

Chapter 2

Diversity Utility and Potential of Actinobacteria in the Agro-Ecosystem

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Abstract Actinobacteria formerly referred to as Actinomycetes are Gram-positive saprophytic bacteria, with widespread distribution in nature. They occur in the terrestrial and aquatic environments, and play a dominant role in natural geochemical cycles. Mankind's interest in Actinobacteria, originated in the early nineteenth century, primarily due to their abilities to decompose organic matter and produce antibiotics. Amongst Actinobacteria, the genus *Streptomyces* has received widespread attention due to its ability to produce biologically active compounds that have been widely exploited against infectious agents. But emerging trends in microbial architecture and taxonomy have led to the re-defining of this group of microbes, and have led to the inclusion of several known and novel bacterial genera and species, within the Phylum Actinobacteria. These are widespread in the agro-environment, especially in the rhizosphere, where they produce a wide range of biologically active metabolites and influence plant development in a myriad fashion. We attempt to capture the existing information on the diversity and utility of Actinobacteria in the agro-environment, and the interventions that are required in the future in order to fully exploit this class of microbes, for the benefit of mankind.

2.1 Actinobacteria—An Introduction

Actinobacteria formerly referred to as Actinomycetes or Ray fungi are Gram-positive, saprophytic bacteria, with widespread distribution in nature. The Phylum Actinobacteria represents one of the largest taxonomic units, among the currently recognized major lineages within the domain *Bacteria* (Stackebrandt et al. 1997). Actinobacteria are Gram-positive with a high G+C content in their DNA. The G+C content ranges from 51 % in some *Corynebacteria* to more than 70 % in *Streptomyces* and *Frankia*. An exception to this is the genome of the obligate pathogen *Tropheryma whipplei*, with less than 50 % G+C. Actinobacterial morphologies range from coccoid (*Micrococcus*) or rod-coccoid (e.g., *Arthrobacter*) to fragmenting hyphal forms (e.g., *Nocardia* sp.) or permanent and highly differentiated branched

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Table 2.1 A schematic representation of the diversity within Phylum Actinobacteria as laid out in the Bergeys Manual of Systematic Bacteriology (2nd edition)—Volume 5. (Source: Abridged from Ludwig et al. (2012b)).

Phylum: Actinobacteria					
Classes (6)					
<i>Actinobacteria</i>	<i>Acidimicrobiia</i>	<i>Coriobacteriia</i>	<i>Nitriliruptoria</i>	<i>Rubrobacteria</i>	<i>Thermoleophilina</i>
Orders (15 + 1 ^a)	Order (1)	Order (1)	Orders (2)	Order (1)	Order (2)
Families (43)	Families (2)	Family (1)	Families (2)	Family (1)	Families (4)
Genera (128)	Genera (5)	Genera (13)	Genera (2)	Genus (1)	Genera (4)

The figures in parentheses represent the numerical value of the taxonomical unit

The numerical value includes taxa that appear in the approved list, validly published and taxa that are not validly published as on 01-01-2008

^a Order—*Incertae sedis* (uncertain placement)

mycelium e.g., *Streptomyces* sp. (Atlas 1997). Some unusual developmental features displayed by some actinobacterial genera, include the production of sporulating aerial mycelium which is a common feature of the genus *Streptomyces* or the persistent non-replicating state exhibited by certain mycobacteria. While most members of the Actinobacteria are aerobic, few can grow under anaerobic conditions. Though widely known as soil dwellers, Actinobacteria are also present in a wide variety of aquatic and marine environments (Asquith et al. 2013).

