TRENDS IN AGRICULTURE SCIENCE
Popular Article
Vol.3 Issue 04 April 2024, Page: 1725-1728

Actinomycetes as biocontrol agents for management of plant diseases

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https://doi.org/10.5281/zenodo.11003697

Abstract

Fungicides and chemicals can control crop diseases to a certain level, but due to their concerns regarding human health and environment, utilization of microorganisms as biological control agents is the best alternative. Plant beneficial microbes are abundant in the soil nearby the plant roots and within the healthy plant tissue. In recent years, application of actinomycetes as biocontrol agent against phytopathogenic fungi has increased. Numerous strains of actinomycetes have been extensively utilized to manage plant diseases. Actinomycetes are reservoir of several bioactive compounds and industrially important enzymes. It is widely distributed in the agro-environment, particularly in the plant rhizosphere, and influences plant growth and protection against diseases. Considering the potential of the actinomycetes and their frequency and dominance in the agro-environment, it would be judicious to promote actinomycetes inoculants for the management of plant diseases.

Introduction

Plant diseases cause huge yield losses, upto 50% in developing countries (Ziedan, 2022). Conventional methods to manage plant diseases are use of synthetic pesticides, but their application causes harm to human, animal, and environmental health and also results in resistance development microorganisms (Torres et al. 2021). With the objective of achieving food production efficiency from ecological and economic points of view, the search for an alternative to decrease the use of synthetic pesticides in agriculture is a global priority. In recent years, the use of actinomycetes as a biocontrol agent on phytopathogenic fungi has been an alternative to the application of synthetic fungicides. Actinomycetes are Gram-positive bacteria found in different habitats, humidity, pH, and temperature. Actinomycetes have been isolated from different environments, such as terrestrial, marine, hypersaline, wetlands, and plant endophytes, among others (Tatar, 2021).

Actinomycetes

Actinomycetes form vegetative or aerial mycelia and are capable of reproducing by binary fission. *In vitro* culture and the natural environment have a typical smell of humid soil because of the production of two geosmin and 2-methylisoborneol volatile organic compounds. Spore production is a result of nutrient depletion, allowing actinomycetes to remain latent until they find favourable conditions for growth. Additionally, filamentous and sporulating natures allow them to compete more efficiently against other organisms found in the rhizosphere. Their cell wall is a rigid structure formed by complex compounds, such as peptidoglycan, teichoic and teichuronic acids, and polysaccharides. Actinomycetes also have a high guanine and cytosine content in DNA. Among the different genera, *Streptomyces* has been investigated extensively because it is easy to isolate. The *Streptomyces*, *Micromonospora*, and *Nocardiopsis* species are the main actinomycetes with antifungal activity. Actinomycetes have a slower growth than bacteria. Thus, growth improvement techniques should be applied to obtain desirable actinomycetes in culture media. These techniques are based on selective isolation media and the pre-treatment of samples, such as: soil with calcium carbonate, both by drying and heating, wet, and chemical pre-treatments, among others (Tiwari and Gupta, 2013). One of the ways to stimulate actinomycete populations in soil is by adding bio stimulants and organic fertilizers, such as compost and vermicompost. *S. sampsonii* and *S. flavovariabilis* isolates from soil amended with vermicompost showed the highest antagonistic activity towards *Rhizoctonia solani, Alternaria tenuissima*, *Aspergillus niger*, and *Penicillium expansum* (Javoreková et al. 2021). Application of *S. vinaceusdrappus,* isolated from the marine environment, on tomato plants reduced root rot caused by *R. solani* compared to untreated control (Yandigeri et al., 2015).

Mode of action

The main antagonistic mechanisms of actinomycetes to control phytopathogenic fungi are competence for space and nutrients, mycoparasitism, antibiotics, siderophores, volatile organic compounds (VOCs), and host resistance induction. Additionally, actinomycetes promote plant growth and development through the synthesis of phytohormones, atmospheric nitrogen fixation, and mineral solubilization e.g, phosphate solubilization (Mitra et al., 2022).

1. Competence for space and nutrients: Competence between two or more microorganisms begins for the same carbon source or space for their growth. The fast growth of antagonistic microorganisms allows them to assimilate the available nutrients at a greater amount than phytopathogenic fungi. Competence is an effective biocontrol mechanism when the antagonist is found in sufficient volumes and assimilates nutrients faster and in greater quantity than phytopathogenic fungi.

