Bio-control emerges as a novel and environmentally sustainable method for mitigating soil-borne plant pathogens

Sarita¹, Sunil Kumar²

INTRODUCTION

Soil-borne pathogens pose significant threats to crop yields and agricultural economics worldwide. Consequently, effective crop protection strategies are vital for sustaining agricultural productivity. Historically, the reliance on chemical fungicides has been prevalent to enhance crop yields. However, the indiscriminate use of these chemicals has led to detrimental effects on the environment, human health and overall ecosystem balance by unintentionally harming non-target organisms. In response to these challenges, alternative approaches have gained traction in recent years for managing soil-borne diseases. Among these alternatives, biocontrol emerges as a promising eco-friendly solution, mitigating the risks associated with chemical residues on human health and the environment. Biocontrol Agents (BCAs) offer a less toxic and more flexible alternative to chemical pesticides. These agents exert their effects through various mechanisms, including antibiotic, competition for resources, parasitism and the Induction of Systemic Resistance (ISR). Bacteria such as Bacillus spp., Pseudomonas spp. and fungi like Trichoderma spp. are widely recognized as effective bio-control agents against soil-borne diseases. Notably, bacteria such as Bacillus spp. and Agrobacterium radiobacter thrive in soil and the rhizosphere, making them particularly suitable for agricultural applications. This review emphasizes the intricate interactions among soil-borne pathogens, their natural antagonists, plants and the environment, with a focus on fostering sustainable agricultural practices. However, successful implementation of biocontrol strategies requires appropriate management approaches tailored to specific agricultural ecosystems, ensuring their efficacy and sustainability in the long term.

Key Words: Biocontrol; Systemic resistance; Rhizosphere; Ecosystem

METHODOLOGY

What are biocontrol agents?

The term 'biocontrol' have used in several areas of biology, especially in plant pathology and entomology. The biocontrol in which the living organism such as bacteria, fungi, nematode or predatory insect those suppresses the growth and development of other organism populations. The term biocontrol agents apply to the use of microbial antagonists which suppresses the growth of pathogens included mainly hosts-specific. The microbial antagonist that used to control the soil-borne plant diseases, by making bio-formulations called bio-pesticides. Bio-pesticides are eco-friendly approaches for the control of soil-borne pathogens in peanut by the mechanisms involved in their antagonistic activity (Figure 1).

Initially, a diverse array of microorganisms is gathered and subjected to screening for biocontrol efficacy. Numerous isolates undergo screening to pinpoint a disease-suppressive strain (illustrated as a yellow rod). However, it's improbable for this strain to exhibit effectiveness across various conditions. A strategy for identifying new strains that collectively demonstrate efficacy across diverse conditions involves unraveling biocontrol mechanisms and discovering additional biocontrol agents sharing these mechanisms. Genetic analyses can unveil biocontrol mechanisms, such as the role of antibiotic X in biocontrol mechanism. Understanding these mechanisms and the associated genes can facilitate the development of nucleic acid probes tailored to identify new strains with identical biocontrol mechanisms, as depicted by a probe for gene antX. Despite sharing similar biocontrol mechanisms, strains harboring antX may exhibit genetic diversity in significant aspects. This diversity enables some new strains to be effective on different crops across various geographic regions or as part of genetically diverse mixtures. This approach facilitates the identification of extensive collections of disease-suppressive strains, bypassing the necessity to replicate the extensive research [6].

The function of prospective bio-control agents in management of soil-borne pathogens

Soil-borne pathogens survive in soil as soil inhabitants and sapropoles, widely distributed depend upon the cropping and production practices. Soil with poor irrigation facilitates the growth of several soil-borne pathogens which included mainly fungal pathogens like Phytophthora, Pythium while, Fusarium and Verticillium will occur more frequently in damp soils rather than in dry soils [7]. The usage of Plant Growth-Promoting Rhizobacteria

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(PGPR) as biocontrol agents, against the soil-borne fungal pathogens, is a complementary strategy [8,9]. The biocontrol provided by PGPR involves competition, parasitism, antibiosis, etc., which act as a natural process [10,11]. Pathogen suppression by PGPR occurs mainly by the activities involved in PGPR rapid growth, multiplication and survival [12]. Biocontrol agents contribute directly to plant growth by production of phytohormones like cytokines, gibberellins and auxin, increase nutrient uptake, siderophore and lytic enzyme production, induction of systemic acquired resistance and reduction the level of ethylene [13].

