ROLE OF ACTINOMYCETES IN AGRICULTURE

Abstract

Agriculture's advancement in technology brings with it several challenges and problems. According to certain predictions, the need for agricultural supplies would increase by up to 70% by 2050 (Bindraban *et al.,* 2018). Chemical fertilisers and insecticides are frequently used to improve plant nutrition and protection. However, when these products are overused, they accumulate in nature and induce eutrophication of water bodies, resulting in harmful effects on human health (Khan *et al.,* 2014; Bonner *et al.,* 2017).

Microorganism-based products provide a practical solution for reducing pesticide usage while maintaining high productivity and safeguarding the environment and human health. Biopesticides that utilize microbial biological control agents (MBCAs) have proven to be highly effective against significant agricultural phytopathogens (Umesha *et al.,* 2018; Thakur *et al.,* 2020) due to their natural molecular mechanisms that allow for precise target specificity. This results in decreased pest populations and a restored ecological balance in the environment (Abbey *et al.,* 2019).

Actinomycetes stand out for their unique bioactive characteristics among the various microorganisms that can be used in agricultural products (Matsumoto *et al.,* 2017). These are biologically significant bacteria typically found in soil and can create a wide range of metabolites of commercial value, including antibiotics, hormones, and enzymes. According to Jakubiec-Krzesniak *et al.* (2018), these substances are typically by-products of secondary metabolism utilized during the critical phases of their development and reproduction. The objective of this chapter is to provide a clear understanding of the key concepts related to the use of actinomycetes in agriculture for protecting against diseases and pests.

Keywords: nitrogen fixation, non-legumes without forming nodules, polymer in dead plant, animal and fungal material

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I. ACTINOMYCETES AS SUCCESSFUL BIOCONTROL AGENTS

Phytopathogenic microorganisms, such as fungi, bacteria, viruses, pests, and plant parasitic nematodes are considered to have a substantial negative effect on productivity and are capable of producing diseases that impair plant performance. To counteract this, environmentally friendly actinomycetes were considered as the potential biocontrol agent among many microbial biological control agents due to their mode of action (Mashela *et al.,* 2017, Penh *et al.,* 2020).

Actinomycetes protect plants from harmful pests and diseases using both direct and indirect mechanisms. Antibiotics, lytic enzymes, and insecticidal and nematicidal metabolites are examples of direct mechanisms that control undesirable species without coming into direct contact with them. In contrast, indirect mechanisms occur when undesirable species are directly impacted by actinomycetes, such as through competition for nutrients and space (Kohl *et al.,* 2019), induced systemic resistance (ISR), volatile organic compounds (VOCs), and systemic acquired resistance (SAR) (Pacios-Michelena *et al.,* 2021).

Antibiosis is a direct method of biocontrol utilized by actinomycetes to prevent pathogen growth through the production of harmful metabolites (Maramorosch *et al.,* 2009; Arseneault *et al.,* 2017). Streptomyces is a widely recognized group of actinomycetes that provide more than 60% of the antibiotics utilized in agriculture and horticulture. Lytic enzymes suchas chitinases play a crucial role in the antibiosis mechanism by breaking down cell walls and essential components of fungal cell walls that impede their growth (de Oliveira *et al.,* 2020). Hyperparasitism is also another type of direct bio control in which an organism acquires nutrition by colonizing a pathogen. This method is more commonly observed in fungal species but can occasionally occur in bacteria and requires further investigation in biopesticide formulations (Köhl *et al.,* 2019).

Secondary metabolites produced by the actinomycetes have the potential to inhibit phytopathogens. For example, Pan *et al*. (2015) reported that Bafilomycins B1 and C1 released by Streptomyces *cavourensis* NA4 had shown antifungal abilities against *Rhizoctonia solani, Botrytis cinerea*, and *Fusarium* sp., Furthermore, 1H-Pyrrole-2-carboxylic acid (PCA) from *Streptomyces griseus* H7602 inhibited the growth of *Phytophthora. capsici* (Nguyen *et al*.,2015).

Actinobacteria are known for producing enzymes that effectively combat plant diseases, such as glucanases, chitinases, cellulases, lipases, amylases, and proteases (Jog *et al.,* 2016). For example, Gopalakrishnan *et al*. (2011) in their study found that Streptomyces strains were able to decrease the incidence of Fusarium wilt in chickpea plants by producing different metabolites. These metabolites included cellulase and protease enzymes, as well as hydrogen cyanide. In addition, *S. cavourensis* SY224 which produces chitinase and beta-1,3 glucanase and 2-furan carboxaldehyde has been shown to control anthracnose disease in pepper (Lee *et al.,* 2012).