The metabolic versatility of Actinobacteria stems from their ability to secrete diverse metabolites ranging from extracellular enzymes to antibiotics. Notable among these metabolites are the antibiotics (Lechevalier and Lechevalier 1967), by virtue of which the Actinobacteria tend to occupy a coveted position in the pharmaceutical industry. Actinobacteria also exhibit diverse lifestyles in nature, wherein they occur as pathogens (e.g., *Mycobacterium* sp., *Nocardia* sp., *Tropheryma* sp., *Corynebacterium* sp., and *Propionibacterium* sp.), soil inhabitants (*Streptomyces* sp.), plant commensals (*Leifsonia* sp.), nitrogen-fixing symbionts (*Frankia*), and gastrointestinal tract inhabitants (*Bifidobacterium* sp.) (Ventura et al. 2007). Considering their morphological, physiological and functional utility, Actinobacteria have been rightly assigned a distinct position amongst bacteria. The diversity and importance of the Actinobacteria can be gauged from the fact that the second edition of the Bergey's Manual of Determinative Bacteriology has dedicated an entire volume for the Phylum Actinobacteria. This volume comprises of two parts, and contains descriptions of Actinobacteria based on their phylogenetic affinities (Ludwig et al. 2012b). The Phylum Actinobacteria is now divided into six classes, which contain several orders and families (Ludwig et al. 2012a). A brief schematic representation of the taxonomic distribution of Phylum Actinobacteria is given in Table 2.1.

Subsequent to the taxonomic delineation of Actinobacteria, as outlined in the Bergey's manual, many new genera and species continue to be validly published. This chapter is intended to throw light on the diversity, potential and utility of Actinobacteria, within the agro-ecosystem, where they play important roles in nutrient cycling, disease suppression and plant growth promotion, besides causing diseases in a number of cultivated plants.

2.2 Diversity and Utility of Actinobacteria in the Agro-Ecosystem

Within agroecosystems, actinobacteria have several utilities, which are described in greater detail in the ensuing sections.

2.2.1 *Actinobacteria as Plant Disease Suppressors and Sources of Agro-Active Antibiotics*

Actinobacteria have long gained significance in the agro-environment due to their ability to produce a wide range of antibiotic molecules that suppress the growth and development of a wide range of soil dwelling plant pathogens. It is estimated that as many as three-quarters of all *Streptomyces* species are capable of antibiotic production (Alexander 1977). This can be gauged from the fact that nearly 1000 secondary metabolites were discovered from Actinobacterial sources during the period 1988–1992, with the genus *Streptomyces* being single most contributor to this (Tanaka and Omura 1993). Apart from antibiotic production, several Actinobacteria have the ability to colonize plant surfaces and thereby exclude plant pathogens. Parasitization of the fungal pathogens is another mode of plant disease suppression by Actinobacteria (Yuan and Crawford 1995). Some Actinobacteria impede the growth of plant pathogenic organisms by the production of high levels of extracellular lytic enzymes such as the chitinases and the glucanases (Mahadevan and Crawford 1997; El-Tarabily 2006). The degradation of signal molecules involved in the pathogenesis quorum-sensing (Uroz et al. 2003), and the induction of plant resistance mechanisms (Shimizu et al. 2005; Conn et al. 2008) are also commonly encountered amongst Actinobacteria.

Most path breaking discoveries of agro-active antibiotic molecules originated from Japan, during the later part of the last century and many of the compounds are still in use. Some of the early important agro-active antibiotic molecules that were isolated from Actinobacteria, and have been put to commercial use are described herein. Kasugamycin a bactericidal and fungicidal metabolite obtained from *Streptomyces kasugaensis* (Umezawa et al. 1965) inhibits protein synthesis in microorganisms but not in mammals. The Hokko Chemical Industries, Japan has developed systemically active kasugamycin for control of rice blast caused by the fungus *Pyricularia oryzae* and bacterial diseases caused by *Pseudomonas* in several crops. Similarly, Polyoxin B and D isolated as metabolites of *Streptomyces cacaoi* var. *asoensis* by Isono et al. (1965), primarily interfere with the fungal cell wall synthesis by specifically inhibiting the enzyme chitin synthase (Endo and Misato 1969). Polyoxin B was deployed against a wide range of fungal pathogens in fruits, vegetables and ornamental crops. It is also used to control rice sheath blight caused by *Rhizoctonia solani*. The Validamycin family of antibiotics were discovered in 1968. Validamycin A is a pro-drug which is converted within the fungal cell to validoxylamine A, an extremely strong inhibitor of trehalase (Kameda et al. 1987). This mode of action gives, Validamycin A, a toxicological

