Chapter

Actinobacteria: Potential Candidate as Plant Growth Promoters

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Abstract

Plant growth enhancement using plant beneficial bacteria has been viewed in the sustainable agriculture as an alternative to chemical fertilizers. Actinobacteria, among the group of important plant-associated bacteria, have been widely studied for its plant growth promotion activities. Actinobacteria are considered as a limelight among agriculturists for their beneficial aspects toward plants. They are naturally occurring spore-forming bacteria inhabiting the soil and known for their plant growth-promoting and biocontrol properties. The mechanisms behind these activities include nitrogen fixation, phosphate solubilization, siderophore production, and other attributes such as antifungal production of metabolites, phytohormones, and volatile organic compound. All these activities not only enhance the plant growth but also provide resistance in plants to withstand unfavorable conditions of the environment. Hence, this chapter emphasizes on the plant growth traits of actinobacteria and how far it was studied for enhanced growth and bio-fortification.

Keywords: actinobacteria, rhizosphere, PGPR, growth promotion

1. Introduction

Plant growth-promoting (PGP) microbes (epiphytic, endophytic, and rhizospheric) are likely to enhance the growth and productivity of crop by increasing the nutrient content. These plant microbiomes have been sorted out from diverse sources belonging to all three domains: archaea, bacteria, and fungi. The microbes associated with the plant rhizosphere are termed as rhizospheric microbes, and among them, actinobacteria are most dominant in nature [1]. As many researches stated actinobacteria as major microbial population present in the soil. The actinobacteria are known to have high G-C (57–75%) contents and comprise a broad group of filamentous, spore-forming, gram-positive, and aerobic bacteria that form branching filaments or hyphae and play a fundamental function in ecology along with soil nutrient cycle. Actinobacteria resemble to unicellular bacteria, they are different by not having distinct cell wall; instead they produce mycelium, a nonseptate and more slender [2]. Actinobacteria are widely dispersed in both terrestrial ecosystem, as present in soil, and aquatic ecosystems as in fresh and marine water. The terrestrial actinobacteria contribute in recycling process and are essential to the decomposition of many complex mixtures of polymers and organic material, located in dead plants, animals, and fungal materials. The phylum actinobacteria is currently recognized as the largest taxonomic units within the bacterial domain and recognized for its economic importance because it produces various biological active substances like vitamins, antibiotics, and enzymes. It is estimated that almost 23,000 bioactive secondary metabolites are produced by many microorganisms and almost 45% (10,000 out of 23,000) of these bioactive microbial metabolites are produced by actinomycetes. Among these actinomycetes, *Streptomyces* are classified as most abundantly occurring *Actinomycete* in the soil, while *Nocardia*, *Micromonospora*, and *Streptosporangium* are the less abundant [3]. Streptomyces has established its importance in numerous sectors like health and agriculture, and it is also considered as most dominant actinobacteria, for root colonization and close association with plant roots. Actinomycetes are diversified organisms having various applications on many fields. Plant growth-promoting rhizobacteria (PGPR) actinobacteria promote the plant growth through a variety of mechanisms including production of phytohormones, antibiotics, siderophore, volatile organic compound, and different hydrolytic enzymes. These also promote nutrient fixation for easy

Actinobacteria	Host plant	Target pathogen	References
Streptomyces sp. S30, *Streptomyces* sp. R18	*Lycopersicon esculentum*	*Rhizoctonia solani*	[5]
Actinoplanes	*Cucumis* sp.	*Pythium aphanidermatum*	[6]
Streptomyces diastaticus, *Streptomyces fradiae*, *S. collinus*	Medicinal plants	*Fusarium oxysporum*, *Alternaria solani*, *Sclerotium rolfsii*	[7]
Streptomyces sp. DBT204	*Solanum lycopersicum*	*Fusarium proliferatum*	[8]
Leifsonia xyli, BPSAC24, *Streptomyces* sp. BPSAC34	*Curcuma longa*, *Eupatorium odoratum*, *Mirabilis jalapa*	*Fusarium oxysporum* ciceri, *F. oxysporum*, *F. graminearum*, *Rhizoctonia solani*	[9]
Microbispora spp.	*Solanum tuberosum* L.	*Streptomyces scabies*	[10]
Streptomyces spp. R-5	*Rhododendron* sp.	*Phytophthora cinnamomi*	[11]
Streptomyces sp. MBPu-75	*Cucumis* sp. and *Cucurbita* sp.	*Colletotrichum orbiculare*	[12]
Streptomyces sp. RM 365	Leguminous plants	*Xanthomonas campestris*	[13]
Streptomyces sp. PRY-2RB2	*Pseudowintera colorata*	*Nocardia parvum* MM562	[14]
Nocardiopsis sp. ac 9, *Streptomyces* sp. ac19	*Elaeis guineensis* Jacq.	*Ganoderma boninense*	[15]
Streptomyces sp. AzR-051, *Streptomyces* sp. AzR-010	*Azadirachta indica*	*Alternaria alternate*	[16]
Mutabilis CA-2	*Cleome arabica*, *Aristida pungens*	*Rhizoctonia solani*	[17]

