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Biological control: Mechanism and their role in sustainable management of plant diseases in climate change scenario

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Abstract
An promising substitute approach for managing plant diseases is biological disease control. It also offers methods that are in line with the objective of a sustainable farming system. By comprehending the ways in which antagonists and pathogens interact to control plant diseases biologically, we may be able to develop and put together improved biocontrol agents and modify the soil's natural environment to foster successful biocontrol. There are several biological controls that can be used; however, in order further development and adoption effectively, more research is required to fully comprehend the complex relationships that exist between human, plants, and the environment. As people become more aware of their health, biological control appears to be the greatest option instead of suppressing disease. Bio-agents reduce disease without endangering the environment. Studies have demonstrated that the bio agents cause plants to grow. Since bio agents are not harmful to plants, their formulation must support the growth and activity of the microbes they contain. In light of fungicides' past, biological control will become an alternative tactic for managing plant diseases in the near future. However, because an agro-ecosystem is a dynamic, functional system with several elements influencing disease and crop development, further IPM techniques for crop disease control are still required in a variety of environmental conditions. In order to successfully reduce crop yield loss and disease development in the various crop systems, other IPM control measures outside biological control should be taken into consideration and utilized for the economic threshold.

Keywords: Biological control, mechanism, sustainable management, pathogen

1. Introduction

The reduction of harmful activity of one or more species, commonly referred to as natural destroyer, is a broad definition of 'biological control. Biological control, on the other hand, in plant pathology refers to the intentional use of introduced or resident biotic organisms, other than disease-resistant host plants, to reduce the activity and population of one or more plant pathogens (Pal and Gardener 2006) [43]. Therefore, understanding the process of biological control of plant diseases through interactions between the pathogen and bio-control agent may enable us to modify the soil environment to foster successful biocontrol or enhance biocontrol strategies (Chaur, 1998) [12].

Chemical control of plant infections results in toxic chemical residue accumulation and the development of resistance in microorganisms, making them more difficult to control and affecting productivity, which can cause major ecological problems. In recent years, biological control of plant pathogens has been considered as a potential control strategy. Nowadays, majority of crops are successfully managed against microbial contamination and plant diseases through the application of synthetic pesticides. However, because of their residual toxicity, the frequent and careless use of these chemical fungicides has put human and animal health at risk. Considering the detrimental effects of chemical fungicides on ecosystems that support life, alternative approaches to the management of pathogenic microorganisms are desperately needed. In addition, there is a strong desire to reduce or eliminate the use of synthetic pesticides in agriculture. Using novel tools based on bio-control agents (BCAs) for disease and pest management alone or in conjunction with lower chemical dosages for plant pathogen control - which minimizes chemical impact on the environment - is one of the most promising approaches to achieving these goals (Vinale *et al*., 2009) [65].

Biological control of plant diseases (Heydari and Pessarakli, 2010) [23] has been proposed as a potential alternative to chemical management of plant diseases. According to Pal and Gardener (2006) [43], biological control refers to the deliberate use of introduced or resident living organisms - aside from disease-resistant host plants - to limit the activities and populations of one or more plant pathogens or to reproduce one organism using a different organism. A deeper comprehension of the complex relationships that exist between plants, people, and the environment will be necessary for the continued development and successful implementation of biological controls, which have many potential applications.

The most promising bio-control agents against various plant infections in diverse environments are fungi from Trichoderma group and bacteria, including *Pseudomonas aeruginosa* and *Bacillus subtilis*. Thus, the concept of biological control of plant pathogens has become more inclusive and includes a variety of mechanisms. Therefore, this chapter's purpose is to provide an overview of the idea, background, types, and mechanisms of biological control of plant pathogens.

2. Historical background

Since ancient times, man has tried to increase crop yield and reduce the severity of crop plant diseases by altering cultivation techniques that reduce short- and long-term expenses (Singh and Chawla, 2012; Gupta and Sharma 2014) [54, 17]. Many approaches have been used to manage diseases through the use of fungal antagonists since the discovery of microbes and their interactions.

