Actinomycetes as Agroalleviate against Inciters: A Review

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Abstract

The important roles that actinomycetes, a varied group of Gram-positive bacteria, play in soil ecosystems have attracted a lot of attention. They have established themselves as strong contenders for biocontrol against a range of agricultural pathogens due to their abundant synthesis of bioactive secondary metabolites, including antibiotics. This review provides a thorough synthesis of the existing literature on actinomycetes potential for biocontrol against plant disease inciters. The review starts off by examining the special qualities and ecological importance of actinomycetes, emphasising their capacity to produce a large number of secondary metabolites. Their wide range of antibacterial chemicals, which are the foundation of their biocontrol systems, are given particular attention.

The paper then explores the diverse biocontrol methods that actinomycetes utilise. These mechanisms include the ability to fix nitrogen as well as the synthesis of chitinases, siderophores, antibiotics, and antifungal chemicals. The processes in question give competitive benefits that are examined in relation to their ability to impede the development and proliferation of inciters, hence protecting crop health. The review also discusses how actinomycetes might be used in sustainable agriculture. The talk covers how to maximise their biocontrol potential in terms of formulations, application methods, and compatibility with current farming practises. Aspects to maximise their effectiveness while reducing their negative effects on the environment are also examined.

An viewpoint on potential obstacles and future research prospects in the use of actinomycetes as agroalleviates is provided at the end of the article. The investigation of new actinomycete strains, the clarification of intricate microbial interactions in soil ecosystems, and the creation of customised biocontrol approaches for particular crop-pathogen systems are three main areas of interest. In conclusion, this analysis offers a thorough assessment of actinomycetes' potential for biocontrol against plant disease initiators. Using the amazing potential of these soil-dwelling bacteria, our work seeks to promote sustainable agriculture practises by synthesising current information and highlighting opportunities for future research.

Key Words: Actinomycetes, Diversity, Secondary metabolites, Biocontrol

1. Introduction

Sustainable agriculture is a holistic approach to farming that aims to meet current agricultural needs while ensuring the long-term viability of ecosystems and resources for future generations. It emphasizes environmentally friendly and socially responsible practices that balance economic productivity with ecological health. The concept recognizes that traditional agricultural methods, often reliant on synthetic inputs and large-scale monocultures, can lead to soil degradation, loss of biodiversity, water pollution, and other negative impacts. The need for sustainable agriculture arises from several interconnected challenges as, environmental degradation, biodiversity loss, resource scarcity, climate change, food security, health concerns **(Oyedoh et al., 2013).**

In response to these challenges, sustainable agriculture promotes practices such as crop rotation, agroforestry, integrated pest management, organic farming, and conservation tillage. These approaches aim to minimize environmental impacts, enhance soil health, promote biodiversity, conserve water, and reduce the reliance on synthetic inputs. By adopting more holistic and resilient practices, sustainable agriculture seeks to create a balance between agricultural productivity, environmental health, and social well-being **(Shanthi, 2021).**

Actinomycetes are a diverse group of microorganisms that thrive in soil ecosystems and play a vital role in shaping the soil microbiome. They are filamentous bacteria known for their unique morphology and exceptional ability to produce a wide range of bioactive compounds. These microorganisms have captured the attention of researchers and agricultural scientists due to their immense potential in contributing to sustainable agriculture. Abundant in terrestrial environments, actinomycetes are essential players in nutrient cycling, organic matter decomposition, and soil structure maintenance. Their filamentous growth forms intricate networks that aid in the breakdown of complex organic materials, releasing essential nutrients back into the soil. This activity directly influences soil fertility and the overall health of agricultural ecosystems **(Gousia et al., 2023).**

What truly distinguishes actinomycetes is their prolific production of secondary metabolites. These bioactive compounds have proven applications in various agricultural contexts. Actinomycetes are known for producing antibiotics that can suppress harmful pathogens responsible for crop diseases. This natural biocontrol mechanism aligns with the principles of sustainable agriculture by reducing the need for synthetic chemical pesticides that can harm beneficial organisms and lead to environmental contamination. Furthermore, actinomycetes are adept at synthesizing enzymes that aid in nutrient solubilization and uptake by plants. This promotes efficient nutrient utilization, which is a crucial aspect of sustainable agriculture focused on optimizing resource use. Actinomycetes can also produce plant growth-promoting substances that enhance root development, nutrient absorption, and stress tolerance in crops, contributing to increased yields and improved crop resilience **(Abdallah et al., 2013).**

