INTRODUCTION
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India is an agriculture based country where over 43% of territory remains employed in agricultural activities. The agriculture sector has been successful in keeping pace with rising demand for food. As the population of our country rises, it is necessary to improve the crop yield to meet the requirements. With an increased awareness of environmental issues such as excessive fertilizers, herbicide and pesticide use, it is important to find alternative methods to improve crop yields. Rice is one of the most widely cultivated crops all over India. The biotic stresses mainly due to bacterial, fungal and viral diseases are the major limiting factor for successful cultivation of rice. Although number of diseases are reported in rice, the sheath blight (ShB) caused by \textit{Rhizoctonia solani} Kuhn is becoming the major constrain for rice production world over especially in the intensified cultivation systems (Slaton et al., 2003). The yield losses due to ShB were estimated between 6% and 50% outside India, whereas in India up to 69% was recorded (Roy, 1993). Hence, strategies to control ShB of rice are gaining priority in research and it directly reflects the future food needs with respect to growing population all over the world especially in tropical Asian countries like India. To meet the requirement of growing population and changing life style, about 300 million tonnes of food grains including 130 million tonnes of rice will be required by 2025, against the current production of 234.50 and 94.01 million tonnes of food grains and rice respectively during 2010-11 (Manibhushanrao, 1989; Sambilla and Rosegrant, 1996).

Breeding for disease resistant to sheath blight is still in a rudimentary stage, and no variety has been selected on disease resistant against all anastomosis groups of \textit{Rhizoctonia solani}. Thus no universally useful resistant variety is available to farmers, although attempts have been made to incorporate resistant genes into some rice cultivars (Bonman et al., 1992). Control measures normally used are usually only partly effective because \textit{Rhizoctonia solani} is able to produce survival structures which can persist in the soil for at least 2 years (Ou, 1985). Several fungicides have been tested for many years for rice disease control. Some potentially effective fungicides are highly phytotoxic on rice and if disease is not severe, these fungicides tend to cause more damage than good (Groth et al., 1990).
In this scenario, alternative control measures are to be developed for ShB disease, the biological control is one such efficient disease management strategy gaining momentum in recent years. Biological control has become an attractive option for controlling rice sheath blight disease, and many other diseases (Cook, 1993). Attempts were made to control the ShB of rice using bacterial and fungal biocontrol agents (BCAs) (Mew and Rosales, 1986; Rabindran and Vidhyasekaran, 1996; Krishnamurthy and Gnanamanickam, 1998; Mathivanan et al., 2005; Singh and Sinha, 2007). Nevertheless, often the BCAs perform well in laboratory and greenhouse experiments with controlled environmental conditions but failed in the field to suppress the disease. Availability and maintenance of quality BCAs in viable form is still a hurdle in rural areas. Moreover, the farmers are fascinated by the immediate cure by the chemical agents instead of slowly acting BCAs. In this scenario, the microbial metabolites produced by the BCAs can be used to suppress the disease in crop plants and they can be applied easily as like any other fungicides in the field. Further, they do not accumulate in the environment and hence, will not cause any environmental problems and health hazards. Therefore, the use of secondary metabolites of microbial origin is a wise choice in combating many plant diseases including ShB of rice.

Plant growth promoting rhizobacteria (PGPR) play a key role in the suppression of bacterial and fungal plant pathogens (Defago and Hass, 1990). The PGPR directly promote the plant growth by production of growth promoting substances or facilitate the uptake of certain nutrients from the soil. On the other hand PGPR can also prevent the proliferation of phytopathogens and thereby indirectly support plant growth (Compant et al., 2005). Moreover, they are involved in nutrient cycling, maintenance of soil fertility and to establish positive interactions with plant roots in agricultural environments. Improvement of the beneficial association between microorganisms and plants, particularly in the rhizosphere, is an important area of research of global interest.

In recent years, actinomycetes have drawn much attention worldwide because of their plant growth promotion ability and biocontrol potential against plant pathogens. Microbial biocontrol agents have been promoted as an effective and environmentally friendly option to control the soil borne diseases. Among the microbes, actinomycetes are
one of the most important groups of soil microorganisms which are significant producers of secondary metabolites such as antibiotics, pesticides, antiparasitic compounds, lytic enzymes (McCarthy and Williams, 1990; Omura, 1992; Lange and Sanchez Loper, 1996) and are being used as potential group of bio control agents. Soil actinobacteria are promising group of antifungal and root-colonizing microbes to protect several plants from soil borne fungal pathogens (El-Tarabily and Sivasithamparam, 2006). Among actinomycetes, Streptomyces sp. is considered as predominant genus for producing more than 75% of total bioactive molecules (Demain 2000). Apart from their biocontrol potential, they also have plant growth promotion traits which are not adequately studied and reported. Streptomyces are well known as antifungal agents against various plant pathogens (Errakhi et al., 2007; Li et al., 2011; Zacky and Ting, 2013; Cuppels et al., 2013). The members of Streptomyces are known for their production of antimicrobial metabolites, hydrolytic enzymes, plant growth hormones, phosphate solubilization, hydrogen cyanide, siderophore and control plant diseases through local and systemic resistance (Conn et al., 2008; Harikrishnan and Shanmugaiah, 2013). However, reports regarding the bearing of PGP traits, i.e., phosphate solubilization, organic acid production, siderophore production and secretion of numerous enzymes, which directly or indirectly help plant growth promotion are scanty (Doumbou et al., 2001; Sadeghi et al., 2012). Indian soils are rich in microbial diversity, especially actinomycetes and the wealth of indigenous micro-flora of India has not been fully explored (Prabavathy et al., 2006). Hence the present study was initiated with the following objectives.

- To isolate Actinomycetes from rice rhizosphere soils collected from diverse locations of Tamil Nadu.
- To screen Actinomycete isolates for antagonistic activity against sheath blight pathogen, *R. solani*.
- Optimization and characterization of Plant growth hormone produced by *Streptomyces* sp. VSMGT1014.
- To study functional characterization and optimization of antifungal secondary metabolite produced by *Streptomyces aurantiogriseus* VSMGT1014.
Purification and characterization of antifungal secondary metabolite from the *Streptomyces aurantiogriseus* VSMGT1014.

To study the mechanism of purified metabolite against *R. solani* and control of sheath blight of rice in greenhouse conditions.