Table 1.
Biological activities of some isolated actinobacteria.

uptake by the plant and develop abiotic stress tolerance in plants. Actinobacteria are also considered to have the potential to be used as promising biocontrol agents because they produce spore which can resist environmental stress. The actinobacteria help plants by suppressing disease-causing microbes and enhancing nutrient availability and assimilation which subsequently have beneficial impact on the agricultural sector by accelerating plant growth [4]. Although actinomycetes have many applications in different sectors including health and agriculture, this chapter will only focus on actinomycetes' role as PGPR. Some commonly isolated actinobacteria, its host plant, and targets are mentioned in **Table 1**.

2. Actinobacteria's role in PGPR activity

Plant growth and development of important organs in plant are facilitated by plant hormones called plant growth regulators (PGR). These PGR can influence plant growth even at very low concentration. Actinobacteria act as PGPR, and its impact is determined by considering the effectiveness and ability to influence PGR in root system. Different mechanisms used for promoting PGR by actinobacteria are classified into direct and indirect method (**Figure 1**).

The direct method exhibits various activities including solubilization of phosphorus, nitrogen fixation, iron acquisition, and production of different phytohormones, for instance, indole acetic acid (IAA), cytokinins, and gibberellins. In indirect method, actinobacteria promote plant growth in many ways such as synthesizing extracellular enzymes for fungal cell wall degradation producing antibiotics, volatile compounds (VOCs), inducting systemic resistance, as well as competition for nutrients [18].

2.1 Direct method for plant growth promoter by actinobacteria

Actinobacteria promote the growth of plants by involving in various direct activities as shown in **Table 2**.