edge since vertebrates do not depend on the hydrolysis of the disaccharide trehalose for their metabolism. The antifungal metabolite Mildiomycin obtained from *Streptovercillium rimofaciens* (Iwasa et al. 1978), is highly active against several powdery mildews on various crops (Harada and Kishi 1978). This inhibits fungal protein biosynthesis and is fairly safe to higher forms of life (Feduchi et al. 1985).

Avermectins are a series 16-membered macrocyclic lactone derivatives, obtained from the soil dwelling actinomycete *Streptomyces avermitilis*. They possess anthelmintic and insecticidal properties (Ōmura and Shiomi 2007). Eight different Avermectins were isolated as four pairs of homologous compounds. These compounds have a major and minor components ranging in ratios from 80:20 to 90:10 (Pitterna et al. 2009). Other compounds derived from the Avermectins include Ivermectin, Selamectin, Doramectin and Abamectin. The lethality of Avermectins has been attributed to their ability to block the transmittance of electrical activity in nerves and muscle cells by stimulating the release and binding of gamma-aminobutyric acid (GABA) at nerve endings. This leads to an influx of chloride ions into the cells, thereby causing hyperpolarisation and subsequent paralysis of the neuromuscular systems (Bloomquist 1993, 1996).

In agriculture, Avermectin B1 (abamectin), has been widely used for the development of formulations for the control phytophagous mites and insect pests on a variety of agricultural and horticultural crops worldwide. Abamectin is currently registered for use on ornamental plants, citrus, cotton, pears and vegetable crops as a foliar spray. It has low toxicity to non-target beneficial arthropods but it is highly unstable to light and has been shown to photodegrade rapidly on plant and soil surfaces and in water following agricultural applications. It has been found to be easily degraded by soil microorganisms, with very low levels of residues in crops. Abamectin does not persist or accumulate in the environment. Its instability combined with low water solubility and tight binding nature to soil limit Abamectin's bioavailability in non-target organisms and are considered as limiting factors for its ability to contaminate the environment (Lasota and Dybas 1990).

The Hindustan Antibiotics Limited (HAL), India has been a pioneer in the development of antibiotics for agro-usage. Two popular products manufactured by this firm are Streptocylene (a combination of Streptomycin and Tetracycline), which is a broad-spectrum systemic antibacterial antibiotic highly active against phytopathogenic bacteria and has shown effective control of various bacterial crop diseases. It is recommended for both prophylactic as well as curative applications. Aureofungin a metabolic product of *Streptovercillium cinnamomeum*, is a fungicide which is original research product of HAL. It has broad spectrum activity against various fungal infections (Dhuley et al. 1995).

Though reports of novel antibiotics from Actinobacteria are quite regular in scientific literature, reports of proper elucidation of their structure and mode of action on target and non target organisms are quite scarce. One such well characterized molecule is the metabolite 2-methylheptyl isonicotinate obtained from the culture filtrate of *Streptomyces* sp. 201. This bioactive compound, with antifungal and antibacterial activity, showed marked inhibition against dominant soil-borne phytopathogens such as *Fusarium oxysporum*, *F. moniliforme*, *F. semitectum*, *F. solani*

Table 2.2 Metabolites production by Actinobacteria in relation to plant disease suppression