In the context of sustainable agriculture, actinomycetes offer a promising avenue for reducing the reliance on synthetic inputs while simultaneously enhancing soil health and plant productivity. Their ability to contribute to disease management, nutrient cycling, and growth promotion aligns seamlessly with the goals of ecologically sound and economically viable farming practices. By harnessing the potential of actinomycetes, we pave the way for a more sustainable and resilient agricultural future.

2. Habitat, Isolation and diversity of Actinomycetes

Actinomycetes exhibit remarkable diversity in terms of species and habitats, making them a fascinating group of microorganisms with significant agricultural potential. Found abundantly in soil ecosystems, they contribute to the soil's microbial community composition and overall ecosystem function **(Ezeobiora et al., 2022).**

Actinomycetes are available in area samples of Soil, aquatic and extreme with terrestrial, freshwater and marine, extreme environment respectively **(Hayakawa,2008; Goodfellow and Williams, 1983; Ezeobiora et al., 2022).**

Actinomycetes can isolate by using general methods as serial dilutions, streaking, pour plate technique and centrifugation by using different growth media according to different habitat samples (**Table 1).** Growth media is also differentiate according to habitat of samples. These isolates further can study by using morphological, physiological, biochemical and molecular methods (**Table 2).**

Table 1. Growth media useful according to sample type for Actinomycetes isolation (Sharma et al., 2014)

Area	Media
Plant Samples	Starch yeast casein agar(SYCA),Actinomycetes Isolation agar (AIA), Humic Acid vitamin gellan gum (HVG),Tap water yeast extract agar (TWYE), Coal –vitamin agar (CVA)
Water	Chitin agar media, M3 agar medium, Benett"s medium, Starch-casein agar, Asparagine agar, Glycerol-glycine agar, AIM medium
Soil	Starch-casein medium, Humic acid-vitamin agar, Starch casein nitrate agar(SCS), Hair hydrolysate vitamin agar(HHVA), Bennet"s agar(BA),)Arginine-glycerol salt(AGS)medium, Chitin medium, Modified Benedict"s medium, Soybean meal-glucose medium, Gauze's agar medium, Czapek's agar medium, Egg albumen medium, Glucose-asparagine medium, Glycerol-asparaginate agar 2, Chitin agar, Starch casein nitrate(SCN) agar medium, Yeast extract-malt extract agar, Mineral salt(MS) medium, Coal-vitamin agar

The vast diversity of actinomycetes (**Table 3**) species is reflected in their various morphologies, growth patterns, and metabolic capabilities. This diversity leads to the production of a wide array of secondary metabolites, which are organic compounds not directly involved in the microorganisms' primary metabolic processes. These metabolites are often bioactive in nature, serving diverse ecological roles.

Table 2. Study methods and types for Actinomycetes isolate (Eppard et al., 1996)

Study Methods	Types
Morphological	Macroscopic methods - Cover slip culture, Microscopic methods - Slide culture method
Physiological	Range of pH for growth, Optimum temperature for growth, Salinity
Biochemical	Catalase production, Urease production, Hydrogen sulfide production, Nitrate reduction, Starch hydrolysis, Gelatin liquefaction, Methyl red test, Vogues-proskauer test, Indole

	production, Citrate utilization, Casein hydrolysis
Molecular	RFLP using any one of genomic DNA, RAPD, PFGE, ARDRA, Use of genus specific primers

Table 3. Different family of Actinomycetes and Species involved (Sharma et al., 2014)

