

Actinobacteria in Plant Health: A Sustainable Approach to Biocontrol and Disease Management

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Abstract

Actinobacteria are a diverse group of Gram-positive bacteria found in various ecosystems, including soil, plant rhizospheres, and marine environments. Their presence contributes significantly to microbial diversity, influencing ecosystem stability and plant health. These bacteria play a crucial role in promoting plant growth under normal and stress conditions through multiple mechanisms, including enhanced nutrient uptake, production of phytohormones, and induction of pathogenesis-related (PR) proteins. Additionally, actinobacteria stimulate enzymatic activity, produce antibiotics, and synthesize secondary metabolites that aid in plant defense. One of the key attributes of actinobacteria is their ability to suppress plant pathogens through the production of bioactive compounds, including antimicrobial metabolites and lytic enzymes. These metabolites not only inhibit the growth of pathogens but also activate systemic resistance in plants, improving their ability to withstand infections. Furthermore, actinobacteria contribute to soil fertility by decomposing organic matter and facilitating nutrient cycling, thereby enhancing plant resilience. The biotechnological potential of actinobacteria is immense, as their use in agriculture can offer an eco-friendly alternative to chemical pesticides and fertilizers. By harnessing these beneficial microbes, sustainable plant protection strategies can be developed, reducing crop losses due to pathogenic stress while promoting healthier plant growth and productivity.

Keywords: Actinobacteria, Plant Défense mechanisms, Biocontrol agents, Plant Growth Promotion, Rhizosphere Microbiome

1. Introduction

Organisms that are gram positive in nature with high guanine & cytosine content are currently recognized among the bacterial domain (Barka et al. 2016). These bacteria are characterized under the phylum actinobacteria that forms the largest taxonomic units. The wide distribution of actinobacteria majorly exist in free living state among both, the aquatic and terrestrial ecosystems. The terrestrial ecosystem in comparison with other sources encounters higher microbial population. Actinobacteria are also termed as soil dwelling, saprophytic organisms (streptomyces) that resides both on the soil (having High alkalinity and organic matter) and up to 2

metres underground. Their population density gets affected by changing climatic conditions along with their existing habitat. Actinobacteria are present in the mass of 10^6 to 10^9 cells per gram of soil,[1-4] which includes 95% of the actinobacterial strains isolated under genus *streptomyces*. The normal growth conditions include optimal temperature between 25°C– 30°C. Vegetative growth and reproduction of actinobacterial species is favoured maximum between pH 6 to 9, in low humidity producing mycelium like filamentous fungi. Such actinomycetes reproduce by sporulation. At nutritional level most of them are

chemoheterotrophic with an exception of being heterotrophic or chemoautotrophic. Actinobacteria are aerobic, anaerobic and filamentous. They produce geosmin (organic product) that renders earthy odour in the soil. Growth percentage in actinobacterial population ranges 20% (spring), >30% (autumn), and only 13% in winter (Salwan & Sharma, 2020). [4]

2. Taxonomy

Depending upon the 16SrRNA sangers sequencing methodology and phylogenetic analysis, actinobacteria are classified into six classes, six orders, and fourteen suborders. Actinobacteria forms the largest class among 43 families and 16 orders. Molecular markers like *rob*, *atpD*, *gyrB*, *recA*, *trpB* and *ssgB* distinguishes among the closely related genera. Actinobacteria consist of a large genome in comparison to other bacteria varying from 1 to 12 Mb in size having average genome size of 5 Mb (Salwan & Sharma, 2020). The genome also consists limited number of plasmids. Genome of actinobacteria is characterized by the presence of high G + C content of > 70 % reported in *Streptomyces* and *Pseudo nocardia*, and < 50 % in *Gardnerella vaginalis* and *Tropheryma whipplei*. [5]

3. Abiotic and Biotic Stress in Plants

Abiotic stress refers to adverse environmental factors such as high temperatures, water deficiency, nutrient scarcity, salinity, and low iron availability, which negatively impact plant physiology, particularly photosynthesis. Water stress, influenced by precipitation variability, evaporation, and soil moisture retention, limits plant growth and reduces yield, especially in crops like tomatoes. Biotic stress, on the other hand, arises from bacterial, fungal, or viral infections, affecting crops at various growth stages. Globally, plant diseases reduce crop yields by 20%, with fungi responsible for 85% of these losses. While chemical pesticides are widely used for pathogen control, they pose significant risks to human health, ecosystems, and soil quality, leading to issues like groundwater contamination, soil acidification, and pesticide resistance in pathogens. This highlights the need for biological control as a sustainable and long-term reported for their potential to colonize plant roots and produce antibiotics in situ. This property highlights. [6]