2. Mycoparasitism by production of degradative enzymes: Cell wall-degrading enzymes such as chitinase, β-1,3-glucanase, protease, and cellulase are important for mycoparasitism and antifungal activities. Actinomycetes are known to produce chitinase, β-1,3-glucanase, pectinase, xylanase, cellulase, amylase, protease, and lipase. Actinomycetes originated from agricultural soil have been producers of protease.

3. Antibiosis: Antibiosis is an antagonistic interaction between a plant, pathogen, and actinomycetes spp. and involves the secretion of low-molecular-weight diffusible antibiotics which are detrimental to phytopathogens (Gajera et al., 2013). Approximately 80% of commercial antibiotics are produced by actinomycetes e.g., streptomycin by *Streptomyces griseus*, cycloheximide by *S. griseus*, kasugamycin by *S. kasugaensis* etc.

4. **Siderophores production:** Siderophores are iron chelating secondary metabolites that bind iron with high specificity and affinity making iron unavailable for the pathogens.

5. Volatile Organic Compounds (VOCs): Volatile organic compounds (VOCs) are low molecular weight compounds that evaporate easily at a normal temperature and pressure, which gives them the ability to diffuse through the atmosphere and soil. Most VOCs are lipid-soluble and thus have low water solubility. These organic compounds travel great distances in structurally heterogeneous environments, as well as in solid, liquid, or gaseous compounds. VOCs produced by actinomycetes inhibit the growth of phytopathogenic fungi, promote plant growth, possess nematocidal activity, and induce systemic resistance in plants. They inhibit the mycelia, causing

Official Website: trendsinagriculturescience.com
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Published: 21 April, 2024
ISSN: 2583-7850

swelling, conidia collapse, and structural alterations in the fungal cell wall. The *Streptomyces* species produces 2-ethyl-5-methylpyrazine and dimethyl disulfide that inhibit mycelial growth and spore germination (Kaari et al., 2022). VOCs such as S-methyl ethanethioate, 1,2-dimethyldisulfane, 2-methyl propanoic acid, acetic acid, 3-methyl-butanoic acid, undecan-2-one, nonan-2-one, and 2-isopropyl-5-methylcyclohexan-1-ol have been reported from the actinomycetes *Nocardiopsis* sp., which inhibit mycelial growth of fungi (Widada et al., 2021).

6. Induction of host resistance: Actinomycetes are capable of inducing defense responses in plants through the overproduction of: (1) enzymes related to defense, which strengthen the cell wall structure, avoiding the entrance of phytopathogenic fungi, their colonization toward the plant, and catalyzing phenolic compound oxidation to quinones that are toxic for fungi; (2) proteins (PR) related to pathogenesis, such as chitinase hydrolytic enzymes, and β-1,3-glucanase that break the phytopathogenic fungi cell wall structure; (3) phytoalexins, which are toxic for phytopathogenic fungi, inhibit germ tube elongation and growth, decrease mycelial growth and limit glucose absorption; (4) lignification promotion that contributes to plant cell wall hardening and (5) callus formation induction that isolates stress (biotic and abiotic) in the tissue, locally, by depositing a physical barrier. Actinomycetes such as *Streptomyces spiralis, Micromonospora chalcea,* and *Actinoplanes campanulatus* help in induction of resistance.

7. Mineral solubilization: Phosphorus is considered as growth limiting macronutrient. Phosphate solubilizing actinomycetes have been employed in agriculture and considered important due to their potential of ecological amelioration.

Actinomycetes based commercial products

Actinomycetes are an option to manage the plant pathogenic fungi in crop plants and their application reduces the use of synthetic fungicides. Some of the available actinomycetes based commercial products are Mycostop, Actinovate, Kasugamycin, Agrimycin, Paushak, Cuprimicin 17, Astrepto 17 etc.

Future Scope:

Actinomycetes are capable of effectively managing the plant diseases caused by fungal and bacterial pathogens. Although there are sufficient studies on the disease management achieved by various actinomycetes in laboratory or controlled-environment but attempts to develop commercial formulations have met with problems in practice. Main problem in obtaining commercial products based on microorganisms is that their biocontrol capacity is different under *in vitro* trials and field experiments. In order to develop actinomycete biocontrol agents for commercial use, the consistency of their performance must be improved. Developing a commercial microorganism product is a complex, time-consuming, costly and interactive process. The actinomycete formulation must show repeated positive results at reasonable prices and should be easy in handling.

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Published: 21 April. 2024
ISSN: 2583-7850

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Published: 21 April, 2024
ISSN: 2583-7850