Family	Species
Streptosporangiaceae (Maduromycetes)	*Planomonospora, Planobispora, Kutzneria, Spirillospora, Streptosporangium, Streptoalloteichus*
Pseudonocardiaceae	*Saccharomonospora, Actinopolyspora, Amycolata, Kibdellosporangium, Pseudonocardia, Saccharopolyspora, Amycalotopsis/Nocardia, Kibdellosporangium*
Streptomycetaceae	*Streptomyces, Microellobosporia, Nocardioides, Kitasatosporia, Chainia, Streptoverlicillium*
Mycobacteriaceae (Actinobacteria)	*Nocardia, Rhodococcus, Brevibacterium, Proactinomyces, Mycobacterium*
Thermomonosporaceae	*Thermoactinopolyspora, Thermoactinomyces, Thermopolyspora, Micropolyspora/Faenia, Thermomonospora, Saccharothrix, Actinomadura, Microbispora, Actinosynnema, Nocardiopsis, Microtetraspora/Nonomuria*
Other (unclassified) species	*Alkalomyces, Catellatospora, Erythrosporangium, Streptoplanospora, Microechinospora, Salinospora, Actinosporangium, Microellobosporia, Frankia, Kitasatoa, Westerdykella, Waksmania, Excelsospora, Synnenomyces, Elaktomyces, Sebekia*

3. Secondary metabolites of actinomycetes

Actinomycetes are renowned for their prolific production of bioactive secondary metabolites such as antibiotics, antifungals, enzymes, and growth-promoting compounds. These metabolites are the result of complex biochemical pathways and are believed to have evolved as competitive strategies within microbial communities. In the context of agriculture, these bioactive compounds offer valuable tools for pest and disease management, as well as for enhancing plant growth and health **(Alam et al., 2022).**

The rich metabolic potential of actinomycetes has spurred extensive research into discovering and characterizing their metabolites. This exploration has led to the identification of compounds with the capacity to suppress plant pathogens, stimulate plant growth, and contribute to nutrient cycling. Harnessing the diversity of actinomycetes and their metabolites holds significant promise in developing sustainable agricultural practices that rely less on synthetic chemicals and more on naturally derived solutions **(Aggarwal et al., 2022; Selim et al., 2021).**

Overall, the diversity of actinomycetes and their metabolite production capabilities provide a reservoir of bioactive compounds with potential applications in sustainable agriculture (**Table 4**). Understanding and tapping into this diversity offers opportunities to address key challenges in modern farming while maintaining environmental and ecosystem health.

Table 4. Different metabolites produced from Actinomycetes and its role (Patil & Chaudhari, 2011)

Metabolites	Organisms	Role
Rhamnose	*Saccharopolyspora erythrae*	In insect control
Rapamycin	*Streptomyces hygroscopicus*	Antifungal
FK520 Ascomycin	*Streptomyces hygroscopicus* var. *ascomyceticus*	Antifungal
Jiggangmycin	*Streptomyces hygroscopicus*	Antifungal
Amphotericin B	*Streptomyces nodosus*	Antifungal
CE -108	*Streptomyces diastaticus*	Antifungal
Rimocidin	*Streptomyces diastaticus* Var. 108	Antifungal
Shurimycins A and B	*Streptomyces hygroscopicus*	Antifungal, Antibacterial
Nachangmycin	*Streptomyces nachangensis*	Insecticidal
Fortimicin A (Astromicin)	*Micromonospora olivasterospora*	Antibacterial
Monomycin	*Actinomyces circulates* Var. *monomycini*	Antibacterial
Maduramycins	*Actinomadura rubra*	Antibacterial
Arizonins A1 and B1	*Actinoplanes arizonaensis* sp. nov.	Antibacterial
Candiplanecin	*Ampullariella reguralis*	Antifungal
Kanchanamycins	*Streptomyces olivaceus*	Antifungal, Antibacterial

4. Actinomycetes and Biocontrol mechanisms

It has been demonstrated by a number of both classical and contemporary researchers that actinomycetes play a major role in the treatment of plant diseases through a variety of ways. When using such a method, it is important to comprehend the mechanisms actinomycetes' role as bioagents behind disease suppression provided for the successful using these entities for the purpose of managing diseases. Among the mechanisms and interactions that contribute to the conflict, either alone or Actinomycetes and other microbial bioagents work in concert to (a) block the pathogen by means of antibacterial substances (antibiosis), (b) iron-related competition creation of siderophores, (c) rivalry for nutrition and colonisation sites provided by roots and seeds, (d) the induction of defence systems in plants, and (e) inactivation of germination-promoting agents found in exudates from seeds or roots, (f) destruction of the pathogen's pathogenecity components, such as toxins, parasitism, which may result in the production of enzymes that break down extracellular cell walls, such as chitinase and ɔ-1, and 3 glucanase, which has the ability to lyse pathogen cell walls **(Torres-Rodriguez et al., 2022).** While there is no reason for any of the processes to be mutually exclusive, a single actinomycetes strain may often demonstrate many modes of action. It's possible that many mechanisms, or combinations of mechanisms, contribute to the suppression of plant disease in some strains.

