Actinobacteria for Biotic Stress Management

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Abstract

Actinobacteria are one of the active members of soil micro flora, and they play a key role in soil nutrients cycling and crop yield. *Actinobacteria* in rhizosphere of different plants produce various growth-promoting substances that stimulate growth of plants even under unfavorable environmental conditions such as drought, heavy metal-polluted soils, salinity, and nutrient deficiencies. Several *Actinobacteria* are involved in the solubilization of phosphate and zinc in soil which play significant role in number of metabolic pathways. They also produce plant hormones such as auxins and gibberellins which promote plant growth by increasing seed germination, root elongation, and dry weight of the root. Production of lytic enzymes such as amylase, protease, cellulase, chitinase, and glucanase plays an important role in plant disease control and in turn improves soil health. Various *Actinobacteria* are found to produce different types of siderophores which starve plant pathogens for iron and inhibit their growth. These multifaceted plant growth-promoting activities of *Actinobacteria* make them an agriculturally important organism. One of the most important members of this group known as *Streptomyces* species strain 5406 has also been practiced in China for biological control of pathogens of cotton plant. Actinobacterial role as PGP has been investigated in wheat, rice, and beans. *Actinobacteria* are also found to produce ACC (1-aminocyclopropane-1-carboxylate) deaminase which protects the plants under environmentally stressful conditions. This chapter

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R. Z. Sayyed (ed.), *Plant Growth Promoting Rhizobacteria for Sustainable Stress Management*, Microorganisms for Sustainability 13,
https://doi.org/10.1007/978-981-13-6986-5_14

summarizes the efforts of researchers to demonstrate the beneficial role of *Actinobacteria* on plant health and agricultural productivity.

Keywords
Actinobacteria · PGP · Biocontrol · Stress management · Trehalose · ACC deaminase

14.1 Introduction

There are a number of different species of bacteria which grow in, on, or around plant tissue and around rhizospheric soil of bacteria and stimulate plant growth by a variety of mechanisms. All these bacteria are collectively called as plant growth-promoting rhizobacteria (PGPR). Due to the hazardous effect of chemical fertilizers and pesticides on human life, it is necessary to get attention on search for alternatives like PGPR. Recent research data on application of PGPR to soil reflects a significant increase in overall growth parameters including plant height, root length, and dry matter production of shoot and root of plants. Investigation of mechanism of mode of action of PGPR is increasing at a rapid rate so as to develop them commercially as biofertilizer. PGPR are currently commercialized as novel inoculum for plant growth promotion through direct and indirect mechanisms. The direct mechanisms of plant growth promotion may involve the synthesis of substances or facilitation of the uptake of nutrients from the environment (Verma et al. 2010). The direct growth-promoting mechanisms are nitrogen fixation, increasing the availability of nutrients in the rhizosphere, and production of phytohormones such as auxins, cytokinins, and gibberellins (Sevilla et al. 2001; Vessey 2003). The indirect mechanisms of plant growth promotion include the production of antimicrobial substances to lessen or prevent the deleterious effects of phytopathogens on plants or increasing the natural resistance of the host (Verma et al. 2010; Cartieaux et al. 2003). The indirect mechanisms of plant growth promotion are biocontrol agent, competition for sites on roots and displacement of pathogens, induced systemic resistance, tolerance under stress conditions (Dunne et al. 1998; Kloepper and Beauchamp 1992; Lorito et al. 1998).

