolated Bacillus amyloliquefaciens from mangrove for biocontrol of Capsicum bacterial wilt. *Biological Control.* **54:** 359-365.

Idris, E. E. S., Iglesias, D. J., Talon. M. and Borriss, R. 2007. Tryptophane- dependent production of indole-3-acticacid (IAA) affects level of plant growth-promotion by *Bacillus amyloliquefaciens* FZB42. *Molecular Plant Microbe Interactions.* **20:** 619-26.

Jha, P. N., Gupta, G., Jha, P. and Mehrotra, R. 2013. Association of rhizospheric/endophytic bacteria with plants: a potential gateway to sustainable agriculture. *Green Journal of Agricultural Sciences.* **3:** 73-84.

Ji, X., Lu, G., Gai, Y., Zheng, C. and Mu, Z. 2008. Biological control against bacterial wilt and colonization of mulberry by an endophytic*Bacillus subtilis* strain. *FEMS Microbiology and Ecology.* **65:** 565-573.

Jose, A. C. and Christy, P. H. 2013. Assessment of antimicrobial potential of endophytic bacteria isolated from *Rhizophoramucronata. International Journal of Current Microbiology and Applied Sciences.* **2(10):** 188-194.

Kalraa, A., Darokar, M.P., Mahesh, C., Nitin, A. and Singh, A. K. 2010. Endophytic bacteria from *Ocimum sanctum* and their yield enhancing capabilities. *Current Microbiology.* **60:** 167-171.

Khan, M. R., Fischer, S., Egan, D. and Doohan, F. M. 2006. Biological control of *Fusarium* seedling blight disease of wheat and barley. *Phytopathology.* **96:** 386-394.

Khan, M. W. 1993. Mechanisms of interaction between nematode and other plant pathogens. In: Khan M. W. (ed) Nematode Interactions. Chapman and Hall, London. pp. 55-78.

Kishore, G. K., Suresh, P. and Podile, A. R. 2005. Biological control of collar rot disease with road-spectrum antifungal bacteria associated with groundnut. *Cannadian Journal of Microbiology.* **51:** 123-132.

Kobayashi, D. Y., Reedy, R. M., Bick, J. A. and Oudemans, P. V. 2002. Characterization of chitinase gene from Stenotrophomonasmaltophilia strain 34S1 and its involvement in biological control. *Applied and Environmental Microbiology.* **68:** 1047-1054.

Krishnamurthy, K. and Gnanamanickam, S. S. 1997. Biological control of sheath blight of rice: Induction of systemic resistance in rice by plant-associated *Pseudomonas spp. Current Science.* **72:** 331-334.

Kuhls, K., Lieckfeldt, E., Samuels, G. J., Meyer, W., Kubicek, C. P. and Börner, T. 1997. Revision of *Trichoderma* section *Longibrachiatum* including related teleomorphs based on an analysis of ribosomal DNA internal transcribed spacer sequences. *Mycologia.* **89:** 442-460.

Labuschagne, N., Pretorius, T. and Idris, A. M 2010. Plant growth-promoting rhizobacteria as biocontrol agents against soil-borne plant diseases. *Microbiology Monographs.* **18:** 211-230.

Levenfors, J. P, Eberhard, T. H., Levenfors, J. J., Gerhardson, B. and Hokeberg, M. 2008. Biological control of snow mould (Microdochiumnivale) in winter cereals by *Pseudomonas brassicacearum*, MA250. *Biocontrol.* **53:** 651-665.

Li, H., Zhao, J., Feng, H., Huang, L. L. and Kang, Z. S. 2013. Biological control of wheat stripe rust by an endophytic *Bacillus subtilis* strain E1R-j in greenhouse and eld trials. *Crop Protection.* **43:** 201-206.

Liu, B. H., Qiao, L. and Huang. 2009. Biological control of take-all in wheat by endophytic*Bacillus subtilis* E1R-j and potential mode of action. *Biological Control.* **49:** 277-285.

Lugtenberg, B. and Kamilova, F. 2009. Plant growth-promoting rhizobacteria. *Annual Review of Microbiology.* **63:** 541-556

Milner, J. L, Silo-Suh, L., Lee, J. C, He HY.,Clardy, J. and Handelsman, J. 1996. Production of kanosamine by *Bacillus cereus* UW85. *Applied and Environmental Microbiology.* **62:** 3061-3065.

Mondal, K. K. 1999. Benecial effects of indigenous cotton rhizobacteria on seed germinability, growth promotion and suppression of bacterial blight disease. *Indian Phytopathology.* **52:** 228-235.