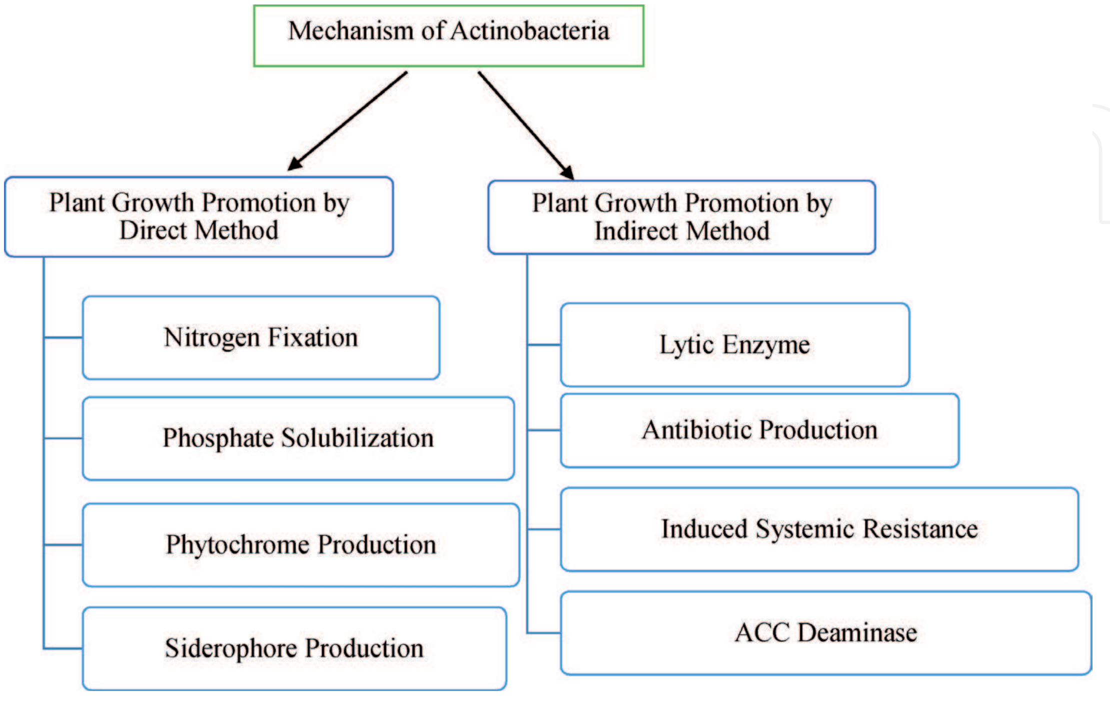

Figure 1.
Mode of action of actinobacteria.

Actinobacteria	PGP traits	Host plant	Reference
Streptomyces sp. GMKU 3100	Siderophore production	Rice (*Oryza sativa L.)*	[19]
Streptomyces sp.	IAA production Phosphate solubilization	Wheat	[20]
Streptomyces griseoflavus P4	Nitrogen fixation	Soybean (*Glycine max*)	[21]
Microbispora spp. *Micromonospora* spp. *Nocardia* spp.	IAA production	Mandarin (*Citrus reticulata L.*)	[22]
Streptomyces spp.	IAA production	Sorghum Rice	[23]
Arthrobacter sp. strain EZB4	ACC deaminase activity	Pepper (*Capsicum annuum* L.)	[24]
Micromonospora endolithica	Phosphate solubilization	Carrot (*Daucus carota*)	[25]
Streptomyces sp.	Nutrient uptake	Clover	[26]
Streptomyces sp.	Gibberellic acid, IAA,	Marine environments	[27]
Streptomyces olivaceoviridis, *S. rochei*	Auxin, gibberellin, and cytokinin synthesis	Wheat	[28]
Brevibacterium epidermidis RS15, *Micrococcus yunnanensis* RS222	Nitrogen fixation IAA production ACC deaminase activity	Canola	[29]
Streptomyces spp.	Phosphate solubilization	—	[30]
Actinobacteria	Phosphate solubilization, Nitrogen fixation	Soya bean	[31]

Table 2.
Direct plant growth-promoting (PGP) properties of actinobacteria.

2.1.1 Nitrogen fixation

Nitrogen is a well-known and key element of nucleic acids and proteins, and it is also an indispensable nutrient for plant growth. Nitrogen gas is abundantly found in the air, constituting 78% of the atmosphere, but it is not directly available to plants for uptake unless it is converted into its soluble form [32]. Biological nitrogen fixer (BNF) used nitrogenase enzyme system which converts the atmospheric nitrogen required by plants into ammonium and nitrates [33]. Additionally, synthetic nitrogen fertilizers are also supplied to balance the limited availability of nitrogen provided by biological nitrogen fixer. But these fertilizers might be harmful to health and agricultural sustainability. Therefore, actinobacteria are good choice to be utilized as BNF to improve the plant growth for sustainable agriculture. *Frankia* is a versatile actinobacterium which enters in the root cell through different ways, such as intracellular using root-hair or intercellular by means of root invasion, and fixes nitrogen under both free-living and symbiotic conditions in nonlegume plants [34]. In addition to *Frankia*, many other endophytes like *Agromyces*, *Arthrobacter*, *Micromonospora*, *Corynebacterium*, *Propionibacterium*, *Mycobacterium*, and *Streptomyces* also demonstrated N-fixing ability [35].

2.1.2 Phosphorus solubilization

After nitrogen, the second major element, for plant growth, is phosphorus [36]. Phosphorus exists in soil as both inorganic and organic forms [37], but 0.1% phosphorus is available as soluble form to be absorbed by plants. An immediate need of phosphorus is fulfilled by chemical fertilizers, like nitrogen, but the majority of these applied chemical fertilizers are not only expensive but also wasted because it retains in soil as an insoluble form just after the application [37]. In the past decades, many microbes have been described which can solubilize the insoluble phosphorus, and since then, numerous studies by many researchers have been carried out to investigate the phosphate-solubilizing potential of different microbes such as bacteria, fungi, and actinobacteria [38]. Different in vitro and in vivo studies have been executed, which highlight capability to solubilize soil phosphorus by PGP actinobacteria, for instance, *Streptomyces*, *Rhodococcus*, *Arthrobacter*, *Gordonia*, and *Micromonospora* [39]. *Micromonospora endolithica* a non-streptomycete enhances the phosphate-solubilizing ability in bean plants which subsequently increase the growth of bean plants [40]. *Micromonospora aurantiaca*, *Streptomyces* sp., and *Streptomyces griseus* also showed similar results on wheat plants when grown under phosphorus-deficient soil. Many actinobacterial strains also aid in phosphorus solubilization by producing several organic acids such as citric acid, gluconic acid, oxalic acid, lactic acid, malic acid, succinic acid, and propionic acid. Therefore, it is more viable to utilize microorganisms like actinobacteria as biofertilizers economically. Some plant growth-promoting characteristic of actinobacteria is shown in **Figure 2**.