14.2 *Actinobacteria* in Plant Growth Promotion

The phylum *Actinobacteria* includes a considerably high number of plant growth-promoting genera than bacteria (Hamedi et al. 2011). Plant growth-promoting *Actinobacteria* emit a vast collection of chemical modulators, which directly stimulate plant growth and act indirectly by supporting other plant advantageous microbes. Soil-dwelling *Actinobacteria* either kill or inhibit the growth of plant pathogens via antibiotic production, thereby ensuring the good health of plants (Shivlata and Satyanarayana 2017). *Actinobacteria* are a diverse group of Gram-positive, filamentous, spore-forming, free-living bacteria predominant inhabitant of soil. The unique characteristics of bacteria make them a medicinally and agriculturally important organism. They are among the dominant soil microflora and rhizosphere and can colonize tissues of plants without causing any impairment to the plants. Therefore, *Actinobacteria* hold an outstanding position due to their diversity. Due to their typical unicellular and filamentous morphology, their survival in the soil or any unfriendly environment becomes long-lasting. It was widely thought that *Actinobacteria* are only soil inhabitants; however, genomic studies revealed that they are present in both freshwater and extreme environments such as thermal hot springs and Antarctic caves (Bentley et al. 2004). Genome size of *Actinobacteria* is in the range of 0.93 Mb (*Tropheryma whipplei*) and 11.9 Mb (*Streptomyces bingchenggensis*) (Verma et al. 2010). Some *Actinobacteria* harbor circular (*Nocardia*), linear (*Streptomyces*) plasmids. *Actinobacteria* have been considered as a transitional group between bacteria and fungi.. The phylum *Actinobacteria* is one of the most dominant taxonomic units of the domain Bacteria (Ventura et al. 2007) that constitutes six major classes (*Actinobacteria*, *Acidimicrobiia*, *Coriobacteriia*, *Nitriliruptoria*, *Rubrobacteria*, and *Thermoleophilia*).

The rhizosphere, defined as the zone of soil directly influenced by plant roots, represents a unique biological niche within the soil environment (Lechevalier 1989). The rhizosphere supports an abundance of diverse saprophytic microorganisms able to decompose polymeric organic matter such as lignocelluloses and chitin in the soil (Whips 2001), thereby making important contributions to nutrient cycling and the formation of humic substances (Trigo and Ball 1994). Mundt and Hinkle were able to isolate different species of *Streptomyces* and *Nocardia* from 27 different plant species, finding these *Actinobacteria* present endophytes in different plant tissues such as seeds and ovules. Sardi et al. isolated and observed through direct microscope examination the endophytic *Actinobacteria* from the roots of 28 plant species from Northwestern Italy, finding *Actinobacteria* belong to the genus Streptomyces and other common genera, namely, *Streptoverticillium*, *Nocardia*, *Micromonospora*, and *Streptosporangium* (Vurukonda et al. 2018). *Frankia* is known to form effective symbiosis with the species of *Alnus* and *Casuarina.* Survival and establishment of PGPR in the rhizosphere is a major apprehension of agricultural microbiologists. A chief source of concern is reproducibility in the field due to the composite interaction between the plants, microbes, and the environment (soil fertility and moisture, day length, light intensity, length of growing season and temperature)

14.3 Mechanisms of Plant Growth Promotion

14.3.1 Phytohormone Production

One of the direct mechanisms by which PGPR promote plant growth is by the production of plant growth regulators or phytohormones (Glick 1995). Botanists recognize five major groups of hormones: auxins, cytokinins, gibberellins, ethylene, and abscisic acid (Saharan and Nehra 2011). Indole 3-acetic acid (IAA) is the member of the group of phytohormones and is generally considered the most important native auxin (Ashrafuzzaman et al. 2009). IAA functions as a significant signal molecule in the regulation of plant development including organogenesis; tropic responses; cellular responses such as cell expansion, division, and differentiation; and gene regulation (Ryu and Patten 2008). IAA is a natural auxin involved in cellular development and physiological processes in plants. Different soil microorganisms including bacteria (Stein et al. 1990), fungi (Finnie and Van Staden 1985), and algae (Rifat et al. 2010) are capable of producing physiologically active quantities of auxins. IAA is naturally stirring in plants, and it controls many physiological processes like cell enlargement and tissue differentiation and responses to light and gravity; similarly it stimulates spore germination and mycelia elongation in the *Streptomyces* sp. (Matsukawa et al. 2007). Several *Streptomyces* sp. such as *S. olivaceoviridi*, *S. rimosus*, and *S. rochei* from the tomato rhizosphere have the ability to produce IAA and improve plant growth by increased seed germination, root elongation, and root dry weight (El-Tarabily 2008). *Actinobacteria* facilitate the production of plant hormones such as IAA and cytokinins that are closely associated with plant growth (Ghosh et al. 2011).