Many Actinobacteria associated with plants, such as *Streptomyces* strains, produce bioactive molecules known as volatile organic compounds (VOCs) that have antifungal properties (Citron *et al.,* 2015). The bacterium *S. angustmyceticus* NR8-2 was found to release antifungal substances through volatile means, such as aldehydes, alcohols, carboxylic acids, and fatty acids. Moreover, this bacterium has the ability to produce β-1,3-glucanase, which helps to control leaf diseases caused by *Curvularia lunata* and *Colletotrichum* sp. on Bekana cabbage of Tokoyo (Wonglom *et al.,* 2019).

Commercialized actinomycete products

Product name	**Organism**	**Target pathogen**	**Biocontrol mechanism**
Fungicide			
Mycostop	*Streptomyces griseoviridis* strain K61	*Alternaria* sp., *Ceratocystis radicicola,* *Fusarium* sp., *Pythium* sp.,	Competition, antibiosis and hyperparasitism
Actinovate, Micro108, Actino-Iron	*Streptomyces lydicus* strain WYEC108	*Erisiphe* sp., *Fusarium* sp., *Sclerotinia* sp., *Laveillula* sp., *Phytophthora* sp., *Rhizoctonia* sp., *Pythium* sp., *Sphaeroteca* sp.	Hyperparasitism and antibiosis
Insecticide			
Vertimec, Agri-Mek SC	Abamectin from *Streptomyces avermitilis*	Leafhoppers, mite, leafminers	Antibiosis
Entrust SC, Tracer	Spinosad and spinosyn D from *Saccharopolyspora spinosa*	Leafminers, fire ants, thrips, lepidopterous larvae (caterpillars)	Antibiosis
Nematicide			
Actinovate	*Streptomyces lydicus* strain WYEC108	*Pratylenchus* sp., *Heterodera* sp., *Meloidogyne* sp.	Antibiosis
Avicta	Abamectin from *Streptomyces avermitilis*	*Heterodera* sp., *Pratylenchus* sp., *M. incognita*, *M. arenaria*, *M. javenica*	Antibiosis

II. PLANT GROWTH-PROMOTING EFFECT OF ACTINOMYCETES

Actinomycetes protect plants against pathogen attacks by displaying biological control abilities (a direct or indirect mechanism) and enhancing the growth and development of plants. Plant-growth-promoting actinomycetes are advantageous to the host plant by modulating phytohormones and increasing nutrient bioavailability. Phytohormones include auxins mainly comprising of Indole acetic acid (IAA), gibberellin, cytokinnins and ethylene that control ACC deaminase. The increase of production of IAA due to actinomycetes tend to stimulate more significant root growth in the plants connected with it, boosting their availability to soil nutrients and improving their growth and development (Alori *et al.,* 2018). They are also capable of hydrolyzing cellulose and lignin present in wood residues, chitin in the exoskeleton of insects thereby making the nutrients available to the plants (Bhatti *et al.,* 2017). *Streptomyces* spp., which belongs to the Actinobacteria group, plays a crucial role in improving soil fertility by contributing to various components that enhance nutrient availability. They generate a variety of enzymes, in addition to siderophores and phosphate solubilization that help in the conversion of complex nutrients into simpler mineral forms, which makes them excellent natural fertilizers (Jog *et al.,* 2016).

Streptomycetes are frequently found in soil as saprophytes and have the ability to infiltrate the rhizosphere and rhizoplane of host plants. Some of these microbes can even colonize and persist as endophytes within host plants, demonstrating their ability to complete their life cycle within the plant. (Meschke *et al.,* 2010). Many species of *Streptomyces* can form beneficial interactions with plants, without causing harm or visible symptoms to the host plant (Palaniyandi *et al.,* 2013). These streptomycetes can promote plant growth and are often present in various parts of the plant, including roots, stems, leaves, flowers, fruits, and seeds (Qin *et al.,* 2011).

The following list outlines the growth-promoting activity of *Streptomyces* sp.