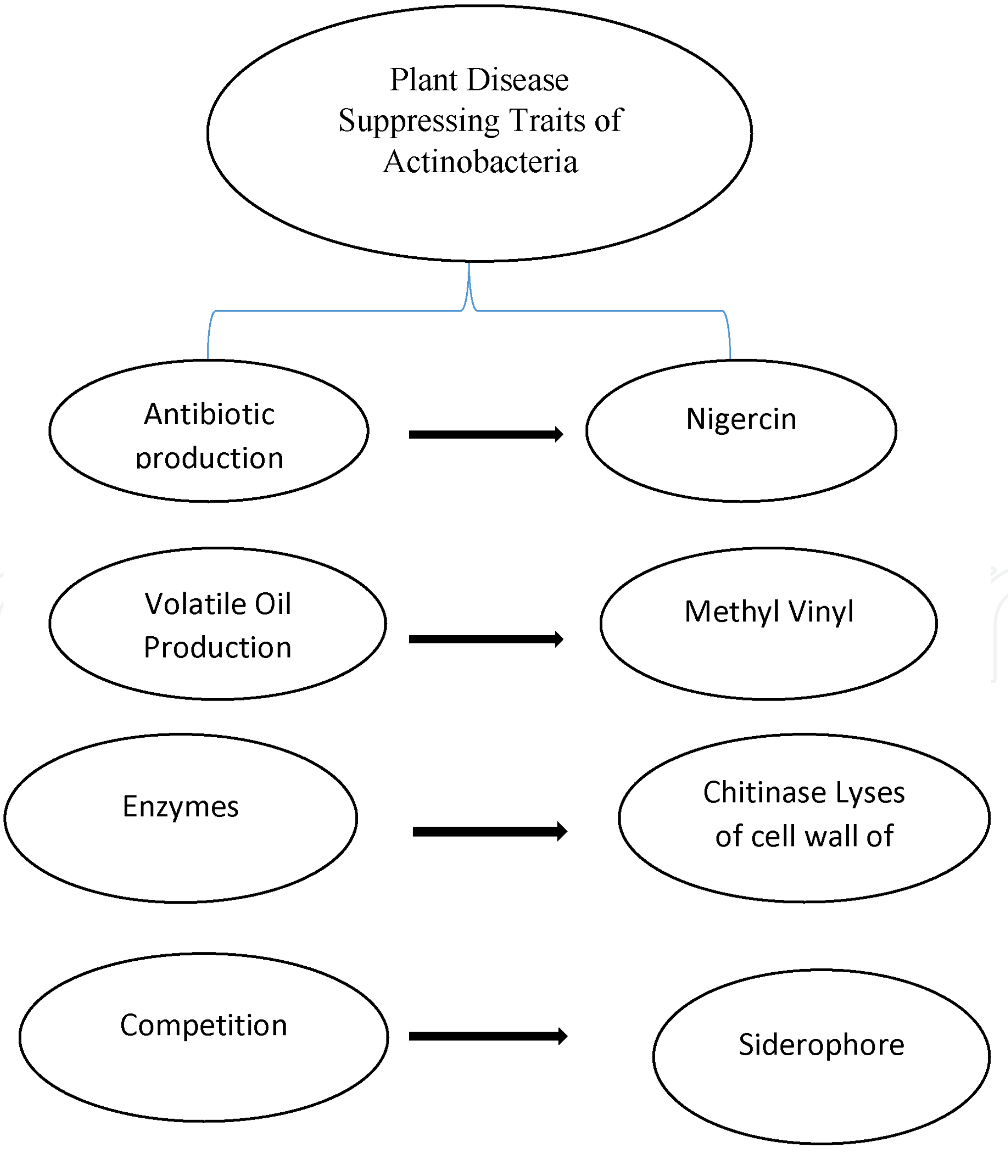

Figure 2.
Plant disease suppressing trait adopted by actinobacteria.