In the present study, 246 actinomycetes were isolated from rice rhizosphere in the southern districts of Tamil Nadu, India and all the isolates were screened against ShB pathogen, *R. solani*. Among them, an isolate designated as VSMGT1014 was selected for further studies owing to its high antagonistic potential. This isolate also showed wide spectrum antifungal activity against plant pathogens. In addition, the VSMGT1014 remarkably promoted the plant growth in rice and green gram. The VSMGT1014 was identified as *Streptomyces aurantiogriseus* based on morphological and biochemical characterization and 16S rRNA sequence analyses. In addition, the production, purification and characterization of an antifungal compound were carried out. A liquid formulation of *S. aurantiogriseus* VSMGT1014 was prepared and evaluated against ShB disease of rice under greenhouse. The purified compound was evaluated against ShB disease in greenhouse experiment along with liquid formulation of *S. aurantiogriseus* VSMGT1014 besides commercial fungicide, carbendazim. The results of the present study were discussed in detail in this thesis.
REVIEW OF LITERATURE
Agriculture

Global demand for food is rising because of population growth, increasing affluence and changing dietary habits. Worldwide, India stands first in rice area and second in rice production, after China. It contributes 21.5 percent of global rice production. Within the country, rice occupies one-quarter of the total cropped area, contributes about 40 to 43 percent of total food grain production and continues to play a vital role in the national food and livelihood security system. The UN/FAO forecasts that global food production will need to increase by over 40% by 2030 and 70% by 2050 (FAO, 2009). Yet globally, water is anticipated to become scarce and there is increasing competition for land, putting added pressure on agricultural production. In addition, climate change will reduce the reliability of food supply through altered weather patterns and increased pressure from pests and diseases. Rice along with wheat forms the bedrock of Indian food security and to meet the country’s stated goal of ensuring food for all, farmers will have to produce more rice from lesser land, using less water, energy and other inputs and keeping in harmony with the fragile environment. Rice is the most important food crop of the developing world and the staple food for more than 60% of the Indian populace, who are also highly vulnerable to inflationary pressure due to high rice price. India has the largest area under rice cultivation and is second only to China in rice production. There are huge gaps between yields currently obtained by farmers and that achieved with improved varieties and management practices. Post-harvest losses are estimated to be about 20–30%. Efficiencies of utilization of nitrogen fertilizer or water remain 30–50% below levels that can be achieved with good management.

Sheath blight disease

The causal agent of sheath blight is *Rhizoctonia solani* Kuhn, teleomorph *Thanatephorus cucumeris* (A. B. Frank) Donk. The fungus belongs to anastomosis group AG-1, intraspecific group I-A of *R. solani*. The basidiomycete fungus *Rhizoctonia solani* is an economically important pathogen with a broad host range and worldwide distribution which causes the most destructive rice sheath blight and severely lowers both rice yield
and quality (Xiong et al., 2013). The disease occurs throughout temperate and tropical rice production areas worldwide and is second to rice blast in economic importance (Lee and Rush, 1983). The increasing importance of rice sheath blight has been associated with the rapid intensification of rice production since the widespread adoption of high yielding cultivars in tropical Asia (Cu et al., 1996). The high yielding rice cultivars require increased nitrogen fertilizer inputs, are grown in denser stands and their high tillering abilities produce a closed canopy; all are factors that create a favourable microclimate for sheath blight development (Savary et al., 1995). Estimates of yield losses can be as high as 25% when the infection is well distributed and severe in a field. Heavily infected plants produce poorly filled grains and additional losses in yield result from increased lodging as a result of death of the culm. A banded blight disease of rice was reported and copious air-borne basidiospores were found to cause banded symptoms and spots on the leaf sheath. This organism was identified as *Thanatephorus cucumeris* (Frank) Donk (Ou, 1985).

The disease spreads through the dispersal of sclerotia in soil, or floating on irrigation water. Interplant spread occurs through leaf-to-leaf contacts, which serve as bridges for mycelial growth to spread from a diseased to a healthy plant (Savary et al., 1997). Although *R. solani* is commonly believed a soil borne pathogen, disease spread through the canopy seems to be more important in sheath blight epidemiology in the tropics (Savary et al., 1995; Banniza et al., 1999). *R. solani* is a generalist pathogen that infects several weed species commonly found in rice fields, which are considered important sources of primary inoculum in the tropics. Control of sheath blight relies mostly on foliar applications of fungicides (IRRI, 1993). The use of crop rotation is also ineffective because inoculum is maintained on many weed species and alternate crops in the absence of rice. Magnesium has severe effect on sheath blight, caused by *Rhizoctonia solani*, development on rice plants from cultivars (Daniel et al., 2014). ShB management typically relies on the application of fungicides in combination with cultural practices. Utilization of naturally occurring host resistance is the most economical and environment-friendly measure for managing ShB (Liu et al., 2013). No host resistance is known for rice sheath blight despite various efforts to look for sources of genetic resistance (Lee and Rush, 1983).
Sheath blight pathogen

Sheath blight pathogen, *Rhizoctonia solani* Kuhn is a widespread and destructive soil-borne pathogen. It consists of a great number of isolates differing in various characteristics (Flentje, 1970). *R. solani* is an important fungal phytopathogen that lives in the soil in the form of sclerotia and does not generates asexual spores. It has a wide host range and distribution and causes sheath blight in some field crops, such as corn, rice, lawn grass and cucumber (Huang et al., 2012). *Rhizoctonia solani*, a member of the multinucleate *Rhizoctonia* group, is a genetically diverse causal agent of rice sheath blight in many developing countries. This organism has resulted in major constraint of rice production over the past two decades (Zheng et al., 2013). Several workers (Houston, 1945; Exner, 1953; Takahasi, 1954) have attempted to group *R. solani* by cultural, physiological, morphological or pathological criteria, but their groupings were finally found to be with only little practice value because of overlapping of these characteristics among groups.

The fungus causing rice ShB is variously named but the most commonly used one is *Rhizoctonia solani* Kuhn. Naiki and Kanoh (1978) classified *Thanatephorus cucumeris* into 5 anastomosis groups according to their virulence. The ShB isolate in India belongs to AG1 group having 3 to 16 nuclei. Basidiospores are very rare in India. Primary infection comes from sclerotia. Basidiospores are formed at night. Two types of mycelium- straight and branched, and lobate-are developed, of which only the latter type is infectious. Lesion is covered by lobate mycelium while the straight type may extend beyond it without causing infection. *R. solani* induce lesion on leaf blades and leaf sheaths of infected plant. *R. solani* produces sclerotia on both abaxial and adaxial leaf sheath surfaces but not in the tissue. *R. solani* forms infection cushions and lobate appressoria on leaf sheath. ShB infection increases peroxidase, chitinase and polyphenol oxidase activity but decreases catalase activity in rice.