4. Diversity and Ecology of Actinobacteria

Actinobacteria are widely distributed in various ecosystems, including soil, rhizosphere, and marine environments. Their presence contributes to microbial diversity and ecosystem stability. Notably, genera such as *Streptomyces*, *Micromonospora*, and *Nocardia* are known for their biocontrol potential. These bacteria establish symbiotic associations with plant roots, promoting nutrient uptake and enhancing resistance to abiotic and biotic stresses. [7]

5. Actinobacteria as biocontrol agents

Biological control aids usage of microbial products as biocontrol agents that undergoes direct and indirect mechanisms in plant defence against pathogen attack (Vurukonda et al., 2018). Actinobacteria are well reported for their potential to colonize plant roots and produce antibiotics in situ. This property highlights the role of actinobacteria as biocontrol agents. Actinobacteria is a suitable alternative for suppression of pathogen and developing induced systematic resistance in plant disease management compromising the usage of agrochemicals. A large number of rhizospheric microorganisms are classified under actinobacteria and are known as plant growth promoter's/ plant growth promoting rhizobacteria (pgpr). Along with colonization of root they also stimulate the plant growth by various mechanisms. Plant growth promoting rhizobacteria are classified as beneficiary bacteria. They reside in the roots of the plant or the rhizospheric soil being closely related to the host plant roots (Li et al., 2021) (Cochard et al., 2022)). While some root associated microorganisms shows detrimental effects on the plant. Nearly 14000 actinobacterial species are isolated from both the host plant and marine ecosystems. Ranging from soil to marine ecosystems, animals and plants actinobacteria reveals their occurrence in variety of sources due to its biotechnological significance. Actinobacteria shows biosynthetic potential in the production of secondary metabolites and renders broad commercial importance (Jose et al., 2021). These secondary metabolites are antibiotics and immunosuppressants useful for the medicinal purpose. Amongst all pharmaceutically important bioactive products the secondary metabolites produced by actinobacteria

contributes in about two third total products. Mechanisms of Plant Growth Promotion Actinobacteria facilitate plant growth through multiple mechanisms, including: [8]

Nutrient Solubilization and Uptake: Actinobacteria enhance the availability of essential nutrients such as phosphorus and nitrogen through solubilization and nitrogen fixation. [9]

Phytohormone Production: The production of auxins, cytokinins, and gibberellins supports root elongation and overall plant development.

Induced Systemic Resistance (ISR): Actinobacteria stimulate the plant immune system, preparing it to combat pathogen attacks effectively. [10]

6. Biocontrol Potential of Actinobacteria

One of the most promising applications of actinobacteria is their ability to suppress plant pathogens through:

- **Antibiotic Production:** Actinobacteria synthesize a wide range of antimicrobial compounds that inhibit pathogen growth.

- **Enzyme Secretion:** Hydrolytic enzymes such as chitinases and proteases break down pathogen cell walls, preventing infections. [11]
- **Competition for Resources:** By outcompeting harmful microbes for nutrients and space, actinobacteria prevent pathogen colonization in the rhizosphere. [12]

7. Actinobacteria and Secondary Metabolites in Disease Management

Actinobacteria produce bioactive secondary metabolites that contribute significantly to plant disease management. Notable metabolites include:

- **Actinomycin, Streptomycin, and Rifamycin:** Effective against a wide range of bacterial and fungal pathogens. (Figure 1)
- **Siderophores:** Iron-chelating compounds that limit iron availability to pathogens, restricting their growth. (Figure 2)
- **Lytic Enzymes:** Degrade pathogenic cell walls, providing an additional layer of protection. [13]