2.1.3 Siderophore production by actinobacteria

Iron is an essential nutrient element for all organisms, which acts as a necessary co-factor for several enzymatic reactions. Many beneficial actinobacteria including *Streptomyces*, *Micrococcus*, *Microbacterium*, *Kocuria*, *Corynebacterium*, and *Arthrobacter* improve the plant growth through production of Fe-chelating compounds. Normally, soil iron resides in insoluble hydroxides and oxy-hydroxides forms that are not available for microbes and plants. For iron availability siderophore, a compound of high iron affinity and low molecular weight is needed to be synthesized [41]. Two major classes of siderophore are catechols and hydroxamate, produced by microbes and various actinobacterial strains that have been nominated as producers of siderophore [42]. Some well-known siderophores that are produced by the genus *Streptomyces* are hydroxamate, desferrioxamines, and coelichelin [43], and other members of actinobacteria like *Rhodococcus* and *Nocardia* produced heterobactin siderophore [44]. Siderophore also plays a role in plant protection from phytopathogens besides its role in plant nutrition. Both siderophore and pathogenic microbe require iron so a competitive environment creates between them in the root vicinity [45]. As actinobacteria produce high-affinity siderophore and fungal pathogen produces low-affinity siderophores, therefore actinobacteria can eliminate the fungal pathogen. *Streptomyces* produce siderophore that is also found to be effective against wilt disease on chickpea caused by *F. oxysporum* f. sp. *ciceri* [46].

2.1.4 Production of hormone

Several rhizospheric and endophytic actinobacteria have been noticed to yield several phytohormones, namely, indole acetic acid (IAA), cytokinins, and gibberellins. These phytohormones show a significant role in the plant growth [47]. The most important phytohormone is indole-3-acetic acid, a principal form of auxin that shows the useful impact on plants by various cellular processes like cell division, elongation, and differentiation. Recently, endophytic actinobacteria are getting more attention because of their role in the production of phytohormones. It has been reported that *Nocardiopsis*, an endophytic actinobacterium, produces the highest percentage of IAA [22]. Many researchers studied that *Streptomyces* endophytes like *S. olivaceoviridis*, *S. rimosus*, *S. atrovirens*, *S. rochei*, and *S. viridis* also produce IAA that is responsible for improved seed germination, root elongation, and growth in different plants [48]. Hence, actinobacteria have the ability to boost the production and growth of plants by producing the phytohormone as shown in **Table 2**.

2.2 Indirect plant growth mechanism of actinobacteria

In indirect plant growth mechanism, actinobacteria also enhance the growth of plants like direct mechanism which is mentioned in **Figure 3**.

2.2.1 Cell wall-degrading enzymes

Actinobacteria synthesize many different extracellular enzymes that help to decompose material in soil. Some of these enzymes include xylanases, chitinases, hemicellulose, nucleases, amylases, lipases, glucanases, pectinase, proteinases, cellulases, ligninases, and keratinase. Mainly soil-living actinobacteria are saprophytic and play a central role in decomposition. Actinobacteria use this mixture of enzymes for decomposition against a variety of phytopathogens and majorly contribute to biocontrol potential by damaging cell wall of these pathogens. Cell wall of many bacteria and fungi is made up of polymers like glycan, cellulose, chitin, protein, and lipids [49]. Actinobacteria are regarded as the dominant organisms that decompose chitin in soil and also considered as promising antagonistic agents for biocontrol because of the hydrolytic reaction on mycelium of the fungi. Acctinobacteria are also observed to produced chitinase enzyme that inhibit fungal growth by cell wall chitin hydrolysis. Many species of *Streptomyces* genus have the potential to degrade the chitin polymer and are, therefore, known as a principal chitinolytic microbial group in soil [50, 51]. A list of some important enzyme secreted by actinobacteria is shown in **Table 3**.