**ShB symptoms and disease cycle**

Sheath blight symptoms usually develop as lesions on sheaths of lower leaves near the water line, when plants are in the late tillering or early inter node elongation stages of growth. These lesions usually develop just below the leaf collar as oval to elliptical, green
to gray, water soaked spots about 0.5 cm wide and 2 - 3 cm long. The lesions expand and the centre of the lesions may become bleached with an irregular tan with brown border. When humidity exceeds 95% and temperatures are in the range of 30 - 32°C, infection spreads rapidly by means of runner shaped lesions with brown borders. Symptoms of sheath blight usually appear when the crop reaches its full vegetative growth at maximum tillering. The disease causes lesions on the leaf sheaths and the leaf blades. Under favorable conditions, the disease may progress: (i) Inwardly from outer to inner sheath (ii) vertically from sheath to sheath and lamina and (iii) horizontally from tiller to tiller and hill to hill. Disease development progresses very rapidly in the early heading and grain filling stages during frequent rainfall and overcast skies. Plants heavily infected at these stages produce poorly filled grain, particularly in the lower portion of the panicle. Under favourable conditions of low sunlight, high humidity (≥ 5%), and warm temperature (28-32°C), the infection spreads rapidly by means of runner hyphae to upper plant parts.

Lesions may coalesce to encompass the entire leaf sheath and stem (Rush and Lee, 1992) Additional losses result from increased lodging or reduced ratoon production due to infection of the culms and reduced carbohydrate reserves (Acharya et al., 1997). As plants senescence during maturity, lesions will dry and become grayish white to tan with brownish borders. Typical lesions on the leaf sheaths are at first ellipsoid or ovoid, somewhat irregular, greenish-grey, ranging in size from 1 to 3 cm long (Ou, 1985). The centre of the lesion typically turns greyish-white with a brown margin. Lesions may coalesce to encompass entire leaf sheaths and stems.

The fruiting bodies called sclerotia are initially white, turning dark brown at maturity and are produced superficially on or near the lesions. Sclerotia are loosely attached and easily dislodged from the plant. Sclerotia are the primary means for the fungus survival between crops. They survive long periods in the soil and will float to the surface of flooded rice fields in the subsequent rice crop, infect rice plants at the water line and continue the disease cycle. They can also attack several weed hosts and cause infection (Singh et al., 2002). Sclerotia can survive from one to several years in the soil. Sclerotia may move from one field to another through irrigation water and during movement they may produce mycelia and secondary and tertiary sclerotia. Sclerotia are produced
superficially on infected tissue and are loosely attached and easily dislodged from the plant when they are mature.

The infected rice seeds may produce 4-6.6% seedling infection in India (Ou, 1985). But on transplantation the infected seedlings were unable to develop disease. Disease cycle takes place predominantly through sclerotia in the humid tropics. Sclerotia, the dormant are shed before/or during the harvest operation and remain in soil and survive for a long time. When the buoyant sclerotia tend to accumulate in undisturbed standing water at the plant-water interface, the aerobic fungus creeps up several centimeters in 24 hr and the primary infections are caused in wetland rice. The pathogen induced lesions on leaf blades and leaf sheaths of infected plants. It produces sclerotia on both abaxial and adaxial leaf sheath surfaces but not in the tissue. The pathogen form infection cushions and lobate appressoria on leaf sheath, and directly penetrate the cuticle or through stomata. Once infection occurs, secondary spread takes place through direct contact. Sclerotia may move from one field to another through irrigation water and during movement they may produce mycelia and secondary or tertiary sclerotia (IRRI, 1973).

**Strategies of ShB control**

Burning the infected crop debris after harvest, keeping the fields weed free and bunds cleaning is necessary to control the disease. Incorporation of Neem (*Azadirachta indica*) and groundnut (*Arachis hypogea*) cake under dry conditions, and ellupa cake, gingelly cake and neem cake under flooded condition reduced the survival of sclerotia of the rice pathogen. High density of seed rate and planting encourage the spread of the disease. Chemical fungicide is the most common strategy to effectively minimize the severity of *R. solani*, but is not considered to be a long term solution because of the potential health and environmental risks (Liu et al., 2012). The application of silicon to complement host resistance to sheath blight appears to be an effective strategy for disease management in rice, especially when the soil is low or limiting in plant available silicon. The application of broad-spectrum fungicides in soil may result in soil contamination, fungicide resistant or harmful effects to non-target organisms. Hence, search for alternatives to chemical control has gained momentum. Azoxytrobin fungicide provides
superior sheath blight control compared with other fungicides used in rice such as carbendazim (Slaton et al., 2003).

Developing disease resistance through transgenic approach has received considerable attention worldwide as a strategy for ShB disease management in rice. Liu et al. (2004) enhanced rice resistance to fungal pathogens by transformation with cell wall degrading enzyme genes from *Trichoderma atroviride*. Pyramiding transgenes for multiple resistances in rice against bacterial blight, yellow stem borer and sheath blight has also been done (Datta et al., 2002). Elite indica rice varieties were transformed with chitinase gene for ShB resistance. However, breeding for ShB resistant has not been very successful because of lack of availability of resistant donor in the cultivated rice varieties (Li et al., 1995; Kim et al., 2003; Tan et al., 2005). Till date the attempted transgenic approaches utilized resistance sources obtained from non-rice genetic background. Hence, the transgenic attempts would not be successful without resistance source from rice.

Biological and cultural controls are the two alternatives to chemical fungicides, which aimed at maximum productivity with least negative environmental and ecological consequences (Baby, 1992). Manipulation of the dose of silicon application in rice resulted in increased resistance towards ShB *in vitro*. Excessive seeding rates, thick plant population and high nitrogen applications favour ShB development and hence these should be avoided in fields with a history of the disease (Castilla et al., 1995). Grass and weeds should be controlled. Long-term crop rotations may reduce the incidence of ShB, but soybean, sorghum and many weeds are susceptible to *R. solani*. Since the limitations of the cultural practices are more than their advantages, the approaches of biological control stand as the first choice for eco-friendly ShB diseases management strategy. Various kinds of microbial antagonists have been investigated as potential antifungal biocontrol agents for ShB disease management (Kandhasamy and Sun, 2012). Biological control using antagonistic microbes alone, or as supplements to minimize the use of chemical pesticides is an integrated plant disease management system strategy of ShB control (Sawai et al., 2013). Several agronomic practices, such as rational use of fertilizers and optimum planting density, involved in regulating antioxidant protective enzyme systems can be
regarded as promising strategy to suppress the sheath blight development (Wei et al., 2014).