**Mycorrhiza as biocontrol agents**

Mycorrhiza is the most prevalent form of symbiotic relationship between plant roots and soil fungi. Symbiosis is so well balance that many of the host cells are invade by the fungal endophyte but there is no visible tissue damage and under certain conditions, it enhances the growth and vigor of the plant. The potential role of mycorrhizal fungi as biocontrol agent for the control of fungal plant diseases has recently received considerable attention [14]. Vesicular Arbuscular (VA)-mycorrhizal infection generally inhibits or sometimes increases and occasionally has no effect on diseases caused by fungal pathogens [15-18]. Arbuscular Mycorrhizal Fungi (AMF) represent a functionally important component of soil microbial community, being of particular significance for plant mineral nutrition in tropical agro ecosystems [19]. Bodker et al., [20] noted the effect of phosphate and the arbuscular mycorrhizal fungus *G. intraradices* on disease severity of root rot of pea. In Kerala wilt infested area of solanaceous crops, the mycorrhizal fungi (*Glomus* sp., *Acaulospora* sp. and *Scytonema* sp.) were the major species and were minimum in tomato and maximum in brinjal [21]. Dai et al., [22] has been reported that in chilli phosphorus content was highest at 150% of organic manure application. Significantly more phosphorus content was observed in mycorrhizal plants than the non-mycorrhizal plants. Oyetunji et al., [23] has been reported that plants inoculated with the *G. mosseae* has much thickened cell walls particularly at the edges as compare to uninoculated plants. *G. mosseae* and *T. koningii* inoculations, controlled Fusarium wilt of pepper. However, these were inoculated at least a week earlier then attack by the pathogen. Tomato roots inoculation with mycorrhizal fungus strains significantly influenced the number of tomato leaves and improved the health status of the plant (Figure 2) [24].

![Figure 1](image1.png) Proposed model for a biocontrol research and development program

![Figure 2](image2.png) (A): Maintenance of mycorrhizal fungi; maintenance of mycorrhizal fungi on wheat; (B): Arbuscules; (C): Hyphae inside root system; (D): Spore with attachment; (E): Spores inside the root; (F): Entry point of hyphae
**Pseudomonas as biocontrol agents**

The genus *Pseudomonas* belong to the category of non-spore forming, gram-negative and rod-shaped natural biocontrol agent living in disease suppressive soils and can rapidly grow, colonize and survive in a highly competitive ecosystem for their survival included food and space. Many researchers have been found that fluorescent *Pseudomonas* strain represents antagonistic activity against fungal pathogens and abundant in the rhizosphere of different crops. *Pseudomonas putida* WCS35r, are genetically engineered to produce the phenazine and 2,4-Diacetylphloroglucinol (DAPG), showed modified ability to suppress the plant diseases in wheat [25]. The strains of *Pseudomonas* can colonize in the root system of several crops, maintaining the control population densities in the rhizosphere [26]. Two isolates of *Herbaspirillum* spp. and *Pseudomonas* spp. produced volatile compounds having the potential to inhibit the growth of *Fusarium oxysporum* f. sp. cubense race 4. The identified compounds were methanethiol, 3-undecene and 2-pentene 3-methyl. Talc-based preparation of *P. fluorescens* when applied to soil@ 15 g/plant on banana significantly checked wilt disease [27]. The ability in *P. fluorescens* for suppressing *Fusarium* depends on its potential to produce antibiotic DAPG. DAPG obtained from *P. fluorescens* when applied to soil significantly inhibited spore germination and growth of *F. oxysporum*.

**Application of Trichoderma for control of soil-borne pathogens**

The most commonly used bio pesticide in living form namely *Trichoderma* spp. have been found effective in suppressing the soil-borne plant pathogens [28]. *Trichoderma* a genus was first proposed by Persoon 1794 in Germany and described it as fungi having mealy powdery-like appearance enclosed by a hairy covering. Some species of the genus *Trichoderma* have been used as effective biocontrol agents against soil-borne, foliar and postharvest fungal pathogens in several plant crops, including peanut [29]. *Trichoderma* species such as *T. viride* and *T. harzianum* reduced the incidence of collar rot disease in groundnut caused by *Aspergillus* niger in a screen house study (Figure 3) [30].

**RESULTS AND DISCUSSION**

**Mechanisms of action of biocontrol agents**

The biological control may have resulted from many different types of interactions among the organisms (Table 1). In the mechanism of biocontrol, the pathogens are antagonized by the presence and activities of antagonists. Direct antagonist results from the direct contact or highly selective for the pathogens expressed by the antagonists, while in case of indirect antagonisms results from the activities that do not directly target the pathogens. Many of the biocontrol agent viz., *Trichoderma* spp., *Bacillus* spp., *Pseudomonas fluorescens* and *Agrobacterium radiobacter* (K84) strain [36-38].

**TABLE 1**

<table>
<thead>
<tr>
<th>Types</th>
<th>Mechanism</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct antagonism</td>
<td>Hyperparasitism/predation</td>
<td>Amelopomycis quisquisalis</td>
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<tr>
<td></td>
<td></td>
<td>Lysobacter enzymogens</td>
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<tr>
<td></td>
<td></td>
<td>Pasteuria penetrans</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trichoderma virens</td>
</tr>
<tr>
<td>Antibiotics</td>
<td></td>
<td>2,4-diacetylphloroglucinol</td>
</tr>
<tr>
<td>Lytic enzymes</td>
<td></td>
<td>Cyclic lipopeptides</td>
</tr>
<tr>
<td>Mixed-path antagonism</td>
<td>Unregulated waste products</td>
<td>Chitinase</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Glucanases</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proteases</td>
</tr>
<tr>
<td></td>
<td>Physical/chemical interference</td>
<td>Ammonia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrogen cyanide</td>
</tr>
<tr>
<td></td>
<td>Competition</td>
<td>Blockage of soil pores</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Germination of signals consumption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Molecular cross-talk</td>
</tr>
<tr>
<td></td>
<td>Indirect antagonism</td>
<td>Confused</td>
</tr>
<tr>
<td></td>
<td>Induction of host resistance</td>
<td>Exudates/leachates consumption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Siderophore scavenging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical niche occupation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contact with fungal cell walls</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Detection of pathogen-associated molecular patterns</td>
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<tr>
<td></td>
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<td>Phytohormone-mediated induction</td>
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</tbody>
</table>