Production of IAA in *Streptomyces* is tryptophan dependent and it follows the route of indole acetamide (Lin and Xu 2013). *Streptomyces filipinensis* No. 26 isolate promoted the growth of tomato grown under greenhouse conditions by stimulating the root and shoot length and produced IAA at a concentration of 77.43 μg/100 g of dry weights on the roots (Khamna et al. 2009). A significant quantity of IAA (52.3 μg/ml) was secreted by *Streptomyces* sp. isolated from the rhizosphere region of medicinal plants (Khamna et al. 2009). Maximal IAA secretion of 143 μg/ml was also observed for *Streptomyces* sp. isolated from the rhizosphere region of medicinal plants (Manulis et al. 1994). It is reported that 80% of microorganisms isolated from the rhizosphere of crops possess the ability to synthesize and release auxins as secondary metabolites which are known to promote root elongation and plant growth (Patten and Glick 2002). *Streptomyces* genus has been reported to produce high amount of growth-regulating hormone IAA in vitro. Similarly, many *Actinobacteria* are known to produce IAA and reported to increase plant shoot and root lengths. Although above-reported cultures are known to produce only IAA, an interesting fact of three Actinobacterial species, namely, *Streptomyces olivaceoviridis*, *S. rimosus*, and *S. rochei* cultures, was that they produced all three growth hormones, viz., auxin-, gibberellin-, and cytokinin-like substances, and enhanced the growth of wheat plants (Aldesuquy et al. 1998).

Cytokinins are a class of phytohormones which are known to encourage cell divisions, cell enlargement, and tissue development in certain plant parts. Gibberellins (GA) are a class of phytohormones most commonly associated with modifying plant morphology by the extension of plant tissue, particularly stem tissue (Salisbury 1994). Gibberellic acid (GA) is an important member of gibberellins family and acts as a natural plant growth hormone, controlling many developmental processes such as the induction of hydrolytic enzyme activity during seed germination, stem elongation, induction of flowering, improvement of crop yield, overcoming dwarfism, elimination of dormancy, sex expression, enzyme induction and leaf and fruit senescence, etc. (Rangaswamy 2012; Rios-Iribe et al. 2010; Burckner and Blechschmidt 1991; Kumar and Lonsane 1989).

14.3.2 Solubilization of Minerals

Phosphorus is an essential macroelement necessary for the growth and development of living organisms. It is a primary part of various biological molecules such as nucleic acids, phospholipids, and energy-rich compounds (ATP, NADH, and NADPH). It has a vital role in several metabolic pathways such as cell division, signal transduction, macromolecular biosynthesis, and photosynthesis (Shenoy and Kalagudi 2005) and constitutes approximately 3% of total dry cell weight (Bhardwaj et al. 2014). In general, the available form of P is present in very low concentration (less than 1 mg/kg) as a result of the formation of metal complexes with Fe, Al, and Si (Hamdali et al. 2008). Promod and Dhevendaran (1987) observed maximum solubilization of insoluble phosphate by *Pseudomonas* and *Vibrio* in 3 days. Zone of solubilization around the colony on media containing solid agar and release of phosphate in the medium could be recognized to the release of organic acids, viz., citric, glyoxalic, malic, ketobutyric, succinic, fumaric, and tartaric by the microbes. Phosphate solubilization is most frequent among *Actinobacteria* such as *Streptomyces*, *Micrococcus*, *Micromonospora*, *Kitasatospora*, and *Thermobifida*.