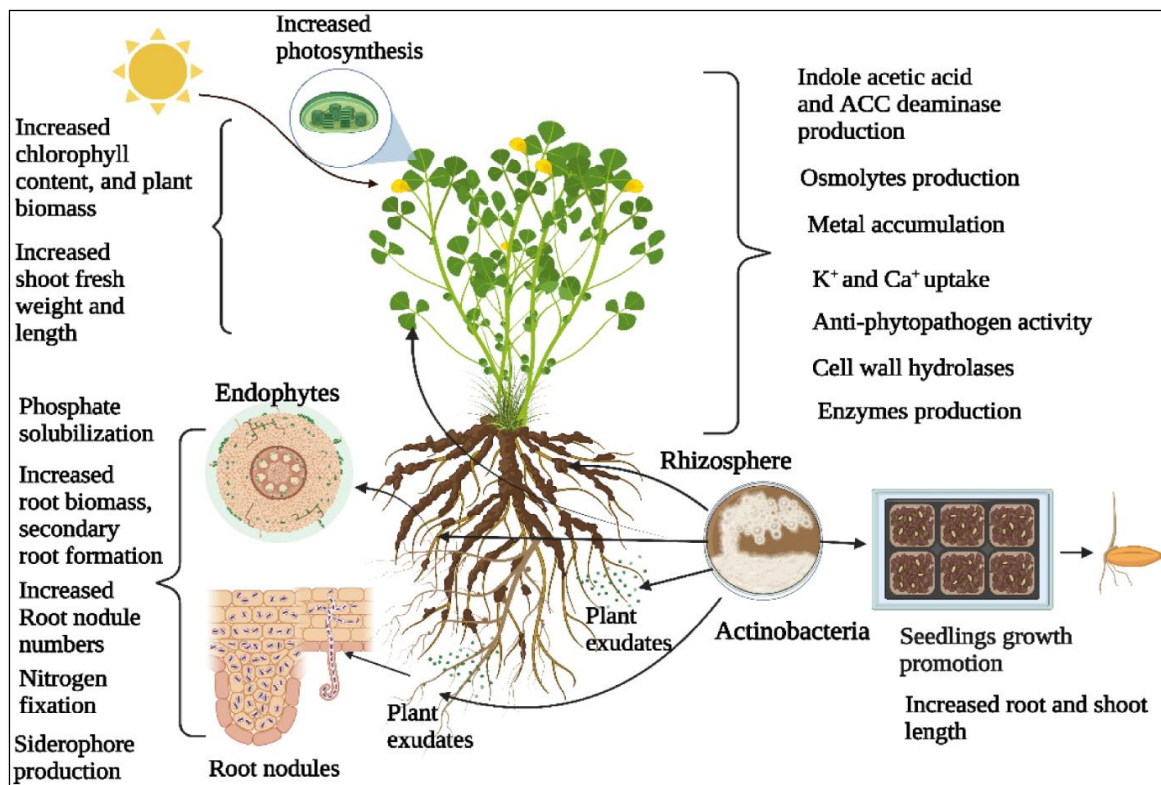


Figure 1 Actinobacteria's role in Plant Defence (Narsing Rao et al., 2022)

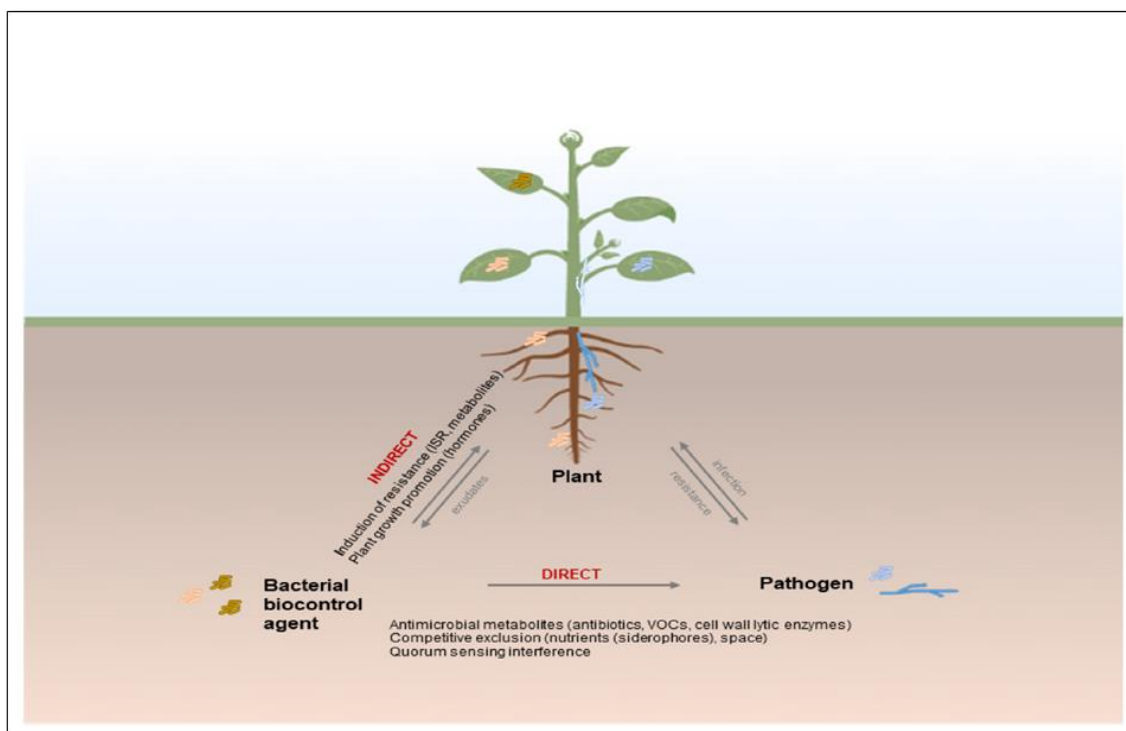


Figure 2 Mode of Action of Actinobacteria (Bonaterra et al. 2022)

Table 1 Streptomyces (20 metabolites)-Host-Pathogen Interaction (Dow et al., 2023)