Mulya, K., Watanabe, M., GotoTakikawa, M. and Tsuyumu, S. 2006. Suppression of bacterial wilt disease in tomato by root dipping with *Pseudomonas uorescens* PfG32: the role of antibiotic substances and siderophore production. *Annals of Phytopathological Society.* **6:** 134-140.

Nagendran, K., Karthikeyan, G., Faisal, M., MuthurajRaveendran, P., Prabakar, K. and Raguchander, T. 2013. Management of bacterial leaf blight disease in rice with endophytic bacteria. *World Applied Sciences Journal.* **28:** 2229-2241.

Nelson, M. N. and Sorenson, J. 1999. Chitinolytic activity of *Pseudomonas uorescens* isolates from barley and sugar beet rhizosphere. *FEMS Microbiology and Ecology.* **30:** 217-227.

Nishida, M., Matsubara, T. and Watanabe, N. 1965. Pyrrolnitrin, a new antifungal antibiotic, microbiological and toxicological observations. *Journal of Antibiotics.* **18:** 211-219.

Ownley, B. H., Weller, D. M. and Thomashow, L. S 1992. Influence of in situ and in vitro pH on suppression of *Gaeumannomycesgraminis* var. *tritici* by *Pseudomonas fluorescens* 2-79. *Phytopathology.* **82:** 178-184.

Pérez-Montaño, F., Alías-Villegas, C., Bellogín, R. A., Del Cerro, P., Espuny, M. R., JiménezGuerrero, I., López-Baena, F. J., Ollero, F. J. and Cubo, T. 2014. Plant growth promotion in cereal and leguminous agricultural important plants: from microorganism capacities to crop production. *Microbiology Research.* **169:** 325-36.

Pieterse, C. M. J., Van Pelt, J. A., Ton, J., Parchmann, S., Mueller, M. J., Buchala, A. J., Métraux, J. P. and Van Loon, L. C. 2000. Rhizobacteria-mediated induced systemic resistance (ISR) in *Arabidopsis* requires sensitivity to jasmonate and ethylene but is not accompanied by an increase in their production. *Physiological and Molecular Plant Pathology.* **57:** 123-134.

Pratella, G. C., Mari, M., Guizzardi, F. and Folchi, A. 1993. Preliminary studies on the efciency of endophytes in the biological control of the postharvest pathogens *Monilinialaxa* and *Rhizopusstolonifer* in stone fruit. *Postharvest Biology and Technology.* **3:** 361-368.

Purnawati, A., Sastrahidayat, I. R, Abadi, A. L and Hadiastono, T. 2014. Endophytic bacteria as biocontrol agents of tomato bacterial wilt disease. *Journal of Tropical Life Science.* **1:** 33-36.

Raaijmakers, J. M., Vlami, M. and de Souza, J. T. 2002. Antibiotic production by bacterial biocontrol agent. *Anton van Leeuwenhook.* **81:** 537-547.

Rajendran, L., Saravanakumar, D., Raguchander, T. and Samiyappan, R. 2006. Endophytic bacterial induction of defence enzymes against bacterial blight of cotton. *Phytopathologia Mediterranae*. **45:** 203-214.

Ramanujam, B., Basha, H., Vinaya, H., Chowdappa, P. and Rangeshwaran, R. 2012. Induction of defense related enzymes and phenols in chilli plants by *Bacillus subtilis* against anthracnose pathogen, *Colletotrichumcapsici*. *Indian Phytopathology*. **65:** 382-385.

Ramli, N., Suriza, M., Mohamed, Abu Seman, I., Ahmad Zairun, M. and Mohamad, N. 2016. The potential of endophytic bacteria as a biological control agent for Ganoderma disease in oil palm. *Sains Malaysiana*. **45:** 401-409.

Saba Banday, Dar, G. H and Fatima, N. 2008a. Influence of biocontrol agents on plant growth and white root rot of apple. *Plant Disease Research*. **23(2):** 46-50.

Saba Banday, Dar, G. H., Ghani, M. Y., Vinay Sagar and Fatima, N. 2008b. *In vitro* interaction of bioagents against *Dematophora necatrix* and *Pythium ultimum* causing apple root rot in Jammu and Kashmir. *SKUAST Journal of Research* **10:** 341-345.

Sad, N., Cherif, M., Fliss, I., Boudabbous, A. and Antoun, H. 2001. Evaluation of bacterial isolates from salty soils and *Bacillus thuringiensis* strains for the biocontrol of*Fusarium* dry rot of potato tubers. *Journal of Plant Pathology*. **83:** 101-118.