Actinobacteria are of unique interest since these filamentous bacteria are often able to colonize plant tissue and to produce spores, a resistant form important for survival in agricultural soil (Hamdali et al. 2008). These interesting characteristics of *Actinobacteria* were mainly established under laboratory conditions (Hamdali et al. 2008) with green house by using phosphate-solubilizing *Actinobacteria*. The P-solubilizing ability of *Actinobacteria* has attracted interest in recent years because this group of soil organisms is not only capable of surviving in extreme environments (e.g., drought, fire.) but also possess other potential benefits (e.g., production of antibiotics and phytohormones-like compounds) that could simultaneously benefit plant growth (Hamdali et al. 2008). A study by Hamdali et al. (2008) has indicated that approximately 20% of *Actinobacteria* can solubilize P, including those in the common genera *Streptomyces* and *Micromonospora*. Rock phosphate-solubilizing *Actinobacteria* were reported to promote the growth of wheat plants in vitro as well as in vivo (Hamdali et al. 2008). The primary mechanism of P solubilization by PGPA is due to the production of organic acid and acidification of rhizosphere, thereby solubilization of unavailable to available form of P (Palaniyandi et al. 2011). Further, phosphorus availability enhancement is attributed to the chelation of cations such as Fe^{+2}, Al^{+3}, or Ca^{+2} which form insoluble phosphates and thereby help in the solubilization of insoluble phosphate. *Actinobacteria* can hydrolyze phytate (which constitutes up to 60% of soil organic phosphorus) by secreting phosphates such as phytases and acidic/alkaline phosphatases (Palaniyandi et al. 2011).

Dastager and Damare (2013) isolated *Actinobacteria* from the sediments of Chorão Island, Goa province, India. Out of 200 isolates, 30 isolates were prominent in the phosphate solubilization activity, and maximum solubilization was recorded to be 89.3 ± 3.1 to 164.1 ± 4.1 μgm/L after 6 days of incubation in six of all isolates.

Zinc is also one of the preliminary requirements for plants in tissue development and reproduction. Reported concentration of zinc in plants is around 5–100 mg/kg. It is involved in tissues of growing plant for proper development and reproduction. Any zinc deficiency leads to reduced synthesis of carbohydrates, nucleotides, auxins, cytochromes, chlorophyll, and membrane integrity which ultimately develops susceptibility to heat stress (Singh et al. 2015).

14.3.3 Siderophores Production

Siderophores are the low molecular weight (200–2000 Da) compounds secreted by bacteria to chelate the iron which is present in the environment in the insoluble form. Availability of iron in the ocean water limits marine production. As a strategy to cope up this iron-deficient condition, marine bacteria found to have the ability to produce amphiphilic siderophores like ferrioxamines (Boiteau et al. 2016). *Actinobacteria* has been reported to have the ability to produce ferrioxamine-type siderophores which are reported in eastern South Pacific Ocean remains (Table 14.1). Siderophores are mainly classified as catecholate, hydroxamate, and carboxylate type, and some bacteria have the ability to produce mixed carboxylate-hydroxamate type. Production of siderophores is extracellular or intracellular. Synthesis of siderophores occurred by non-ribosomal peptide synthetase (NRPS) or NRPS independent pathways (Oves-Costales et al. 2009). Siderophores produced by one *Actinobacteria* helps the development of other *Actinobacteria*. According to the report available, siderophore desferrioxamine E produced by *S. griseus* stimulated the growth and development of *S. tanashiensis* (Yamanaka et al. 2005). Patzer and Braun (2010) found that DNA of *Streptomyces* comprises siderophore biosynthetic