Actinobacterium	Metabolite	Reference
<i>S. kasugaensis</i>	Kasugamycin	Umezawa et al. (1965)
<i>Streptomyces</i> <i>cacaoi</i> var. <i>asoensis</i>	Polyoxin B and D	Isono et al. (1965)
<i>S. griseochromogenes</i> 2 A-327	Blasticidin S	Kono et al. (1968)
<i>Streptoverticillium rimofaciens</i>	Mildiomycin	Iwasa et al. (1978)
<i>S. hygroscopicus</i> var. <i>geldanus</i>	Geldanamycin	Rothrock and Gottlieb (1984)
<i>S. griseus</i>	Faeriefungin	Smith et al. (1990)
<i>Micromonospora carbonacea</i>	Cellulase	El-Tarabily et al. (1996)
<i>S. olivaceoviridis</i> , <i>S. rimosus</i> <i>S. rochei</i>	Auxins, Gibberillins, Cytokinins	Aldeasuquy et al. (1998)
<i>S. olivaceoviridis</i> , <i>S. rimosus</i> <i>S. rochei</i>	Amylase, Proteinase	Aldeasuquy et al. (1998)
<i>S. violaceusniger</i> YCED9	Guanidylfungin A	Trejo-Estrada et al. (1998)
<i>S. humidus</i>	Phenylacetic Acid	Hwang et al. (2001)
<i>S. padanus</i>	Fungichromin	Shih et al. (2003)
<i>S. chinaensis</i> AUBN1/7	Resistoflavin	Gorajana et al. (2005)
<i>Streptomyces</i> sp. B8005	Resistomycin and Tetracenomycin D	Kock et al. (2005)
<i>Streptomyces</i> sp. ACH505	Auxofuran (fungal growth promoter)	Riedlinger et al. (2006).
<i>Actinoplanes campanulatus</i>	β -glucanase	El-Tarabily et al. (2009)
<i>Streptomyces</i> CMU-H009	Indole Acetic Acid	Khamna et al. (2010)
<i>Streptomyces</i> sp. 5 strain	Increased Dehydrogenase activity	Stamenov et al. (2012)

and *R. solani*. The compound had no effect on seed germination and seedling development of the test plant species (Bordoloi et al. 2002). Oligomycins A and C, are macrolide antibiotics produced by the actinobacterium *Streptomyces diastaticus*, and exhibit a strong activity against *Aspergillus niger*, *Alternaria alternata*, *Botrytis cinerea* and *Phytophthora capsici* (Yang et al. 2010). The metabolites produced by Actinobacteria in relation to plant disease suppression are listed in Table 2.2.

Besides antibiotic molecules, commercial biocontrol formulations containing Actinobacteria as active ingredients are also available as tools of plant health management. Mycostop®, a biofungicide used for the control of *Fusarium* wilt of carnation and root rot disease of cucumber, contains living *Streptomyces griseoviridis* cells (White et al. 1990). Actinovate® a biocontrol formulation registered in USA, contains the actinobacterium, *S. lydicus* as its active ingredient and has been recommended for a wide range of environments ranging from green houses to turf grasses. MicroPlus® is an inoculum of *Streptomyces lydicus* WYEC 108, that has been reported to possess both disease suppression and plant growth promotion abilities. In an early report on the insect pathogenic properties of Actinobacteria, *Brevibacterium frigoritolerans* has been reported to cause bacteremia like symptoms in the soil borne larvae of the subterranean insect pests *Anomala dimidiata* and *Holotrichia longipennis*. Grub mortality occurred between the second and fifth

Table 2.3 Actinobacteria reported to possess antagonistic potential against plant pathogens