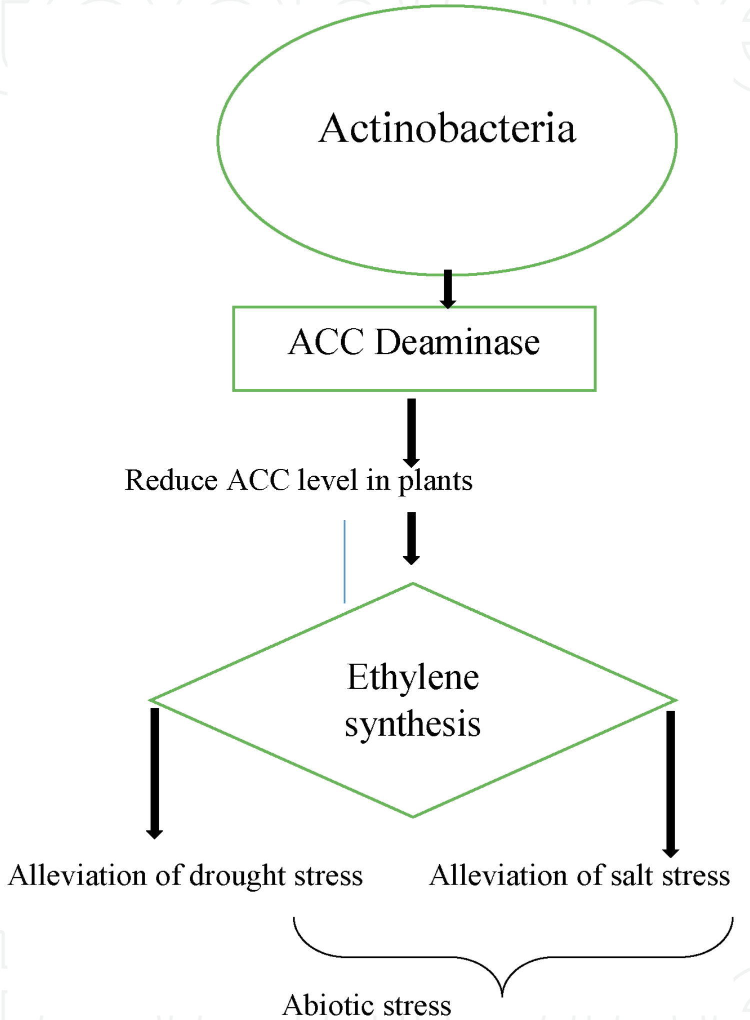

Figure 3.
Alleviation of abiotic stress in actinobacteria.

Enzymes	Actinobacteria	References
Chitinase	*Streptomyces viridificans*, *S. coelicolor*, *S. griseus*, *S. albovinaceus*, *S. caviscabies*, *S. setonii*, *S. virginiae*	[52]
Chitinase, glucanase	*S. cavourensis* SY224	[53]
Cellulose	*Thermomonospora* spp. *Actinoplanes philippinensis*, *A. missouriensis*, *Streptomyces clavuligerus*	[54]
Ligase	*Nocardia autotrophica*	[25]
Amylases, lipases, β-1-3-glucanase	*Thermomonospora curvata*, *Streptomyces* spp.	[55]
Chitinase, glucanase and protease	*Streptomyces* spp. 80	[56]

Table 3.
Production of hydrolytic enzymes by actinobacteria.

2.2.2 Actinobacteria's role as nutrient promoter

As PGP, actinobacteria also act to raise the soil fertility by exhibiting various activities; hence, it is acknowledged as a main natural nutrient enhancer. Besides siderophore producer and phosphate solubilizer, actinobacteria also produce many kinds of enzymes like lipase, amylase, peroxidase, xylanase, chitinase, keratinase, pectinase, cellulase, and protease. This cocktail of enzymes helps to convert nutrients into simple mineral forms, and due to this nutrient cycling ability of actinobacteria, it is considered as an optimal candidate for natural fertilizers [38]. These actinobacteria also promote the soil metal-mobilizing ability like Fe, Zn, and Se, which ultimately increase the germination of seeds and plant growth. Current research has exposed that the root colonization of arbuscular mycorrhizal fungi increases growth of crop and zinc and iron content of chickpea grains [57]. Under greenhouse and field conditions, two PGPR, namely, *Mesorhizobium* sp. and *Pseudomonas* sp., also enhance the production and acquisition of Fe in chickpea [58]. Some previous studies elaborated that actinobacteria enhance plant growth in various crops like cereals, oilseeds, and leguminous by mobilizing the minerals. PGP *Streptomyces* were also observed to increase Fe and Zn quantity by 38% and 30%, respectively, in grains of chickpea [59].