Species	**Host plant**	**Observation of PGP traits in plants**	**References**
Streptomyces spiralis	Cucumber	Promoting the Growth of Plants	El-Tarabily *et al.,* 2009
Streptomyces sp	Isolated from soil	Production of siderophores, solubilization of phosphate, and the fixation of N_2.	Franco-Correa *et al.,* 2010
Streptomyces carpinensis, S. thermolilacinus, S rochei,	Rhizosphere of wheat	Siderophore production, synthesis of IAA, and solubilizing phosphate.	Jog *et al.*, 2012
Streptomyces sp.	Green gram (mung bean)	Improved plant growth	Rungin *et al.*, 2012

Streptomyces sp.	Sorghum	Improved agronomic characteristics of sorghum	Gopalakrishnan *et al.*, 2013
Streptomyces aurantiogriseus	Rice	IAA production	Harikrishnan *et al.,* 2014
Streptomyces sp. RP1A-12	Groundnut	Increase in seed germination, root and shoot length, nodule number and plant biomass	Jacob *et al.,* 2018
S. violaceusniger AC12AB	Potato	Fixing nitrogen, and solubilizing phosphates, IAA	Sarwar *et al.,* 2019
Streptomyces A20	Rice	Siderophores production, extracellular enzymes, Indoleacetic acid (IAA), and phosphate solubilization	Rocio *et al.,* 2020

III. BOOSTING PLANT IMMUNITY SYSTEMICALLY WITH ACTINOBACTERIA

Induced systemic resistance (ISR) is a broad-spectrum response to pathogens that can be effective in various plant species. Flagella, lipopolysaccharides (LPS), biosurfactants, siderophores, volatile organic compounds (VOCs), antibiotics, and quorum-sensing molecules are some of the bacterial elicitors of ISR. Upon recognition of elicitors cascade of reactions occurs in the plants leading to the induction of ISR and then followed by the activation of various molecular and cellular host defence responses (Verhagen et al., 2010). Jasmonic acid (JA) and ethylene (ET), salicylic acid (SA) are the signal molecules that plays a crucial role in the priming of resistance in plants by actinobacteria which are regulated by the jasmonic acid or ethylene signalling pathway and by the activation of the salicylic acid signalling pathway.

The ability of two *Micromonospora* strains, ALFpr18c and ALFb5, to enhance the defence responses of various tomato cultivars against *Botrytis cinerea* has been revealed by Martinez-Hidalgo *et al*. (2015). This is achieved through the activation of jasmonates, which play a crucial role in the plant's defence mechanism. Meanwhile, Singh and Gaur (2017) found that *Streptomyces griseus* can induce systemic resistance against *Sclerotium rolfsii* in chickpeas. *S. griseus* helped in eliminating the oxidative stress caused by the pathogen, which occurs as a result of priming with the microbe, by the production of enzymes like PAL, peroxidase (PO), ascorbate peroxidase (APX), superoxide dismutase (SOD), catalase (CAT), chitinase (CHI), and β-glucanase (GLU) besides increasing the defense related enzymes and phenolic compounds.

According to Vilasinee *et al*. (2019), the use of *Streptomyces* sp. strain NSP3 can activate the defence responses of tomato plants against *F. oxysporum* f.sp. *lycopersici.* The most effective method of utilizing this strain against the pathogen is through both seed treatment and soil application, which induces the expression of PR genes such as PR-1a, Chi3, Chi9, and CEVI-1. Lee *et al.* (2021) revealed that *Streptomyces* sp. JCK-6131 protected the plants in two ways, one is by the production of antimicrobial substances and the second way is by priming. Pathogenesis-related genes were induced after treatment with *Streptomyces* sp., implying that both the salicylate and jasmonate signaling pathways were engaged at the same time. Therefore, priming with Actinobacteria can activate the plant defence responses even in the absence of a pathogen, eliciting both JA/ET- and SA-related signalling, which is associated with increased levels of PR proteins and plant secondary metabolism.

IV. CONCLUSION

Actinomycetes, which can be found both in the soil and within plants, are capable of producing essential metabolites that are directly linked to their interactions with the environment's microbiome and the host plant. These metabolites include phytohormones modulators, lytic enzymes, nutrient uptake facilitators, antibiotics, and other active compounds which provide plants protection against diseases, pests, and nematodes besides promoting growth and development. Actinobacteria can also be utilized in defence priming, which is a successful method for modern plant protection method involving JA/ET- and SA-mediated signalling, which aids in the production of defence compounds even in the absence of a pathogen. With the extensive biological benefits of actinomycetes, the agricultural industry can develop sustainable and productive products like biofertilizers and bio pesticides that promote better plant nutrition and protection in plants.

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