Actinobacterium	Plant pathogen	Reference
<i>S. griseochromogenes</i> 2A-327	<i>Alternaria</i> sp	Kono et al. (1968)
<i>Nocardia dassonvillei</i>	<i>Fusarium oxysporum</i> f.sp. <i>albedinis</i>	Sabaou et al. (1983)
<i>Spirillospora albida</i>	<i>Phytophthora megasperma</i> var. <i>glycinea</i>	Sutherland et al. (1984)
<i>S. hygroscopicus</i> var. <i>geldanus</i>	<i>Rhizoctonia solani</i>	Rothrock and Gottlieb (1984)
<i>Micromonospora globosa</i>	<i>Fusarium udum</i>	Upadhyay and Rai (1987)
<i>S. griseus</i>	<i>Fusarium</i> spp.	Smith et al. (1990)
<i>S. violaceusniger</i> YCED9	<i>Pythium ultimum</i>	Crawford et al. (1993)
<i>Streptomyces</i>	<i>Streptomyces scabies</i>	Liu et al. (1995)
<i>S. humidus</i>	<i>Phytophthora capsici</i>	Hwang et al. (2001)
<i>S.violaceusniger</i> strain G10	<i>Fusarium oxysporum</i> f.sp. <i>cubense</i>	Geetha and Vikineswary (2002)
<i>S. padanus</i>	<i>Rhizoctonia solani</i>	Shih et al. (2003)
<i>S.aureofaciens</i> CMUAc130	<i>Fusarium oxysporum</i>	Taechowisan et al. (2005)
<i>Actinoplanes campanulatus</i>	<i>Pythium aphanidermatum</i>	El-Tarabily et al. (2009)
<i>Kitasatospora</i> sp.	<i>F. oxysporum</i>	Moussa et al. (2011)
	<i>Phytophthora infestans</i>	
<i>Streptomyces</i> sp.	<i>Fusarium</i> sp.	Panneerselvam et al. (2012)
	<i>Alternaria</i> sp.	
<i>Streptomyces</i> sp.	<i>Xanthomonas axonopodis</i>	Poovarasan et al. (2013)

weeks after inoculation under in vitro conditions (Selvakumar et al. 2011). A non-exhaustive list of the Actinobacterial antagonists are presented in Table 2.3.

2.2.2 Actinobacteria and Plant Growth Promotion

Plant growth promotion by Actinobacteria has attracted the attention of researchers much later when compared to the well-known PGPR's. Several Actinobacteria are now reported to promote plant growth by mechanisms such as nutrient mobilization, growth hormone production, siderophore production and stimulation of beneficial rhizospheric microbes. A list of Actinobacteria with plant growth promotion traits that have been reported in the recent past are mentioned in Table 2.4.

2.2.2.1 Symbiotic Diazotrophic Actinobacteria

A unique genus amongst the Actinobacteria is *Frankia*, which has the ability to fix atmospheric nitrogen both in the free living state and in association with several tree species. When *Frankia* are associated with tree species, the association is referred to as 'Actinorhizal'. Though the actinorhizal association has been known to occur in all terrestrial ecosystems, with the exception of Antarctica (Baker and

Table 2.4 Reports of plant growth promotion by Actinobacteria

Actinobacterium	Plant growth promotion trait	Reference
<i>Streptomyces</i> sp.	Chitinase activity	Ames et al. (1989)
<i>S. thermoautotrophicus</i>	Nitrogen fixation	Gadkari et al. (1992)
<i>Streptomyces griseoviridis</i> strain K61	Growth nutrient treatment of cut flowers, potted plants and greenhouse cucumbers	Mohammadi and Lahdenpera (1992)
<i>Rhodococcus</i> sp. strain EJP75	Promotes secondary mycorrhizal lateral roots in the <i>Pinus sylvestris</i> – <i>Lactarius rufus</i> ectomycorrhizal symbiosis	Poole et al. (2001)
<i>Frankia</i>	Hydrogenases	Leul et al. (2005)
<i>S. padanus</i> AOK-30	Enhanced drought tolerance	Hasegawa et al. (2006)
<i>Arthrobacter</i> sp. strain EZB4	ACC deaminase activity	Sziderics et al. (2007)
<i>Kitasatospora</i> sp.	IAA production	Shrivastava et al. (2008)
<i>Streptomyces</i>	Solubilizes phosphate	Hamdali et al. (2008)
<i>Kitasatospora</i>	Plant growth promotion	Oliveira et al. (2009)
<i>Thermobifida</i>	Plant growth promotion	Franco-Correaa et al. (2010)
<i>Micrococcus</i> sp.	ACC deaminase activity	Siddikee et al. (2010)
<i>Rhodococcus</i> sp.	ACC deaminase activity	Francis et al. (2010)
<i>S. canus</i>	IAA, GA ₃ production	Panneerselvam et al. (2012)
<i>Streptomyces</i> strain AzR-051	IAA production	Verma et al. (2011)
<i>Streptomyces</i> sp.	Siderophore (Ferulic acid)	Schrey et al. (2012)
<i>Streptomyces</i> sp. AcM29	Siderophore (desferrioxamine B)	Schrey et al. (2012)
<i>Streptomyces</i> sp. 5 strain	Growth promotion in rye grass	Stamenov et al. (2012)
<i>Streptomyces</i> AcM 20	Increased photosynthetic yield	Schrey et al. (2012)
<i>Streptomyces</i> sp. DH6	Siderophore producer	Kaur et al. (2013)
<i>Streptomyces</i> sp. DH32	Phosphate solubilizer	Kaur et al. (2013)
<i>Streptomyces</i> sp. P2–3	Nitrogen fixer	Kaur et al. (2013)
<i>Streptomyces</i> sp. MR-14	Protease activity	Kaur et al. (2013)