2.2.3 Actinobacteria in bioremediation of metals

Anthropogenic activities are the main cause of metal pollution of agricultural lands which led to a decrease in the fruitful agricultural cropland. As reported by the Environmental Protection Agency (EPA), nearly more than 40,000 contaminated sites are present in the United States. Furthermore, due to heavy metal contamination, 50,000 hectare of forest, 55,000 hectare of pasture, and 100,000 hectare of cropland have vanished, and these need retrieval process [60]. PGP like actinobacteria stay in metal-contaminated soil and increase the bioremediation process by extracting and solubilizing mineral. Different reactions like oxidation, metal reduction, and biosorption as well as several substances like organic acids, siderophores, polymeric substances, glycoprotein, and bio-surfactants are released by the microbes which aid in the metal-mobilizing property of these microbes. Many studies have been performed by researchers which demonstrated the metal-mobilizing mechanism [61].

2.2.4 Reduction of plant-pathogen stress by actinobacteria

Primarily, plants use beneficial microorganisms and plant integrated defense mechanism to protect themselves from phytopathogens [62]. Beneficial microorganisms (pathogen antagonistic) alleviate the pathogen stress in plants through different mechanisms like secretion of anti-pathogenic metabolites, competition for space, and nutrients [8]. Actinobacteria also play vital role in plant protection against plant pathogens utilizing nutrients, required by pathogens for growth. Meanwhile, actinobacteria produce different volatile compounds, antibiotics and cell wall degrading enzymes against phytopathogens [63]. Actinobacteria have been reported to produce various antifungal volatile organic compounds against fungal disease [64]. *Streptomyces* actinobacteria also produce many kinds of volatile compounds which have antifungal activities against *Rhizoctonia solani* and *Botrytis cinerea* [65]. Actinobacteria have the ability to produce different hydrolytic enzymes that degrade fungal and bacteria pathogens cell wall, so protect the plants against phytopathogens [66]. A nonspecific (indirect) mechanism has also been developed by plants which provide the long-term protection against a wide range of phytopathogens. PGP actinobacteria have played an important role in developing disease resistance in plants by inducing gene expression related to defense pathway [67]. Plants display two types of indirect or nonspecific defensive mechanism: the one involves salicylic acid (SA) signaling pathway and pathogenesis-related (PR) protein genes, called systemic acquired resistance (SAR), and the other is induced systemic resistance (ISR) that involves two pathways, ethylene (ET) and jasmonic acid (JA) signaling pathways [68]. A study described that *Streptomyces bikiniensis* HD-087 produces metabolites which cause systemic resistance and suppress the *Fusarium* wilt in cucumber raised by *F. oxysporum* f. sp. *cucumerinum* [69]. Some important metabolites which are synthesized by actinobacteria against phytopathogens are shown in **Table 4**.

Endophytic actinobacteria	Host plant	Metabolite	Target pathogen(s)	Reference
Streptomyces sp. NRRL 3052	*Kennedia nigriscans*	Munumbicins A, B, C and D	*Pythium ultimum*, *Rhizoctonia solani*, *Phytophthora cinnamomi*	[70]
S. melanosporofaciens EF-76 and FP-54	Potato	Geldanamycin	*Streptomyces scabiei*	[71]
Micromonospora sp. M39	Rice	2,3-Dihydroxybenzoic acid, phenylacetic acid, cervinomycin A1 and A2	*P. oryzae*	[72]
S. malaysiensis	Wheat	Malayamycin	*Stagonospora nodorum*	[73]
S. cavourensis subsp. *cavourensis* SY224	Pepper	2-Furancarboxaldehyde	*Colletotrichum gloeosporioides*	[74]
Streptomyces chryseus	*Potentilla discolor*	Saadamycin/5,7-Dimethoxy-4-pmethoxylphenyl coumarin	*Botrytis cinerea*	[75]
Streptomyces sp. MSU-2110	*Monstera* sp.	Coronamycin	*Pythium ultimum*, *Fusarium solani*, *Rhizoctonia solani*	[76]
Microbacterium sp. S4S17	*Ferula sinkiangensis*	Coumarin	*Alternaria alternate*	[77]
Streptomyces olivaceus, *Streptomyces* sp. BPSA 121	*Rhynchotechum ellipticum*	Ketoconazole, fluconazole, miconazole	*Fusarium oxysporum*, *Fusarium proliferatum*	[78]
S. miharaensis 100%	Tomato	Filipin III (purified antibiotic)	*F. oxysporum* f. sp. *lycopersici*	[79]
Streptomyces sp. G10	Banana		*F. oxysporum* f. sp. *cubense*	[80]
Streptomyces sp. AMA49	Rice	Bonactin	*Pyricularia oryzae*	[81]
Streptomyces angustmyceticus NR8–2	*Brassica rapa*	Benzaldehyde, butanoic acid	*Colletotrichum* sp. *Curvularia lunata*	[53]