**Biological control of ShB in rice**

Lack of durable sheath blight resistant rice varieties and environmental concerns about chemical usage have led to developing sustainable control methods using microorganisms. Antagonism between organisms is common in the ecosystem and is most prevalent among soil microorganisms. Natural interference between beneficial soil microorganisms and plant pathogens results in zone of buffer, thereby inhibiting or reducing disease development (Kohl et al., 2011). Simply, this natural buffering is the result of biological control of unwanted microorganisms by other competing plant or soil microorganisms (Kohl et al., 2011). Various microbial defense mechanisms may work independently or together, depending on the rhizosphere or phyllosphere characteristics. Microbial antagonistic properties have created new opportunities in biological control technology. The first step in this process is to isolate and identify the role of antagonistic microorganisms responsible for biological control. The next step is to multiply potential antagonists in the laboratory and test them under lab, greenhouse, and field conditions. Before marketing, field efficacy of the final product is tested at multi location sites covering various related crops. Market introduction of new products are known as plant protectants in most countries and similar chemical protectant regulations and protocols apply (Kohl et al., 2011). Several biological control methods have been proposed to control ShB; however, their usage by farmers has been limited due to elusive application techniques and the inconsistency of field effects (Xie et al., 2008).

Managing soil-abundant beneficial microbes for the improvement of plant root and shoot growth and plant health is an exciting field. Complex interactions of soil-plant-microbes can impact plant vigor and yield (Kennedy, 1998). These interactions in the rhizosphere also influence plant health and soil fertility (Jeffries et al., 2003). Rhizosphere microbial interaction benefit plants by increasing soil available crop nutrients (Dey et al., 2004). When *Bacillus subtilis* NJ-18 strain was combined with jinggangmycin, there was an increased suppression of rice sheath blight, and thus could provide an alternative disease control option (Peng et al., 2013). Advancements in biological control have led to
identification and development of antagonistic bacteria with plant and root growth stimulating ability. In order to study the disease infection, rice plants at late tillering stage were inoculated with *R. solani* by placing mycelial plugs beneath the leaf sheath (Kalaivani Nadarajah et al., 2014).

**Importance of biological control**

Biological control of plant pathogens is an established sub-discipline in Plant Pathology. Biological control of plant diseases with microbial antagonists is an effective alternative to chemical control due to the expensiveness and toxicity by accumulation in the soil biota. Recently, the interest in biological control by beneficial microorganisms has increased consistently as an alternative disease control to substitute for various chemical controls against airborne or soil borne plant pathogens (Sang et al., 2011). The use of biocontrol agents is more ubiquitous in greenhouse than in field crops. Biocontrol have been introduced into soil or on seeds, roots, bulbs or other planting material to improve plant growth and health (Mathivanan et al., 2005; Shanmugaiah, et al., 2006; Prashanth et al., 2006). Biological control of plant pathogens has numerous efficient reports (Handelsman and Stabb, 1996; Whipps, 1997; 2001). In addition, the biological control of plant diseases, with the use of biocontrol agents formulation is gaining greater importance among farmers worldwide. Bio fungicides are recognized as an alternative to synthetic fungicides for environmental friendly control of plant diseases. A number of antagonistic microorganisms isolated from the soil rhizosphere and from the rhizoplane showed considerable promise in laboratory tests (Jeong et al., 2012).

**Integrated disease management**

In many countries rice is grown in the same season and the same field year after year, making it more susceptible to soil borne pathogens. Over the time, pathogen inoculum accumulates in crop soil or surrounding fields and can cause epiphytotic disease. Over use or over dependence on chemical control or any other single control method is not sufficient to manage rice ShB. A systemic control approach uniting all ShB disease management options may produce better pathogen management. Integrated disease management (IDM) of rice ShB is broad-based, ecological plant pathogen control
approach, combining all the available disease control methods with each method compensating the deficiencies of others (Kumar et al., 2009). It reduces the emphasis on fungicides by including other disease control methods. IDM is an environmentally-sensitive approach and is gaining popularity worldwide. A monitoring-based IDM program helps enhance the pathogen control and reduces environmental quality related to fungicide crop inputs. Environmental measures to minimize water and air quality problems using an IDM program should be considered for all pesticide or fungicide applications. This program in general covers all major pests and pathogens of rice. However, a suitable IDM program assembling all ShB disease control practices can be developed and used for profitable rice farming.

The main goal of an IDM program is to inhibit plant diseases from occurring by using resources with minimal environmental concerns. Before selecting the appropriate rice cultivar to grow, one should study the cropping system, disease history, pathogen lifecycle, and rotational plan for the chosen field. Collecting random soil samples in the field for nutrient, salinity, and pH analysis helps to determine field suitability and soil nutrient management for rice crop. Also, the soil should be sampled for potential disease-causing nematodes and soil borne pests and pathogens and treated as per IDM guidelines (Parker et al., 2002). Cultural practices such as determining bed size, preparing soil bed, choosing an irrigation system, selecting a planting configuration (number of seedlings, spacing etc.), eliminating weed and alternate host and determining recommended fertilizer applications are important considerations during field preparation. When land preparation is finished, the appropriate cultivar should be selected by considering the time and season of year in which it is to be grown and the range of ShB disease resistance. After planting, fertilizers should be applied based on prior soil sample test results. Monitoring pathogen or pathogen damage (disease symptoms) throughout crop growth until harvest is important to determine which management practices is needed. Ideal IDM program integrates all disease management options such as chemical, cultural (sanitation, crop rotation), biological, mechanical (tillage, radiation, or heating soil), and legal control methods. Fungicide compatibility with IDM programs is very important for sustainable agriculture. Chemicals with low toxicity towards beneficial organisms and non-target species will have
a strong competitive advantage over products with lower standards concerning human and environmental health (Groth, 2008).