Schwintzer 1990), attempts to isolate the microsymbiont, succeeded only as late as 1978 when *Frankia* was isolated in a fastidious in vitro culture (Lechevalier and Lechevalier 1990). *Frankia* strains are known to nodulate 200 actinorhizal plants, spread over 24 genera. They are divided into the following host-infection groups viz., *Alnus* and *Myrica* (Group 1), *Casuarina* and *Myrica* (Group 2), *Myrica* and *Elaeagnus* (Group 3), and those capable of nodulating members of the *Elaeagnaceae* (*Elaeagnus*, *Hippophae*, *Sherpherdia*) (Group 4) (Pawlowski and Sirrenberg 2003; Roy et al. 2007). Strains belonging to the genus *Frankia* are usually not attributed a species name, due to a lack of clarity on the basis for species assignment. Hence, *Frankia alni* continues to be the only recognized species within this genus.

Morphologically *Frankia* possess hyphae, sporangia, spores and vesicles, but they do not form aerial mycelia. The vesicles are the sites of nitrogen fixation. The vesicle wall is composed of multiple lipid layers (hopanoids), and the number of layers increase with an increase in the oxygen concentration in the environment. This acts as a barrier to ambient oxygen levels, which would otherwise inhibits nitroge-nase activity. The vesicle of *Frankia* sets it apart from *Rhizobium*, which normally

fixes nitrogen in the symbiotic state, while it is protected against ambient oxygen levels, but *Frankia* can fix N_2 in the free living state as well as in association with its tree partners. Following root nodule formation and the onset of nitrogen fixation by *Frankia*, the microsymbiont derives its carbon source from plant photosynthates while the host plant benefits from the ammonium and also auxins produced by the endosymbiont (Wall and Berry 2008). The nitrogen fixed by *Frankia* in root nodules is estimated to supply 70–100% of the host plant's nitrogen requirement (Nickel et al. 2001; Myrold and Huss-Danell 2003). *Frankia* strains possess differential nitrogen fixation capabilities under in vitro and in planta conditions. The genotype of the *Frankia* strain, compatibility with the host plant, and nodule age are hypothesized to influence the level of nodule nitrogenase activity (Verghese and Misra 2000). Complex culture conditions coupled with prolonged doubling times often running into days have slowed down research into these unique organisms. But nevertheless, the contribution of the actinorhizal symbiosis, in terms of nitrogen fixation has been estimated to be as high as 25% of the annual global nitrogen fixation in terrestrial ecosystems (Dawson 2008).