Table 14.1 List of *Actinobacteria* producing siderophore

Name of the *Actinobacteria*	Name of the siderophore	References
Streptomyces griseus	Desferrioxamin (Nocardamine)	Imbert et al. (1995); Meiwes et al. (1990); Yamanaka et al. (2005)
Streptomyces tendae	Enterobactin	Fiedler et al. (2001)
Streptomyces coelicolor	Coelichelin	Challis and Ravel (2000); Lautru et al. (2005)
Streptomyces ATCC 700974	Griseobactin	Patzer and Braun (2010)
Streptomyces pilosus	DesferrioxamineB (trade name Desferal)	Müller et al. (1984)

gene cluster encoding proteins similar to DhbABCEFG which is involved in the incorporation of DHBA into siderophores via a non-ribosomal peptide synthetase, and this gene cluster also contains genes which encode proteins for the siderophore secretion, uptake, as well as its degradation. Siderophores produced by *Actinobacteria* have shown to maintain the ecology and productivity of soil and water. Microbial siderophores may stimulate plant growth directly by increasing the availability of iron in the soil surrounding the roots (Kloepper and Beauchamp 1992). Marschner and Römheld (1994) reported that plants may also utilize siderophores synthesized by microorganisms colonizing the rhizosphere; this would be a source of soluble iron for the host plant. Plants such as sorghum, oats, peanut, cotton, cucumber, and sunflower demonstrated the ability to use radio-labelled microbial siderophores as a sole source of iron (Wang et al. 1993).

There is also a positive correlation between siderophore production and observed enhancement of plant growth (Becker 1988). There are multiple proposed mechanisms by which this may occur. First, sequestration of iron in the rhizosphere by PGPR renders the iron less available to potential pathogens in the rhizosphere (Kloepper and Beauchamp 1992) The *Actinomycete*-specific association had a positive influence on the physiology of the host plant.

14.4 Enhancers of Soil Fertility

Composting is microbial degradation of complex organic matter into nutrient-rich humus that nurtures plants and helps in restoration of productivity of eroded soil. *Actinobacteria* secrete various types of peroxidases among which lignin peroxidases facilitate humification and composting via hydrolysis of lignin into humic acid-like complexes. The composition of Actinobacterial community changes during various stages of composting, for example, the presence of both mesophilic (*Streptomyces*) and thermo-tolerant species (*Saccharomonospora viridis*, *Thermobifida fusca*, and *Thermobispora bispora*) has been recorded at different phases of compost formation (Steger et al. 2007). Secretion of different enzymes by *Actinobacteria* like amylases, chitinases, cellulases, and peroxidases makes the *Actinobacteria* suitable for soil fertility as these enzymes help to mineralize the complex organic material into simpler forms which can be assimilated by plants. *Actinobacteria*, such as *Streptomyces* spp., influence soil fertility through the involvement of many components and serve as nutrient enhancers. Besides producing siderophores and solubilizing phosphate, they are known to produce various enzymes including amylase, chitinase, cellulase, invertase, lipase, keratinase, peroxidase, pectinase, protease, phytase, and xylanase which make the complex nutrients into simple mineral forms. This nutrient cycling capacity makes them ideal candidates for natural fertilizers (Jog et al. 2016).

14.5 Stress Tolerance

Biotic stress to the plants is caused by different plant pathogens. Fungi, bacteria, viruses, weeds, insects, and other living organisms damage the plants in a variety of ways. The main abiotic stress to the plants is caused by fungi. There are various reports reflecting the importance of actinobacteria for antiphytopathogenic activity. Kanini et al. (2013) isolated and identified potential antifungal streptomycetes from rhizosphere and nonrhizosphere soil and carried out in vivo experiments on beans. Srividya et al. (2012) evaluated *Streptomyces* sp. 9p as effective biocontrol against chilli soil-borne fungal phytopathogens.

Application of *Actinobacteria* for biotic stress management can be achieved by use of three main strategies. Actinobacterial species which are effective colonizers of plant systems with the production of antiphytopathogenic compounds and plant growth-promoting activities will be the best solution for biotic stress management. Various mechanisms of disease control by *Actinobacteria* have already been discussed in this topic under the heading of *Actinobacteria* as biocontrol agents.