**Candidates for biological control of rice pathogens**

Diverse groups of microbes exist in nature. Biological control agents are not limited to any specific group, but a very few groups of microbes have received attention and have been widely acclaimed as ideal candidates for biological control. Bacterial antagonists in general, *Pseudomonas* and *Bacillus* in particular, are thought to be the most appealing candidates for biological control (Weller, 1988). Bacilli are gram-positive endospore-producing bacteria that are tolerant to heat and desiccation, a feature that makes them very attractive for effective deployment. The pseudomonads are gram-negative rods and have simple nutritional requirements. They are known to be excellent colonizers and are widely prevalent in the rice rhizosphere (Sakthivel, 1989). A number of antagonistic bacteria identified from the rice rhizosphere soils of upland and lowland fields, diseased and healthy plants, and from rice field flood waters (Mew, 1986) have been broadly categorized as fluorescent or non-fluorescent strains. Among them, 91% of the former and 33% of the latter inhibited mycelial growth of *R. solani in vitro*. When used for seed bacterization, these strains reduced rice sheath blight (ShB) severity in greenhouse and field tests. Rosales et al. (Rosales, 1993) have identified different groups of bacterial antagonists for seed borne, foliar, and sclerotium-forming rice pathogens. These antagonists belonged to the genera *Bacillus*, *Pseudomonas*, *Serratia*, and *Erwinia*. A large number of bacterial strains possess the ability to protect rice plants from diseases such as blast (Balasubramanian, 1994), sheath blight (Vasantha Devi, 1989; Thara, 1994), sheath rot (Sakthivel, 1987), and stem rot (Elangovan, 1992). The exploitation of endophytes for biocontrol is an exciting possibility, especially for the control of vascular pathogens (Chen, 1995; Chanway, 1996; Hallmann, 1997). A limited number of fungal antagonists have also been reported against rice pathogens, particularly in the control of *R. solani*, among which *Trichoderma* spp. (Xu, 1999), *Penicillium*, *Myrothecium verrucaria*, *Chaetomium globosum*, and *Laerisaria arvalisare* known to be efficient.
Mechanisms of biological control

The term biological control was coined by the late Harry Smith of the University of California, who defined it as “the suppression of insect populations by the actions of their native or introduced enemies”. Sometime later, the U.S. National Academy of Sciences introduced some modifications to the definition, referring to biological control as “the use of natural or modified organisms, genes or gene products to reduce the effects of undesirable organisms and to favor desirable organisms such as crops, beneficial insects and microorganisms” (Research briefing, 1987). Obviously, due consideration has been given to the advances by the advent of molecular biology to plant pathology and to research in biological control. According to Shurtleff and Averre (1997), biological management or control refers to disease or pest control through counter balance of microorganisms and other natural components of the environment. It involves the control of pests (bacteria, fungi, insects, mites, nematodes, rodents, weeds) by means of living predators, parasites, disease-producing organisms, competitive microorganisms, and decomposing plant material, which reduce the population of the pathogen.

Biological control is often referred to as “classical biological control”, reflecting the historical predominance of this approach. It generally involves importation and establishment of a nonnative natural enemy population for suppression of nonnative or native organisms. Augmentation biological control includes activities in which natural enemy populations are increased through mass culture, periodic release (either inoculative or inundative), and colonization for suppression of native or exotic pests. Inoculative releases are intended to colonize natural enemies early in a crop cycle so that they and their offspring will provide pest suppression for an extended period of time. Inundative releases are conducted to provide rapid pest suppression by the released individuals alone, with no expectation of suppression by their offspring. These two approaches represent extremes on a continuum of activities, with most augmentative releases being a hybrid of the two (Orr, 2000). Many species of actinomycetes, particularly those belonging to the genus *Streptomyces* have been reported to produce volatile organic compounds with antimicrobial activity (Li et al., 2012). Conservation biological control can be defined as the study and modification of human influences that allow natural enemies to realize their
potential to suppress pests. The volatile substances of *S. philanthi* RM-1-138 affected the pathogenic fungus by alterations to their hyphal morphology, and led to a gradual destruction of mycelia and cell death due to cytoplasmic extrusions (Sawai et al., 2013). While augmentation deals with laboratory reared natural enemies or microbial antagonists, conservation deals with resident enemy populations. Therefore, it involves (i) identification and remediation of negative influences that suppress natural enemies and (ii) enhancement of systems such as habitats for natural enemies. Biological protection against infection is accomplished by destroying the existing inoculum, by preventing the formation of additional inoculum, or by weakening and displacement of the existing virulent pathogen population.

**Antibiosis**

Secondary metabolites are commonly observed during the antagonist pathogen interaction. The inhibitory metabolites produced by antagonists may be effective against a wide range of pathogens. Such compounds are referred to as broad-spectrum antibiotics. On the other hand, some metabolites may be active against only a specific organism. In biocontrol mechanisms, one or more antibiotics play a role in disease suppression. The role of antibiotics in biocontrol of plant diseases has been reviewed extensively by many researchers (Fravel, 1988; Thomashow and Weller, 1990; Dowling and O’ Gara, 1994; Handelsman and Stabb, 1996; Chin A Woeng et al., 2003). *S. griseoviridis* (a spore suspension of Mycostop) has the ability to produce metabolites which adversely affected sporulation and spore germination and inhibition of mycelial growth indicative of antibiosis mechanism of biocontrol (Junaid et al., 2013). Pyoluteorin inhibits *Pythium ultimum*, the causal organism of seedling rot of cotton and pyrrolnitrin inhibits the other cotton pathogens *viz.*, *R. solani*, *Thielaviopsis basicola*, *Pythium* sp. and *Verticillium dahliae* (Howell and Stipanovic, 1979; 1980). Strains of *P. fluorescens* produce a broad-spectrum antibiotic and among them, DAPG producing strains were recognized as the most effective rhizobacteria controlling diseases caused by soil-borne pathogens (Keel et al., 1992; De Souza et al., 2003). The antibiotic over producing strains showed improved biocontrol ability than the other strains in several host pathogen systems. Suppression of take-all disease of wheat caused by *G. graminis* var. *tritici* has been correlated with the
colonization of the DAPG producing *P. fluorescens* Q2-87 (Bonsall et al., 1997).

Shanmugam et al., (2001) have purified and characterized an extracellular alpha-glucosidase protein from *Trichoderma viride* which degrades a phytotoxin associated with ShB disease in rice. Phenazine-1-carboxamide have been purified and characterized from a growth-promoting biocontrol bacterium, *Pseudomonas aeruginosa* MML2212 against sheath blight of rice (Shanmugaiah et al., 2010).