Sad, N., Chérif, M., Fliss, I., Boudabbous, A. and Antoun, H. 2001. Evaluation of bacterial isolates from salty soils and *Bacillus thuringiensis* strains for the biocontrol of Fusarium dry rot of potato tubers. *Journal of Plant Pathology* **83:** 101-118.

Salaheddin, K., Valluvaparidasan, V., Ladhalakshmi, D. and Velazhahan, R. 2010. Management of bacterial blight of cotton using a mixture of *Pseudomonas uorescens* and *Bacillus subtilis*. *Plant Protection Science*. **46:** 41-50.

Sarniguet, A., Kraus, J., Henkels, M. D., Muehlchen, A. M. and Loper, J. E. 1995. The sigma factor sigma (S) affects antibiotic production and biological control activity of *Pseudomonas fluorescens* Pf-5. *Proceedings of National Academy of Sciences of USA*. **92:** 12255-12259.

Schulz, B. abd Boyle, C. 2006. What are endophytes. In: *Soil Biology. Microbial Root Endophytes*. Vol. 9.

Shiomi, H. F., Silva, H.A.S., de Melo, I. S., Nunes, F. V. and Bettiol, W. 2006. Bioprospecting endophytic bacteria for biological control of coffee leaf rust. *Scientia Agricola*. **63:** 32-39.

Sikora, R. A. 1988. Inter relationship between plant health promoting bacteria, plant parasitic nematodes and soil microorganisms. *Med FacLandbouwwRijks University Gent*. **53:** 867-878.

Smith, K. P. and Goodman, R. M. 1999. Host variation for interactions with beneficial plant associated microbes. *Annual Review of Phytopathology*. **37:** 473-491.

Strobel, G. Dairy, B., Castillo, U. and Harper, J. 2004. Natural products from endophytic micro organisms. *Journal of Natural Products*. **67(2):** 257-256.

Subramoni, S., Gonzalez, J. F., Johnson, A., Pechy-Tarr, M., Rochat, L. and Paulsen, I. 2011. Bacterial sub family of Lux regulators that respond to plant compounds. *Applied and Environmental Microbiology*. **77:** 4579-4588.

Van Loon, L. C. 2007. Plant responses to plant growth-promoting Rhizobacteria. *European Journal of Plant Pathology*. **119:** 243-254.

Van Loon, L. C., Bakker, P. A. and Pieterse, C. M. J. 1998. Systemic resistance induced by rhizosphere bacteria. *Annual Review of Phytopathology*. **36:** 453-483.

Velusamy, P., Immanuel, J. E. and Gnanamanickam, S. S. 2013. Rhizosphere bacteria for biocontrol of bacterial blight and growth promotion of rice. *Rice Science*. **20(5):** 356-362.

Weller, D. M. 2007. Pseudomonas biocontrol agents of soil borne pathogens: Looking back over 30 years. *Phytopathology*. **97:** 250-256.

Wilhelm, E., Arthofer, W., Eitner, S. and Krebs, B. 1998. *Bacillus subtilis* an endophyte of chestnut (*Castenea sativa*) as antagonist against chestnut blight (*Cryphonectria parasitica*). *Plant cell Tissue Organ Culture*. **52:** 105.

Wood, D. W., Gong, F., Daykin, M., Williams, P. and Pierson, L. S. 1997. N-Acyl-homoserine lactone mediated regulation of phenazine gene expression by *Pseudomonas aureofaciens* 30-84 in the wheat rhizosphere. *Journal of Bacteriology*. **179:** 7663-7670.

Wulff, E. G., Mguni, C. M., Mortensen, C. N., Keswani, C. L. and Hockenhul, J. 2002. Biological control of black rot (*Xanthomonascampestris*pv. *campestris*) of Brassicas with an antagonistic strain of *Bacillus Subtilis* in Zimbabwe. *European Journal of Plant Pathology*. **108:** 317-325.

Yuliar 2014. The effect of suppression of endophytic mangrove bacteria on leaf blight of rice caused by *Xanthomonasoryzae*pv.*oryzae*. *Global Journal of Biology, Agriculture and Health Sciences*. **3(1):** 1-7.

Zaiton, S., Sariah, M., Zainal Abidin, M. A. 2006. Isolation and characterization of microbial endophytes from oil palm roots: Implication as biocontrol agents against *Ganoderma*. *The Planter*. **82:** 587-597.