Table 4.
Metabolites produced by actinobacteria used to suppress disease.

2.2.5 Actinobacteria's role against stress

Several abiotic stress factors including flooding, extreme temperatures, salinity, nutrient stress, drought, and metal stress impose a harmful impact on yields of the crop, as well as it also severally damaged the soil. As described by the Food and Agriculture Organization (FAO), if precautionary steps are not implemented, in the next 25 years 30% land degradation will happen due to abiotic stress factors, and this will rise to 50% in 2050 [16]. Strains of actinobacteria have better tolerance against abiotic stress factors like temperature, salinity, and metal stress, and inoculation of tolerant actinobacteria strain was noticed to encourage the plant growth. Useful effects of PGP *Streptomyces* sp. were observed on maize and wheat under saline conditions [82]. In another in vitro study, *Streptomyces* sp. PGPA39 inoculation showed similar results under saline conditions and ultimately increase the biomass and secondary growth of *Arabidopsis* seedlings (Palaniyandi et al. 2014). Actinobacteria stress tolerance potential was also studied in chickpea [49]. Treatment with *Streptomyces rochei* SM3 in chickpea under stress salt condition decreases mortality (48%) toward *Sclerotinia sclerotiorum* infection and increases biomass (20%). Physiological studies of SM3-treated plants showed increased accumulation of phenolics and proline along with increased catalase and phenylalanine ammonia lyase activities. Further genetic level investigation showed that ET-responsive ERF transcription factor (CaTF2) is triggered by strain SM3 under challenging conditions. Moreover, *Streptomyces padanus* tolerate drought situations by induction of increased osmotic pressure of plant cells and cell wall lignification. Co-inoculation of drought-tolerant *Streptomyces olivaceus* DE10 and *Streptomyces geysiriensis* DE27 endophytic actinobacteria verified the highest yield in wheat [83]. In response to stress, plants produce stress ethylene also known as ET which leads to premature plant death [84]. Microbes synthesize an enzyme known as 1-aminocyclopropane-1-carboxylate (ACC) deaminase that prevents the effect of ethylene due to ethylene precursor ACC conversion to ammonia and a-ketobutyrate which is shown in **Figure 3**. Currently effects of this enzyme on stress management are considered as a central phenomenon of PGP traits and are studied for the past two decades [85]. Some famous actinobacteria that are known to produce ACC deaminase include *Amycolatopsis*, *Streptomyces*, *Nocardia*, *Rhodococcus*, and *Mycobacterium* [86]. Many halo-tolerant actinobacteria having ACC deaminase are isolated from rhizosphere of naturally growing halophytic plants and soil of barren land [29].

3. Conclusion

Production of food to fulfill the need of an increasing population and mimic the reliance on nonrenewable resources and also environmental effect is the greatest challenge of this century. To complete this challenge, the use of plant growth microbes such as actinobacteria is a good choice as an alternative tool for sustainable agriculture. Various studies highlight the abilities of actinobacteria as a plant growth promoter and their additive impact on plant growth and protection. Actinobacteria isolates have shown the multidimensional way to be effective on plant growth. They promote plant growth by involving various activities like production of phytohormones, siderophore production, solubilization of phosphate, fixation of nitrogen, complementing mycorrhizal fungi, and also balancing the ecology of the soil system. Additionally, many studies also have proven the potential of actinobacteria as a biocontrol agent. These characteristics of the actinobacteria group have proved them as inevitable tools for increasing productivity and quality in agriculture. Keeping in mind all these aspects, it is a need of time that we focus on the use of actinobacteria as an alternative tool and reduce the use of harmful chemicals. The studies referred in this chapter also support the belief that the use of eco-friendly microorganisms and designing new formulations with cooperative microbe might contribute to plant growth improvement.

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