**Competition**

Competition is an important mechanism in biological control where two or more microorganisms competing with each other for nutrients and space in the same habitat. Here, the successful competitor will suppress the other(s) due to faster growth and efficient utilization of nutrients. In general, most of the biocontrol agents are aggressive in competition as they grow faster and rapidly utilize the available nutrients there by suppressing the growth of the pathogens. Siderophere production plays a major role in effective colonization of microorganisms (Raaijmakers et al., 1994; De Bellis and Ercolani, 2001). Also, displacement of root microflora by rapidly colonizing BCAs is not an uncommon phenomenon (Kloepper and Schroth, 1981; Chao et al., 1986). The establishment and survival of the introduced bacteria could be due to high growth rate relative to that of indigenous microbial population, resistance to adverse environmental conditions (Chen and Alexander, 1983) or starvation (Acea et al., 1988), cell motility (DeWeger et al., 1987) and production of substances that aid in adherence to plant roots (Vesper, 1987; Anderson et al., 1988; Van Peer et al., 1990). Although *Trichoderma* exhibit diverse biocontrol mechanisms during antagonistic interaction with pathogens, their fast growing ability is considered very important. *Trichoderma* spp. cultured with fungal pathogens in dual plate grew faster and restricts the mycelial growth of pathogens by rapid utilization of nutrients and occupies the available space (Mathivanan, 2005).

**Parasitism**

Destruction of pathogen’s structures is the common phenomenon in parasitism. They show necrotrophy and utilize nutrients from the dying or dead host. The invasion is often initiated by attack and lysis of hyphae or survival structures (Defago and Hass,
Fungi parasitizing other fungi are termed as mycoparasites. The fungal antagonists *Trichoderma* spp. grow towards the hyphae of pathogen and made physical attachment by coiling around the host (pathogen) hyphae. During the host parasite interaction, *Trichoderma* produces hydrolytic enzymes that degrade fungal cell walls. In some cases both cell wall degrading enzymes and antibiotics act synergistically and offer effective inhibition of pathogen growth (Mathivanan, 1995; Nagarajkumar et al., 2004).

**Antibiotic potential of actinomycetes**

Secondary metabolites are mainly made by filamentous microorganisms undergoing complex schemes of morphological differentiation, e. g., molds make 17 % of all described antibiotics and actinomycetes make 74%. Some species are prolific in secondary metabolism: strains of *Streptomyces hygroscopicus* produce over 180 different secondary metabolites. Estimates of the number of microbial secondary metabolites thus far discovered vary from 8000 up to 50,000 (Berdy, 2005; Omura, 1992; Fenical, 1993). Soil, straw, and agricultural products often contain antibacterial and anti-fungal substances. These are usually considered to be “mycotoxins,” but they are nevertheless antibiotics. The advent of penicillin, which signaled the beginning of the antibiotics era, was closely followed by the discoveries of Selman A. Waksman, a soil micro-biologist at Rutgers University. He and his students, especially H. Boyd Woodruff and Hubert Lechevalier, succeeded in discovering a number of new antibiotics from the the filamentous bacteria, the actinomycetes, such as actinomycin D, neomycin and the best-known of these new “wonder drugs”, streptomycin.

Actinomycetes are a group of prokaryotic organisms belonging to subdivision of the Gram-positive bacteria phylum. Most of them are in subclass Actinobacteridae, order Actinomycetales. All members of this order are characterized in part by high G+C content (>55 mol %) in their DNA (Stackbrandt et al., 1997). They are filamentous bacteria which produce two kinds of branching mycelium, aerial mycelium and substrate mycelium. The aerial mycelium is important as the part of the organism that produces spores. For this reason they have been considered as fungi, as is reflected in their name, akitino means ray and mykes means mushroom/fungus, so actinomycete was called ray fungi. Actinomycetes are the most widely distributed group of microorganisms in nature and are also well known
as saprophytic soil inhabitants (Takizawa et al., 1993). The soil actinomycetes produce a volatile compound called geosmin, which literally translates to “earth smell” (Gust et al., 2003). These organic substances contribute the odour that occurs in the air when rain falls after a dry spell of weather. In natural habitats, *Streptomyces* are common and are usually a major component of the total actinomycetes population. Some actinomycete genera such as *Actinoplanes*, *Amycolatopsis*, *Catenuloplanes*, *Dactylosporangium*, *Kineospora*, *Microbispora*, *Micromonospora*, *Nonomuraea*, which are often very difficult to isolate and cultivate due to their slow growth, are called rare actinomycetes.

Actinomycetes have proven to be a rich source of important natural products especially antibiotics. Thus far, approximately 10,000 antibiotics have been found, and almost half of them are produced by *Streptomyces* that originated in the soil (Lazzarini et al., 2000). The majorities of actinomycetes are free living and found widely distributed in many natural environments including various soil, freshwater habitat, marine habitat, organic matter habitats and colonizing plants. Actinomycetes are well known as a group of filamentous, Gram-positive bacteria that produce many useful secondary metabolites, including antibiotics and enzymes (Williams et al., 1993). They are a group of branching unicellular organisms which reproduce either by fission or by means of special spores or conidia. They are closely related to the true bacteria, frequently, they are considered as higher filamentous bacteria. They usually form a mycelium which may be of a single kind designated as substrate (vegetative) or of two kinds, substrate (vegetative) and aerial (sporogenous). They are usually placed in a separate order, the Actinomycetales, which is said to be distinct from the Eubacteriales or the true bacteria. The actinomycetes are generally recognised to represent a large and a heterogeneous group of microorganisms, comprising several genera and numerous species. They vary greatly in their morphology, physiology and biochemical activities. They play an important role in nature by bringing about the decomposition of complex plant and animal residues and the liberation of a continuous stream of available elements, notably carbon and nitrogen essential for fresh plant growth.

Actinomycetes are that group of intracellular branching organisms which reproduce either by fission or by means of spores or conidia. From an ecological point of view,
Actinomycetes stand in an intermediate position between the fungi and the bacteria in terms of numerical frequency of occurrence in various biotypes. They are closely related to the true bacteria and frequently they are considered as higher filamentous bacteria. The outstanding fungal characteristic is a morphological one, the possession of a true branching mycelium. In addition to possessing mycelium, actinomycetes may also show strong parallels with the true fungi in their production of sporangia and motile spores. However, mycelium diameter and spore size is of a lower order of magnitude in actinomycetes as compared with the fungi, averaging 1 µm only. They usually form a mycelium, which may be of a single kind designated as substrate (vegetative), or of two kinds, substrate (vegetative) and aerial mycelium.