Roberts (1874) [46] introduced the term "antagonistism" when he first showed how bacteria and *Penicillium glaucum* exhibited antagonistic behavior in liquid cultures. By inoculating soil with microorganisms presumed to have antagonistic potential, Hartley (1921) [22] performed the first attempt at direct biological control of plant diseases. To combat damping-off caused by *Pythium debaryanum*, he treated forest nursery soils with thirteen antagonistic fungi (Gupta and Sharma, 2014; Baker, 1987) [17, 5]. Weindling (1932, 1934) [68-69] described *Trichoderma lignorum* (*T. viride*) to control plant-pathogenic fungi through mycoparasitism and reported the first use of an antimycotic-producing antagonist in plant disease control (Baker, 1987) [5]. Later on Weindling (1941) [70] coined the term gliotoxin after discovering that *Trichoderma species* secrete an antimycotic that is poisonous to plant pathogens such as *Rhizoctonia solani* and *Sclerotiniaamericana*. This was the first instance a known antimycotic-producing antagonist was used to manage a plant disease (Baker, 1987; Howell, 2003) [5]. The discovery of penicillin by Alexander Fleming in 1928, as well as its purity and usage in pharmaceutical industry, sparked a boom in studies on plant pathogen antagonists (Baker, 1987) [5]. Fungal antagonists may now be used to treat a wider range of plant diseases thanks to developments in modern biotechnology. Many investigations and tests have been carried out in the past few decades to create novel fungal BCAs and evaluate their effectiveness in varied environmental settings.

3. Types of biocontrol agents

Various fungi and bacteria are being observed as potential biocontrol agents against many harm full pathogens causing huge losses to crops. Below Table 1 and Table 2 shows different potential microbes used in biological control.

Table 1: List of Bacterial strains as bicontrol agents against various plant pathogens

Bacterial strains	Targeted disease	Target pathogen	Reference
Azospirillum brasilense	Strawberry anthracnose	*Colletotrichum acutatum*	Tortora *et al.* (2011) [62]
Azotobacter chroococcum	Cotton and rice	*Rhizoctonia solani*	Chauhan *et al.* (2012) [11]
Bacillus subtilis BY-2	Oil seed rape	*Sclerotinia sclerotiorum*	Hu *et al.* (2014) [26]
Bacillus licheniformis BL06	Pepper	*Phytophthora capsici*	La *et al.* (2020) [73]
Bacillus megaterium	Citrus fruit	*Blue mould*	Mohammadi *et al.* (2017) [74]
Bacillus methylotrophicus	Maize/Stalk rot	*Fusarium graminearum*	Cheng *et al.* (2019) [13]
Bacillus subtilis 26DCryChS	Wheat	*Stagonospora nodorum Berk.*	Maksimov *et al.* (2020) [39]
Bacillus thuringiensis	Sclerotiniose/*Brassica campestris* L.	*Sclerotinia sclerotiorum*	Wang *et al.* (2020) [67]
Brevibacillus brevis	Strawberry/Grey mould	*Botrytis cinerea*	Haggag Wafaa (2008) [20]
Brevibacillus brevis	Tomato	*Fusarium oxysporum f.sp. lycopersic*	Chandel *et al.* (2010) [10]
Burkholderia cepacia strain BY	Tomato/Damping-of	*Rhizoctonia solani*	Szczech and Shoda (2004) [57]
Ochrobactrum anthropi BMO-111	Tea/blister blight	*Exobasidium vexans*	Sowndhararajan *et al*. (2013) [56]
P. chlororaphis	Canola plant	*Sclerotinia sclerotiorum*	Savchuk and Fernando (2004) [51]
Paenibacillus alvei K- 165	Cotton/black root rot	*Thielaviopsis basicola*	Schoina *et al.* (2011) [52]
Paenibacillus polymyxa BRF-1	Soybean/Root rot	*Phialophora gregata*	Zhou *et al.* (2008) [72]
Pantoea agglomerans	Wheat root rot	*Rhizoctonia solani* AG-8	Barnett *et al.* (2006) [7]
Pantoea agglomerans	Banana/crown rot	*Colletotrichum musae and Lasiodiplodia theobromae*	Gunasinghe and Karunaratne (2009) [16]
Pseudomonas and Burkholderia	NA	*Phytophthora capsici*	Khatun *et al.* (2018) [33]
Pseudomonas fluorescens	Apple/Mucor rot	*Mucor piriformis*	Wallace *et al.* (2018) [66]
Pseudomonas parafulva JBCS1880	Soybean/Bacterial pustule Rice/Panicle blight	*Xanthomonas axonopodis pv. glycines, Burkholderia glumae*	Kakembo and Lee (2019) [29]
Pseudomonas putida BP25	Blast Disease/Rice	*Magnaporthe oryzae*	Ashajyothia *et al.* (2020) [75]
Rhizobium japonicum	Soybean/Root rot	*Fusarium solani; Macrophomina phaseolina*	Al-Ani *et al.* (2012) [3]