4.1 Competition

Competition between a variety of soil-dwelling species for resources like nutrients, oxygen, and colonisation sites usually takes place in soil. When an antagonist directly competes with pathogens for the aforementioned resources, it appears to be a biocontrol mechanism. Actinomycetes win out because of their robust physiology, capacity for biodegradation, and antagonistic potential **(González-Franco & Robles-Hernández, 2009).**

Various modes of competition exist, such as the competition between root-dwelling microorganisms for infection sites at the root surfaces, and the inhibition of fungal spore germination in soil jþ due to competition for nutrients, particularly carbon **(Alabouvette et al. 2006).** Similar to this, actinomycete's capacity to degrade heavy metals can lead to competition in soils for trace elements like iron, copper, zinc, manganese, etc.

Actinomycetes create siderophores, which are tiny molecular weight molecules with a high iron affinity that chelate ferric ions to acquire them competitively. **Haas and Defago (2005)** claim that siderophores can induce iron shortage, which can operate as a diffusible bacteriostatic or fungistatic antibiotic.

4.2 Parasitism

This event is characterised by physical interaction between the pathogen and antagonists, which results in the pathogen's death by breaking down its cell wall (**Shimizu, 2011**). In this scenario, the likelihood of the hydrolytic enzymes produced by the bioagent is higher **(Adams, 1990).** The main structural elements of most fungi are ß-1,3-glucan and chitin, which are denatured by extracellular enzymes such ß-1,3-glucanases, cellulases, and chitinases. According to **Dunne et al. (2000),** the mutant strain of *Stenotrophomonas maltophilia* W81 produced more extracellular protease, which enhanced *Pythium ultimum* biocontrol. In one study, **Sun et al. (2006)** found that the parasitic activity of four actinomycetes strains decreased the tomato root gall disease severity index by 13.4–58.9% when compared to the no treatment control.

Based on their capacity to produce chitinase and glucanase, Streptomyces has also been demonstrated to play a significant role in the mycoparasitism of phytopathogenic fungi in the same environment **(Herrera-Estrella, & Chet, 1999; Karimi et al., 2012).**

4.3 Antibiosis

The term "antibiosis" describes the inhibition or elimination of the pathogen by metabolic products generated by the antagonist. These products can include volatile substances, toxic substances, antibiotics, and other substances that, at low concentrations, are harmful to the growth or metabolic processes of other microorganisms **(Gomes et al., 2000**; **Fravel 1988).** Actinomycetes are the most productive microbes, contributing significantly to the production of many antibiotic classes **(Bizuye et al., 2013).** *Streptomyces violaceusniger* strain G10 was shown to biologically regulate *Fusarium oxysporum* f. sp. *cubense* in a study by **Getha and Vikineswary (2002)** by antibiosis. Numerous substances, including as pyrrolnitrin (PRN), pyoluteorin (PLT), 2,4-diacetylphloroglucinol (2,4-DAPG), and other phenazine (Phz) derivatives, have been successfully implicated in the biological regulation of phytopathogens.

4.4 Enzyme Production

It is well known that microbial enzymes have hyperparasitic activity, which involves excreting cell wall hydrolases to target pathogens. The main way that *Streptomyces sp*. strain 385's chitinase had antagonistic effects was by inhibiting spore germination and germ tube elongation, limiting growth by breaking down and lysing fungal mycelia, and so on **(Compant et al., 2005).**

Nonetheless, in certain actinomycetes strains—such as *Streptomyces* sp. strain 385—chitinolytic activity seems to be less necessary; instead, B-1, 3-glucanase is preferentially synthesised and lyses the fungal cell wall of *F. oxysporum* f. sp. *cucumerinum* **(Singh et al. 1999).**