The actinorhizal association begins with a compatible frankiae and host plant coming in contact. This is followed by the microsymbiont entering the host tissues by root hair deformation, penetration into the root epidermis and cortex, similar to the rhizobial—legume entry mode. But the actinorhizal nodule has a markedly distinct internal structure (Wall and Berry 2008). The lateral roots of actinorhizal plants modified by the infection process, become individual lobes. Multiple lobes make up a root nodule. The most striking feature that distinguishes the Actinobacterial nodule from the legume nodule is the proximity of infected cells to the outer periphery of the nodule lobe (Baker and Schwintzer 1990). In contrast to this, in legume nodules; layers of vascular tissue surround the infected cells, and thereby limit the exposure of nitrogenase to ambient oxygen levels. Since, Actinobacterial nitrogen fixation is confined to the highly specialized vesicle, the proximity of the infected cells to the outer periphery does not affect nitrogen fixation by Actinobacteria (Pawlowski and Sprent 2008).

2.2.3 *Actinobacteria and Recycling of Organic Matter*

The role played by Actinobacteria in the recycling of the enormous quantum of biomass generated as a result various anthropogenic activities is significant. Actinobacteria genera such as *Nocardia*, *Streptomyces* and *Micromonospora* are ubiquitous in composting processes (Waksman et al. 1939). Actinobacteria play a major role in the degradation of lignocelluloses, in the agro-environment and help return to the soil a huge quantum of plant nutrients. During the composting process a gradual increase of the temperature of the composting pile, is followed by sustained high temperatures (thermophilic) and a gradual cooling (maturation) of the composting mass (Halet et al. 2006; Hongyan et al. 2007). Microbial profiling studies during composting processes have revealed that Actinobacteria dominate during the thermophilic stage while they closely associate with fungi in the maturation stage

(Yu et al. 2007). Owing to their metabolic versatility, Actinobacteria can degrade organic molecules ranging from cellulose to complex chain lignins (Pérez et al. 2002). Very often the disease suppressive ability of composts has been attributed to the inherent Actinobacterial populations (Craft and Nelson 1996). Previous studies have suggested that the soil physical characteristics and organic matter are the main factors affecting the number and type of Actinobacteria on the soil and application of composts has been recommended to increase the Actinobacterial for both disease suppression and nourishment of the soil (Miyashita et al. 1982).

2.2.4 Actinobacteria as Plant Pathogens

Though Actinobacteria are primarily saprophytic in nature, some Actinobacteria are known to cause diseases in plants. Such Actinobacteria gain opportunistic entry into the plant system through wounds, while few others are considered as typical plant pathogens. Actinobacteria belonging to families Microbacteriaceae (*Clavibacter*, *Curtobacterium* and *Leifsonia*) and family Nocardiaceae (*Rhodococcus fascians*) are known to cause various plant pathogenic symptoms viz., galls, fasciation, gummosis, stunting and wilt in several vascular plants (Harrison 1962; Faucher et al. 1993; Boucek-Mechiche et al. 2000; Agbessi et al. 2003). The most popular of the Actinobacterial diseases is “scab” caused by members of the genus *Streptomyces*. Some Actinobacterial plant pathogens are highly host specific, a property that facilitates the quick identification of pathovars of *Clavibacter michiganensis*, *Leifsonia xyli* and *Curtobacterium flaccumfaciens* pathovars. Generally, these high-specificity pathogens do not produce symptoms on non-host plants. A typical example is the actinobacterium *Leifsonia xyli* subsp. *cynodontis* that causes stunt disease on Bermuda-grass. Though the same sub species can colonize other crop plants such as maize, rice and sugarcane, it is incapable of causing disease in non host crops (Haapalainen et al. 2000). Similarly, *C. flaccumfaciens* has been isolated as an endophyte from many crops, and some strains are known to reduce the severity of symptoms induced by the plant pathogenic *Xylella fastidiosa* when inoculated in the non-host *Catharanthus roseus* (Sturz et al. 1998; Lacava et al. 2007). Table 2.5, lists the plant pathogenic Actinobacterial species and their host range.