Plants have to face biotic and abiotic stress mainly. Abiotic stress includes different environmental conditions. Abiotic stresses like drought, flooding, salinity, and extreme temperatures can be managed by using the bacterial strains which can produce cytokinins, ACC deaminases, abscisic acid, trehalose, exopolysaccharides, and volatile organic acids. Abiotic stress results in the production of stress ethylene. So the main strategy for management of this stress is by lowering the amount of ethylene. This can be achieved by ACC deaminase-producing bacteria. Management of abiotic stresses can be achieved by three main strategies using *Actinobacteria*.

14.5.1 Management of Abiotic and Biotic Stress

14.5.1.1 Trehalose Production

Trehalose is stable non-reducing sugar. High levels of trehalose protects the plants from stresses like extreme temperature, drought, and salinity. Trehalose is resistant to acid and temperature. It forms gel phase and prevents degradation of proteins protecting plants from both high and low temperatures. There are reports of trehalose-producing *Streptomyces* spp.

14.5.1.2 ACC Deaminase Production

Glick et al. (1998) put forward the theory that the mode of action of some PGPR was the production of 1-aminocyclopropane-1-carboxylate (ACC) deaminase, an enzyme which could cleave ACC, the immediate precursor of ethylene in the biosynthetic pathway for ethylene in plants. ACC deaminase activity would decrease ethylene production in the roots of host plants and result in root lengthening. More importantly, *Actinobacteria* alleviate plant stresses by reducing the ethylene level in the root by secreting 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase enzyme (Hamedi et al. 2015).

To combat with biotic and abiotic stress, *Actinobacteria* produces ACC deaminase which inhibits auto-catalytic ethylene synthesis (Grichko and Glick 2001, Mayak et al. 2004a, b, Belimov et al. 2005). ACC deaminase, 1-aminocyclopropan e-1-carboxylate deaminase (EC 3.5.99.7), is one of the plant growth-promoting enzymes. ACC deaminase converts ethylene precursor to ammonia and α-ketobutyrate which is further utilized by bacteria for their growth. ACC deaminase activity provides induced systemic tolerance to plants against stress caused by drought, heavy metals, flooding, and high salt (Jaemsaeng et al. 2018). Symbiotic performance of PGPR depends on ACC deaminase. Reported ACC deaminase-producing strains are *Streptomyces*, *Amycolatopsis*, and *Nocardia* (Nascimento et al. 2014). ACC deaminase enzyme is an inducible enzyme and requires its substrate ACC. This enzyme encoded by gene AcdS which is present in *Actinobacteria*, found in their primary and unique chromosome (Singh et al. 2015). In stressed conditions leguminous plants produce ethylene in high concentration which leads to nodulation and growth inhibition (Nascimento et al. 2016). To overcome this stress-induced effect on crops, it is necessary to maintain the rhizospheric *Actinobacteria* which have the potential to produce ACC deaminase. Screening of *Actinobacteria* for ACC deaminase production potential can be done by growing this *Actinobacteria* in a medium containing 1-aminocyclopropane-1-carboxylate as nitrogen source. *Actinobacteria* exhibiting good growth could be further confirmed using TLC-based method (Wang et al. 2012).

14.5.1.3 Production of Volatile Compound

Bacterial volatiles have been reported to promote growth and to induce systemic resistance in *Arabidopsis*. Strain AOK-30 of *Streptomyces padanus* volatiles are associated with this induced drought tolerance. Based on these earlier reports, tissue-cultured seedlings may recognize and respond to AOK-30 as an external stimulus. Thus, if drought tolerance of tissue-cultured seedlings is enhanced by *Actinobacteria*, perhaps the seedlings can be acclimatized under a relatively lower humidity, enabling the seedlings to grow and escape diseases (Hasegawa et al. 2004). Srivastava et al. (2014) demonstrated that *Streptomyces rochei* SM3 activates ethylene-mediated defense pathway and phenyl-propanoid pathway in chickpea and therefore discharged stresses caused by both biotic (*Sclerotinia sclerotiorum*) and abiotic (NaCl) factors. Hence, this could be a potential candidate for the development of a plant growth-promoting agent (PGPA).