They produce a wide variety of spore types which includes the endospore, long regarded as the typical spore structure of eubacteria (Waksman, 1959). Some genera such as Streptomyces and Micromonospora form an extensive branched mycelium composed of individual hyphae, subdivided by infrequent cross walls. Actinomycetes occur in a wide range of environments in which they have the ability to grow on most naturally occurring substrates (Goodfellow et al., 1989). *Streptomyces hygroscopicus* VMCH-2 isolated from soil of paddy fields was able to antagonize *Pyricularia oryzae* and *Rhizoctonia solani* (Priya and Kalaichelvan, 2011). *Streptomyces lydicus* WYEC108 (S1) are known for the production of antimicrobial metabolites, have a value in biological control program focusing not only on fungal diseases such as early blight and anthracnose but also on bacterial spot of field tomatoes (Cuppels et al., 2013). A promising strain of *Streptomyces* sp. with agricultural traits has been isolated and studied for plant growth promotion and disease management (Mansoor et al., 2012). Actinomycetes have the potential to antagonize in vitro the growth of fungal pathogens such as, *A. niger*, *Fusarium* sp., *Curvularia* sp., *Helminthosporium* sp., *Alternaria* sp., *Rhizoctonia* sp., *Colletotrichum* sp., and *P. capsici* (Zahaed et al., 2014). *Streptomyces albovinaceus*, *Streptomyces caviscabies*, *Streptomyces griseus*, *Streptomyces setonii*, and *Streptomyces virginiae* selected as antagonists of *Moniliophthora* (ex *Crinipellis*) *perniciosa*, the causal agent of cacao Witches’ broom, were examined *in vitro* to detect production of chitinases, β-1,3-glucanases, and cellulases (Macagnan et al., 2008).
Biocontrol potential of *Streptomyces*

Actinomycetes include therapeutically and agriculturally important compounds (Tanaka and Omura, 1993; Mincer et al., 2002). Actinomycetes play an important role in the rhizosphere by secreting a wide range of antimicrobial products, thus preventing the growth of common root pathogens. An effective and convenient method for the application of biocontrol agents against sheath blight of rice is a global necessity. Natural products with antifungal and antibacterial activity also arise in plants, either as pre-formed secondary metabolites or from pathogen induced metabolism (phytoalexins). An indigenous *Streptomyces* isolate CTF9, exhibited promising antifungal activity against *Mucor miehei* and *Candida albicans* in pre-screening studies and the active metabolites was purified and elucidated the structure as phenyl acetic acid and indolyl-3-lactic acid by mass spectrometry (MS) and NMR analysis (Imran et al., 2011). The Jinggangmycin, an antibiotic produced by *S. hygroscopicus* var. *jinggangensis*, is widely used for control of sheath blight of rice caused by *R. solani* in China (Shen 1996). Rhizoxin exhibits potent activity against several phytopathogenic fungi, including *Pyricularia oryzae* and *Rhizoctonia solani* (Iwasaki, 1984). Notonesomycin A (Sasaki, 1986) is a complex macrolide that has been isolated from the mycelium of *Streptomyces aminophilus* subsp. *notonesogenes* 647-AV and has been found to be effective in the treatment of sheath blight disease of rice in a glasshouse test (Sasaki, 1986).

Neopolyoxins show inhibitory activity against phytopathogenic fungi such as *Pyricularia oryzae*, *Rhizoctonia solani*, and *Botrytis cinerea* at concentrations of 0.05-50 µg ml⁻¹ (Kobinata, 1980). Blasticidin S9 isolated from culture filtrates of *Streptomyces griseochromogenes* was the first successful agricultural antibiotic to be developed in Japan. Griseofulvin was introduced into plant protection for the control of early blight of tomato and *Botrytis cinerea* infection in lettuce (Brian, 1951). Blasticidin S shows a potent curative effect against rice blast disease caused by *Pyricularia oryzae* (Misato, 1959) and has been in practical use for the control of rice blast since 1961. Kasugamycin is a water-soluble antibiotic that is produced by *Streptomyces kasugaensis* (Umezawa, 1965). It rapidly superseded blasticidin S as an agricultural antibiotic for control of rice blast, because of the wide margin between its curative and its phytotoxic dosage.
Validamycin A is an antifungal antibiotic that was developed in Japan for the control of rice sheath blight. It was isolated from the culture filtrate of *Streptomyces hygroscopicus* subsp. *limoneus*, which produces five additional components (designated validamycins B-F) together with validoxyl-amines A and B (Horii, 1972). Validamycin A is the main component of the validamycin complex and is specially effective against certain plant diseases caused by *Rhizoctonia* species as well as against sheath blight of rice plants (Wakae, 1975). One spraying of a solution of 30 ppm of validamycin A gives good control of sheath blight, and it has been used commercially for this purpose since 1973. Dapiramicin A exhibits strong *in vivo* activity against sheath blight of rice plants. The activity was equivalent to that of the standard validamycin in a greenhouse test but dapiramicin A was less effective in field tests. *Streptomyces globisporus* suppressed mycelial growth of numerous plant pathogenic fungi, especially that of *Magnaporthe oryzae*, *Bipolaris maydis* and *Cryphonectria parasitica* (Qili et al., 2011). *Streptomyces griseus* H7602 has the capacity to protect pepper plants against *Phytophthora capsici* and established its role as a biocontrol agent (Xuan et al., 2012).

**Plant growth promoting rhizobacteria (PGPR)**

Rhizosphere isolated, free living soil bacteria with proven plant beneficial properties are known as plant growth-promoting rhizobacteria (PGPR) (Kloepper and Schroth, 1978). Besides, PGPR role in increasing plant or root growth, they directly influence increased N uptake, phosphate solubilization, phytohormone synthesis, and production of iron chelating siderophores (Lalande et al., 1989; Bowen and Rovira, 1999; Wu et al., 2012). Some PGPR are used commercially to enhance plant growth and health. For example, PGPR formulations for seed, soil, and spray treatments (leaves and fruits) have been developed. Seed treatment of rice with PGPR resulted in increased root and shoot length of seedlings (Kumar et al., 2009). PGPR beneficial effects have been reported in wide range of crops (Dubey, 1996). Based on PGPR relationship with plants, they are known as symbiotic bacteria and free living rhizobacteria (Khan, 2005). PGPR are also known for biological control of various soil-inhabiting bacteria. PGPR are used in ecofriendly products. They are naturally available in the environment and provide resistance against a broad spectrum of pathogens (Radjacomare et al., 2004). PGP
microbes may promote plant growth either by direct stimulation such as iron chelation, phosphate solubilization, nitrogen fixation and phytohormone production or by indirect stimulation such as suppression of plant pathogens and induction of resistance in host plants against pathogens (Hao et al., 2011; Panhwar et al., 2012).