4.5 Plant Growth Promoters

Suzuki et al. (2000) state that active chemicals, many of which are agro-important, are produced by soil actinomycetes in the rhizospheric arena. Actinomycetes have been identified as one of the microorganisms that may be able to dissolve the insoluble organic and inorganic phosphorus compounds. Actinomycetes had the ability to solubilize phosphate in the estuarine environment, a finding that has been supported by very few research. Fungal phytopahogens such as *Alternaria brassicicola* (rose apple anthracnose), *Colletotrichum gloeosporioides* (potato dry rot), *Fusarium oxysporum* (chinese cabbage leaf spot), *Penicillium digitatum* (orange green mould), and *Sclerotium rolfsii* (damping-off of balsam) exhibited reduced disease symptoms **(Kucey et al., 1989; Sahu et al. 2007). Khamna et al. (2009)** reported a member of the genus Streptomyces that had both siderophore and the ability to produce indole acetic acid (IAA).

Numerous soil actinomycetes, particularly those belonging to the genera *Streptomyces, Frankia, Micromonospora,* and *Nocardia,* have both symbiotic and asymbiotic relationships with plant organs, particularly roots **(Hamedi & Mohammadipanah, 2015; Oyedoh et al., 2023).** Actinomycetes that fix nitrogen from the atmosphere for their host plants are widely distributed and symbiotically connected with plant roots. One example of an actinomyces that is active in nitrogen fixation is the *Frankia* genus **(Benson and Silvester 1993).** According to **Hamdali et al. (2008),** a single actinomycetes strain can positively impact plants by producing siderophores, solubilizing rock phosphate, and opposing fungal phytopathogens, among other multifunctional properties. *Streptomyces lydicus* WYEC108 was found to enhance nitrogen fixation in the roots of immature pea seedlings symbiotic with *Rhizobium* sp. in a study conducted by **Tokala et al. (2002).**

4.6 Induction of Plant Defence

Through a variety of processes, filamentous gram-positive bacteria called actinomycetes contribute to Systemic Acquired Resistance (SAR) in plants. They emit secondary metabolites that have antibacterial qualities, which encourage the synthesis of secondary metabolites in plants and bolster their defence mechanisms. Actinomycetes can also activate defence genes, which results in the production of proteins and metabolites essential for pathogen defence, and modify the levels of plant hormones, including salicylic acid, a major player in SAR. Additionally, they strengthen general plant health through their interactions with beneficial rhizosphere bacteria, laying a stronger basis for SAR. The ability of actinomycetes to stimulate plant vigour and growth strengthens the plant's defences against pathogenic attacks, which together help plants mount a stronger and more resilient SAR response **(Senthilraja,2016).**

Induced Systemic Resistance (ISR) in plants is largely mediated by actinomycetes. Actinomycetes interact with plants to release elicitors, or signalling molecules, which trigger the innate defences of the plant. This triggers the start of signal transduction pathways, which activate genes linked to defence and produce secondary metabolites. These metabolites improve the plant's resistance against a variety of diseases. Actinomycetes can also affect the amounts of plant hormones, including salicylic acid, which is an important ISR regulator. Actinomycetes provide a strong basis for ISR by improving the general health and vigour of the plant, preparing it for quicker and more powerful defence responses in the event of a subsequent pathogen attack. In conclusion,by activating ISR, actinomycetes are strong allies that strengthen a plant's natural defences and increase its resistance to several diseases **(Martínez-Hidalgo et al., 2015).**

5. Conclusion

In conclusion, Actinomycetes show great promise as agroalleviates in the fight against plant disease inciters, demonstrating their diverse range of applications in agricultural settings. Their ability to suppress the growth of harmful microbes and promote plant health and vigour stems from their abundant synthesis of bioactive secondary metabolites, which include antibiotics and chemicals that promote plant growth. Moreover, actinomycetes strengthen a plant's innate immune system against a variety of pathogens by triggering systemic resistance (ISR) through intricate signalling pathways. Their function in supporting plant defence mechanisms is supported by their capacity to regulate plant hormone levels, activate genes linked to defence, and increase the synthesis of secondary metabolites. Furthermore, actinomycetes support a symbiotic environment that inhibits pathogenic inciters, which helps to maintain a healthier rhizosphere. Actinomycetes show themselves to be useful allies in the goal of resilient agriculture as we traverse the requirement for sustainable agriculture.

6. References

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