Heavy metal stress results in low iron supply to the plants. So the best solution for heavy metal stress is use of plant-associated siderophore-producing *Actinobacteria*.

14.6 Management of Biotic Stress (Plant Diseases)

Chemical Pesticides are used to control plant diseases from ancient days. This resulted in severe environmental pollution and decreased diversity of non-target organisms. Microorganisms as biological control agents have high potential to control plant pathogens and no effect on the environment or other non-target organism (Sutthinan et al. 2009). *Actinobacteria*, including *Streptomyces species*, have various qualities of effective biocontrol agents. They are effective colonizers of root system. Several phytopathogen-inhibiting compounds are produced by actinomycetes, and they are also one of the major producers of antibiotics against fungi. They secrete various extracellular enzymes which inhibit plant pathogens including fungi and insects.

14.7 Mechanisms of Biocontrol

14.7.1 Effective Colonizers of Root System

Actinobacteria have the ability to colonize not only the root surfaces, but also the various parts of plants. They have been isolated from seeds and ovules also. To be used as effective biocontrol agents, colonization is one of the essential properties. *Actinobacteria* specifically *Streptomyces* form desiccation-resistant spores. So they can be formulated in powder form to be used as biocontrol agents. *Streptomyces griseoviridis* has the ability to colonize the plant rhizosphere. *Fusarium* wilt of carnation, the damping-off of *Brassica*, and the root rot disease of cucumber are controlled by *S. griseoviridis* which is an antagonistic actinomycete.

14.7.2 Production of Inhibitory Compounds Against Phytopathogens

Actinobacteria, belonging to the genus *Streptomyces* sp., appear to be good candidates to find new approaches to control plant diseases (Běhal 2000). *Actinobacteria* found in rhizosphere soil of medicinal plant may have the ability to produce new inhibitory compounds against phytopathogens. Plant root exudates stimulate rhizosphere growth of *Streptomycetes* that are strongly antagonistic to fungal pathogens. *Streptomyces* sp. Strain 5406 has been used in China to protect cotton crops against soil-borne pathogens. *Actinobacteria* are important natural producers of antibiotics or anti-fungals that could protect the plants against various devastating phytopathogens such as *Pythium ultimum*, the cause of damping-off disease in wheat seedlings (Jain and Jain 2007). Crawford et al. (1993) found that 12 actinomycetes strains isolated from *Taraxicum officinale* rhizosphere were active against *Pythium ultimum*. *Actinobacteria* are able to produce large number of agroactive metabolites that play a role as biocontrol agents exhibiting antagonism against a variety of plant pathogens (Trejo-Estrada et al. 1998; Yuan and Crawford 1995). *Streptomyces nigrescens* produce phosphazomycins that exhibit in vitro activity against *Botrytis cinerea*, *Rhizoctonia solani*, and *Alternaria kikuchiana* (Tomiya et al. 1990). The genus *Streptomyces* has been investigated as a potential biocontrol agent against fungal phytopathogens such as *Pythium ultimum* (Jensen et al. 2002).