The microbial populations in rhizosphere can be influenced by soil characteristics, agronomic practices, and plant type (Radjacommare et al., 2004). Inconsistent results of PGPR applications between the laboratory, greenhouse, and field studies can be due to changes in climate or soil (Lucy et al., 2004). An improved understanding of microbial population dynamics is needed before amending the farming practices to enhance plant growth and yield. PGPR induce pathogen suppression by different modes of action such as antagonism, competition for space and essential nutrients, and initiation of systemic resistance (ISR) (Wu et al., 2012). The concept of activating plants defense pathways to control pathogen infection is appealing, though difficult to implement effectively. Induced resistance occurs when a plant, once appropriately stimulated, exhibits an enhanced resistance upon challenge inoculation with the pathogen (Dutta et al., 2008). This type of resistance is mostly systemic in nature, spreading from point of infection to other distant plant parts (Dutta et al., 2008). Seed treatment with some PGPR strains induced ISR in treated plants (Kloepper et al., 1999; Wu et al., 2012). Various bacterial determinants are claimed to elicit ISR. For example, fluorescent pseudomonads produce siderophores, antibiotics (Persello-Cartieaux et al., 2003) and Bacillus strains produce cyclic peptides and aminopolyols, which triggers plant ISR (Yu et al., 2002).

Although PGPR are grouped as various bacterial taxa, genus Pseudomonas and Bacillus are commercially more exploited (Kumar et al., 2009). Genus Bacillus is considered to be one of the most diverse and comprehensively studied PGPR group (Garbeva et al., 2003; Beneduzi et al., 2008). Several Bacillus and Paenibacillus were commercially exploited for developing common plant growth promoters and biological fungicides, insecticides, nematicides (Beneduzi et al., 2008). In addition, some Bacillus spp. has shown increase in the plant growth and yield (Pal and Jalali, 1998; Ponmurugan and Shyamkumar, 2011). Bacillus spp. are spore forming, gram-positive, rod shaped bacteria which are highly tolerant to adverse environmental conditions (Kokalis-Burelle et
The resistant endospores of *Bacillus* spp. provide tolerance to pH extremes, pesticides, fertilizers, and heavy metals (Ponmurugan and Shyamkumar, 2011). Endospore formation also confers bacterial stability during formulation and storage of products, thereby making it a valuable commercial bacterial inoculant (Kokalis-Burelle et al., 2006). PGPR might be more effective when combined with other ShB disease control methods through an integrated approach. Endophytic actinomycetes isolated from rice plants are potent natural sources and can be applied in agriculture (Madhurama et al., 2012). PGP traits of actinomycetes have been reported on wheat (Sadeghi et al. 2012) and rice (Gopalakrishnan et al. 2013).

**Indole-3-Acetic Acid**

Auxins are classified as the main phytohormone which regulate growth, ontogeny, morphogenesis, adaptive and repair processes in plants. It was shown that auxins play certain role in root formation, elongation and lastly, promotion of ethylene production subsequently evolution and ripening fruits. At the cellular levels, auxins can change characteristics of the cell wall, protoplasm, osmosis and cell respiration. Auxin was present in more than one chemical forms in plant tissues, the active compound might be indole-3-acetic acid (IAA). IAA is the common natural auxin that shows all auxin doing actions and extensively affects plant physiology. Production of IAA by microbial isolates varies greatly among different species and strains and depends on the availability of substrates. Different biosynthetic pathways for IAA production exist, sometimes in parallel in the same organism (Davies, 1995). For many years it was assumed that tryptophan was the only precursor of IAA. *Trp* is considered as the main precursor for the biosynthesis of IAA in plants and microorganisms, but with several possible pathways and intermediates involved in generating the final product, IAA (Thirman and Scoog, 1940).

**Formulations of Biocontrol Agents (BCAs)**

The success of a biocontrol agent depends largely on the ability of the introduced agent to establish itself in the new environment and maintain a threshold population on the planting material or rhizosphere. Commercial production and application of biocontrol agents at farm level demands a few prerequisites, such as:
(i) they have to be viable for longer period (longer shelf life), and

(ii) they need to be tolerant to variable weather conditions and physiological stresses associated with transportation, storage, and application.

Fungal antagonists can be formulated by fluid-bed granulation using dextrin as a binder and a reduced content of alginate. Fungal antagonists can also be formulated as wettable powder, granular or powder using some non reactive substrates such as talc powder. Gram-positive microorganisms such as \textit{Bacillus} sp. and actinomycetes offer heat- and desiccation-resistant spores that can be formulated into stable, dry-powder products (Emmert and Handelsman, 1999). The gram negative microorganisms which are not desiccation tolerant, traditionally formulated into various solid carriers such as wettable powder. Liquid formulations with either aqueous or mineral oil are user friendly. More recently, bacterial antagonists were formulated as floating pellets in the biological suppression of sheath blight disease (Wiwattanapatapee et al., 2007).

Recently \textit{S. pseudovenezuelae} strain was formulated with animal bone charcoal and its disease suppressive ability was tested against \textit{P. aphanidermatum} and \textit{F. oxysporum} f. sp. \textit{radicis-lycopersici}. The formulation was effective against \textit{F. oxysporum} f. sp. \textit{radicis-lycopersici} (Postma et al., 2013). Efficacy of some new fungicide formulations namely kresoxim methyl 40% + hexaconazole 8%, hexaconazole, propiconazole, hexaconazole, tricyclazole, and carbendazim 12% + mancozeb 63% was compared against economically important rice disease sheath blight pathogen \textit{Rhizoctonia solani} (Lore et al., 2012). Spore-based formulations of microbial pesticides were recently developed for control of rice sheath blight (Soe and De Costa, 2012). Application of Thifluazamid was found to be extremely efficient in controlling sheath blight (Prasanna Kumar and Veerabhadraswamy, 2014).

\textbf{Conclusion}

Biological control of fungal plant diseases is gaining importance in recent years as the chemical fungicides pose serious threats to the environment and public health. Sheath blight (ShB) disease caused by \textit{R. solani} is a serious concern for successful cultivation of rice as disease control is a difficult task. Chemical control and cultural practices are less
effective and breeding for ShB resistance is not successful as resistance genes have not been discovered so far. In these circumstances, biological control is an ideal choice for the management of ShB of rice. Among biocontrol agents, actinomycetes are considered as an important one as they not only produce antifungal antibiotics but also improve the plant growth. Different mechanisms are involved in biological control and actinomycetes exercise some of them. They are capable of producing numerous secondary metabolites during antagonistic pathogen interaction. However, there is remarkable scope for the discovery of novel metabolites/antibiotics from the actinomycetes especially *Streptomyces* sp. and research focus in this line is worthwhile.