**Antibiosis**

Antibiosis is a biological interaction between microorganisms, in which the organic substance of low molecular weight produced by microorganisms that affect the metabolic activity and growth of other microbes. A variety of antibiotics have been identified, including compounds such as 2,4-Diacetylphloroglucinol (DAPG), amphisin, coomicin A, hydrogen cyanide, pyoluteorin, phenazine, tensin, pyrrolnitrin, cyclic lipopeptides and tropolone produced by pseudomonads and kanosamine, oligomycin A, xanthobacin and xerotelin A produced by *Streptomyces*, *Bacillus* and *Stenotrophomonas* spp. (Table 2).
TABLE 2

Antibiotics producing bio-control agents against diseases

<table>
<thead>
<tr>
<th>Sources</th>
<th>Antibiotics</th>
<th>Plant diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agrobacterium</td>
<td>Agrocin 84</td>
<td>Crown gall</td>
</tr>
<tr>
<td>Radiobacter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacillus amyloliquefaciens FZB42</td>
<td>Bacilomyacin, Fengycin</td>
<td>Wilt</td>
</tr>
<tr>
<td>Bacillus subtilis UW85</td>
<td>Zwittermicoin</td>
<td>Damping-off</td>
</tr>
<tr>
<td>B. subtilis QST13</td>
<td>Ilurin A</td>
<td>Damping-off</td>
</tr>
<tr>
<td>B. subtilis BBG100</td>
<td>Mycosubtilin</td>
<td>Damping-off</td>
</tr>
<tr>
<td>P. fluorescens F113</td>
<td>2,4-diacyethylphloroglucinol</td>
<td>Damping-off</td>
</tr>
<tr>
<td>P. fluorescens Pf-5</td>
<td>Pyluteorin.</td>
<td>Damping-off</td>
</tr>
<tr>
<td>Trichoderma virans</td>
<td>Gliotoxin</td>
<td>Root rot</td>
</tr>
</tbody>
</table>

Hyperparasitism

- The hyperparasitism means that the pathogens which are directly parasitized or attack with specific BCAs. Generally, mycoparasitism involves four steps:
  - Chemotropic growth, where the biocontrol agent can grow toward the target fungus.
  - The recognition includes specific interaction between lectin of pathogen or carbohydrates receptors on the biocontrol agent surface.
  - Attachment by cell wall degradation such as chitinases and 1,3-glucanases.
  - Penetration, where the biocontrol agent could produce a structure like appressoria for penetrating the cell wall of pathogenic fungus [39].

In some cases, multiple hyper parasites attack a single fungus such as Acremonium alternatum, Cladosporium oxysporum and Gliocladium virens can parasitize the powdery mildew fungi [40]. A classic example is the hypovirus, a hypoparasitic virus on Cryptocercia parasitica, a fungus causing chestnut blight. The hypovirulence of hypovirus reduces the diseases-producing capacity of C. parasitica [41].

Disadvantages of biocontrol strategies

- Requires skilled and expertise.
- Time-consuming in disease control and does not achieve immediately.
- Take more intensive management and future planning.
- Peoples are not aware of this phenomenon.

CONCLUSION

Soil-borne plant diseases like wilt, damping-off, root rot and collar rot, etc., cause a hazardous impact on the yield loss in the agricultural and ornamental ecosystem. The soil-borne pathogens such as Rhizoctonia solani, Phytophthora, Pythium, Sclerotium rolfsii, Fusarium and Verticillium have a wide range of host and destroy many vegetables, ornamental and agricultural plants. In the past few years, the management of the soil-borne diseases was often based on the application of chemical mainly soil fumigants which was successful in managing the disease, but side effects of these chemicals on the environment, human and animals, turned into biggest diversified problems for whole ecosystem. Antagonistic bacteria and fungi are widely used to manage soil-borne diseases. In comparison with chemicals, biocontrol is a healthier and safer mechanism to control harmful pathogens and toxic microorganisms. Biocontrol agents also use as plant growth-promoting factors and biotic stimulation induce the Systemic Acquired Resistance (SAR) of plants against soil-borne pathogens. However, a better understanding of the factors involved and signaling interaction among antagonists and pathogens, soil and plants are yet revealed to promote the bio-control agents as wide applicable bio pesticides in a sustainable agricultural ecosystem.

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