2.3 Actinobacterial Inoculant Technologies—Potential and Drawbacks

Though the knowledge on Actinobacteria and their metabolites have been well documented in the past, in recent times the agro-active antibiotics of Actinobacterial origin have largely remained as artefacts of academic interest and have not seen much thrust in terms of commercial exploitation, in comparison to their counterparts in the pharmaceutical sector. This can be attributed primarily due to competing interests of chemically synthesized molecules. Another factor that pre-empts the utiliza-

Table 2.5 Actinobacteria capable of causing major diseases in plants

Actinobacterium	Disease	Reference
<i>Corynebacterium poinsettiae</i> *	Bacterial canker of common poinsettia	Starr and Pirone (1942)
<i>Corynebacterium betae</i>	Silvering disease of red beet	Keyworth et al. (1956)
<i>Clavibacter michiganensis</i> subsp. <i>tessellarius</i>	Wheat leaf spot	Carlson and Vidaver (1982)
<i>Curtobacterium flaccumfaciens</i> pv. <i>oortii</i>	Yellow pock in tulip bulbs	Collins and Jones (1983)
<i>Clavibacter michiganensis</i> subsp. <i>nebraskensis</i>	Goss's bacterial wilt, blight in maize	Smidt and Vidaver (1987)
<i>Streptomyces ipomoeae</i>	Sweet potato pox	Clark and Matthews (1987); Grau et al. (2006)
<i>Streptomyces scabies</i>	Common scab of potato	King et al. (1992); Johnson et al. (2007)
<i>Clavibacter michiganensis</i> subsp. <i>insidiosus</i>	Bacterial wilt of lucerne	Paschke and Van Alfen (1993)
<i>Rhodococcus fascians</i>	Fasciations, leaf and crown gall of Various monocot and dicot plants	Eason et al. (1996)
<i>Clavibacter michiganensis</i> subsp. <i>michiganensis</i>	Bacterial canker of tomato and pepper	Dreier et al. (1997); Gartemann et al. (2008)
<i>Clavibacter michiganensis</i> subsp. <i>sepedonicus</i>	Bacterial ring rot of potato	Jahr et al. (1999); Shafikova et al. (2003)
<i>Curtobacterium flaccumfaciens</i> pv. <i>basellae</i>	Bacterial leaf spot of Malabar spinach	Chen et al. (2000)
<i>Leifsonia xyli</i> subsp. <i>xyli</i>	Ratoon stunting disease of sugarcane	Evtushenko et al. (2000)
<i>Leifsonia xyli</i> subsp. <i>cynodontis</i>	Stunt disease of Bermuda grass	Li et al. (2004)
<i>Streptomyces turgidiscabies</i>	Common scab of potato	Kers et al. (2005)
<i>Curtobacterium flaccumfaciens</i> pv. <i>flaccumfaciens</i>	Bacterial wilt of beans	Harding et al. (2007)
<i>Curtobacterium flaccumfaciens</i> pv. <i>beticola</i>	Bacterial leaf spot of sugarbeet	Chen et al. (2007)

*Originally described as *Phytomonas poinsettiae*, later classified as *Curtobacterium flaccumfaciens* (Collins and Jones 1983)

tion of Actinobacterial inoculants in the agro-environment is the perceived threat to non-target organisms and higher forms by life by the Actinobacterial secondary metabolites. Though many a times this may not be proved comprehensively, the regulatory regimes in most countries also limit the proliferation of Actinobacterial inoculants. Considering the potential of the Actinobacteria and their prevalence and dominance in the agro-environment, it would be wise to promote Actinobacterial inoculants, after comprehensive biosafety evaluation. Unlike the conventional bioinoculants that are subjected to acute exposures, a safeguard with respect to Actinobacterial inoculants, would be the evaluation of promising Actinobacteria to chronic exposure studies, in order to exclude potential biosafety issues in the future. Another feature that has excluded Actinobacteria from the bio-inoculant market, is the over emphasis on antibiotic producing genus *Streptomyces*, thereby leading to bioregulatory issues. As an alternative to this is need to explore the entire gamut

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