Metabolite	Streptomyces producer	hosts	Pathogen	Mode of action
10-(2,2 dimethyl-cyclohexyl)- 6,9-dihydroxy-4,9-dimethyl – dec-2-enoic acid methyl ester	Streptomyces hydrogenans DH16	Raphanus sativus	Alternaria brassicicola	Inhibited spore germination
2,4-Di-tert-butylphenol (2,4-DTBP)	Streptomyces sp. UT4A49	Solanum lycopersicum	Ralstonia solanacearum	Antibiosis
Antifungalmycin N2	Streptomyces sp. N	Vitis vinifera; Oryza sativa	Rhizoctonia solani	Antibiosis and ISR
Blasticidin – S	S.griseochrom ogenes	Oryza sativa	Pyricularia oryzae	Inhibits protein biosynthesis
conprimycin	S. sp. S4-7	Fragia * ananassa	Fusarium oxysporum	Inhibits cell wall biosynthesis
daunomycin	Actinomadura roseola	Capsicum annuum cv. hanbyul	Phytophthora capsica, Rhizoctonia solani	Inhibited mycelial growth

Filipin III	<i>S. miharaensis</i> strain KPE62302H	<i>Solanum lycopersicum</i>	<i>Fusarium oxysporum</i> f.sp. <i>lycopersici</i>	Protection from wilt
Gopalamicin	<i>Streptomyces Hygroscopicus</i> , MSU-625 and MSU- 616	<i>Vitis vinifera</i> & <i>Oryza sativa</i>	<i>Plasmopara viticola</i> <i>Pyricularia oryzae</i>	Protective and curative effects
Irumamycin	<i>S. subflavus</i> subsp. <i>Irumeansis</i> AM- 3603.	<i>Cucumis sativus</i>	<i>Botrytis cinereal</i> and <i>Colletotrichum</i>	Inhibited growth of filamentous fungi
Kasugamycin*	<i>Streptomyces kasugaensis</i>	<i>Oryza sativa</i> ; Multiple <i>Pyrus</i> cultivars	<i>Pyricularia oryzae</i> ; <i>Erwinia amylovora</i>	Inhibitor of glycoside hydrolase family 18 (GH18) chitinases
Nigericin °	<i>Streptomyces violaceus</i> Niger YCED9	Turfgrass (Species unclear)	<i>Gaeumannomyces graminis</i> 151 <i>Sclerotinia homeocarpa</i> <i>Rhizoctonia solani</i> P	Antibiosis (unknown mode of action)
Oligomycin A (As1A)	<i>Streptomyces libani</i>	<i>Capsicum annum</i> ; <i>Cucumis sativus</i> ; <i>Oryza sativa</i>	<i>Phytophthora capsica</i> ; <i>Colletotrichum lagenarium</i> ;	
Undecyl prodigiosin	<i>Streptomyces lividans</i>	<i>Arabidopsis thaliana</i>	<i>Verticillium dahliae</i>	Interacts with fungal chromosomal DNA
Validamycin* (Validamycin A)	<i>Streptomyces hygroscopicus</i> var. <i>limoneus</i>	<i>Oryza sativa</i> ; <i>Arabidopsis thaliana</i> ; <i>Triticum aestivum</i>	<i>Rhizoctonia solani</i> , <i>Pseudomonas syringae</i> , <i>Botrytis cinerea</i> , and <i>Fusarium graminearum</i>	Antibiosis. Inhibition of toxin biosynthesis Induction of plant defence responses through SA and JA/ ET signalling pathways

Application of Actinobacteria in Sustainable Agriculture Integrating actinobacteria into agricultural practices offers numerous benefits:

Biofertilizers and Biopesticides: Formulations based on actinobacteria enhance soil fertility while reducing dependency on chemical inputs.

Seed and Soil Inoculation: Treating seeds and soil with actinobacterial strains improves germination rates and plant vigor. [15]

Enhanced Tolerance to Abiotic Stress: Actinobacteria aid in drought resistance, salinity tolerance, and heavy metal detoxification, ensuring better crop yields under challenging conditions. Challenges and Future Prospects

Despite their immense potential, the commercial application of actinobacteria faces challenges such as strain stability, large-scale production, and variability in field performance. Future research should focus on:

Genomic and Metagenomic Studies: To identify novel strains with enhanced biocontrol capabilities.

Biotechnological Advancements: Developing efficient bioformulations for improved shelf-life and efficacy. [16]

Field Trials and Regulatory Approvals: Ensuring the practical application of actinobacteria-based products in agriculture.

Conclusion

Actinobacteria represent a promising solution for sustainable plant disease management and agricultural productivity. Their ability to promote plant growth and suppress pathogens through natural mechanisms makes them an invaluable tool in reducing chemical dependency in farming. Future advancements in microbial biotechnology will further enhance their potential, paving the way for environmentally friendly and sustainable agricultural practices.

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