Medicinal plants are known to be rich in secondary metabolites and are potentially useful to produce natural drugs. Medicinal plants support a great diversity of microflora in their rhizosphere including plant growth-promoting rhizobacteria. Active *Actinobacteria* may be found in medicinal plant root rhizosphere soil and may have the ability to produce new inhibitory compounds against phytopathogens. Thangapandian et al. (2007) isolated *Streptomyces* from medicinal plant in rhizosphere soils, and from this study it was observed that eight isolates were showing good antipathogenic activity. Sutthinan Khamna et al. (2009) isolated *Actinobacteria* from rhizosphere of medicinal plants and demonstrated the anti-phytopathogenic activity of *Streptomycetes* against selective plant pathogen. The antibacterial activity of *Actinobacteria* was established in many previous studies; Zamanian et al. (2012) demonstrated a high level of activity for *Streptomyces plicatus* against *E. carotovora* subsp. carotovora, while El Karkouri et al. (2017) isolated an actinomycete strain which inhibited the growth of *E. chrysanthemi* and identified it as *Streptomyces cinereoruber*. Kanini et al. (2013) isolated and identified potential antifungal *Streptomycetes* from rhizosphere and nonrhizosphere soil and carried out in vivo experiments on beans. Srividya et al. (2012) evaluated *Streptomyces* sp. as effective biocontrol against chilli soil-borne fungal phytopathogens. A research conducted by Muiru et al. (2008) evaluated the antibiotic metabolites from two antagonistic *Actinobacteria* isolates for the control of late blight of tomatoes in the greenhouse. Mildiomycin was extracted from a culture of *Streptoverticillium imofaciens*, which has antifungal activity. Mildiomycin is an excellent solution for powdery mildews on various crops). The metabolites were found to give a significant control in the management of late blight and delayed the onset of the disease. Siderophores synthesized by *Actinobacteria* residing in the rhizospheric soil are mainly studied due to their attribute as biocontrol agent against pathogens and in disease-suppressive soils (Loper and Buyer 1991).

14.7.3 Secretion of Extracellular Lytic Enzymes

Actinobacteria are producers of various lytic enzymes. Chitinases and glucanases are important for antifungal activity. Extracellular glucanases are able to hydrolyze glucans from cell wall of fungal pathogen like *Phytophthora* species. Chitin is the component of fungal cell wall and also the cuticle of insects. Chitinase-producing *Actinobacteria* are useful to control fungal pathogens and insects. *Streptomyces* has also been widely used for biocontrolling soil-borne fungal pathogens (Trejo-Estrada et al. 1998). *Streptomyces* antibiotics and lytic enzymes have proved their potential as biocontrol agents against *F. culmorum* responsible for various symptoms like damping roots, stems and spikelet fusariosis in many broadleaf and monocotyledons plants such as cereals. Previous study showed that *Actinobacteria* isolated from Malaysian soil have the potential to inhibit the growth of several plant pathogens. Oskay et al. (2004) also reported about the ability of *Actinobacteria* isolated from Turkey's farming soil. They have the ability to inhibit *Erwinia amylovora*, a bacteria that cause fire-blight in apple, and *Agrobacterium tumefaciens*, a causal agent of crown gall disease (Jeffrey 2008).

14.8 Conclusion

The efficacy of *Actinobacteria* is not only applied in formulation of biofertilizers or biopesticides, but they also appear ideal for innumerable applications in environmental issues. Their adaptive morphology as well as excellent metabolic versatility enables them to establish their populations to all kinds of extreme environments including highly polluted locations. Evaluation of significant role of *Actinobacteria* in terms of decontamination of polyaromatic hydrocarbons has been mentioned in previous literatures. Spores of *Streptomyces rochei* strain PTL2 has been tried in wettable talcum powder, sodium alginate pellets, and sodium alginate-clay pellets to control the disease infestation caused by *Sclerotium rolfsii*. Talcum-based formulation was found to be more effective to reduce the disease and promoted growth of tomato seedlings. Commercial formulations of *Streptomyces* are also available in international market like Actinovate, Novozymes, Mycostop, and Microsat F UNO. These can be applied to soil in the form of granules and slurry. *Streptomyces* have been extensively studied for the production of antibiotics. Literature shows the significance of *Streptomyces* as plant growth promoter and biocontrol agent in agriculture sector. More emphasis on this aspect of *Streptomyces* sp. will surely change the scenario of productivity of crop and soil health.

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