Table 2: List of Fungal strains as biocontrol agents against various plant pathogens

Fungal strains	Targeted disease	Target pathogen	Reference
Aspergillus fumigates	Cocoa/black pod	*Phytophthora palmivora*	Adebola and Amadi (2010) [1]
Paecilomyces lilacinus	Tomato/Root-knot disease	*Meloidogyne javanica*	Hanawi (2016) [21]
Penicillium oxalicum	Tomato/Root-knot disease	*Fusarium oxysporum f. sp. lycopersici*	Sabuquillo *et al.* (2006) [48]
Penicillium sp. EU0013	Tomato and cabbage/wilt	*Fusarium oxysporum*	Alam *et al.* (2010) [2]
Pochonia chlamydosporia	Carrot/Root knot disease	*Meloidogyne incognita*	Bontempo *et al.* (2017) [8]
Purpureocillium lilacinum	Vignaradiata/Root-knot disease	*Meloidogyne incognita*	Khan *et al.* (2019) [32]
Purpureocillium lilacinum	Pineapple/Root knot disease	*Meloidogyne javanica*	Kiriga *et al.* (2018) [34]
Trichoderema hamatum	Cabbage	*Sclerotinia sclerotiorum apothecia*	Jones *et al.* (2014) [28]
Trichoderma asperellum	Beans	*Sclerotinia sclerotiorum apothecia*	Geraldine *et al.* (2013) [15]
Trichoderma asperellum	Onion	*Sclerotium cepivorum*	Rivera-Méndez *et al.* (2020) [76]
Trichoderma asperellum T8a	Mango/anthracnose	*C. gloeosporiodes*	Santos-Villalobos *et al.* (2013) [50]
Trichoderma atroviride	Beans	*Botrytis cinerea*	Brunner *et al.* (2005) [9]
Trichoderma harzianum	Rice/brown spot	*Bipolaris oryzae*	Khalili *et al.* (2012) [31]
Trichoderma harzianum T-22	Soya bean	*Sclerotinia sclerotiorum*	Zeng *et al.* (2012a) [71]
Trichoderma spp.	Tobacco/root rot	*Rhizoctonia solani*	Gveroska and Ziberoski (2011) [18]
Trichoderma virens	Okra/Root-knot disease	*Meloidogyne incognita*	Tariq *et al.* (2018) [58]

4. Mechanism of action of bio-control agents

Understanding and formulating appropriate conditions for implementing biocontrol against pathosystems necessitates research into the fundamental mechanisms of biocontrol. In the last two decades, intensive study has focused on various elements of antifungal action, rhizosphere colonization and plant health benefits (Compant *et al*. 2010) [14]. Several biocontrol studies have been conducted to counteract the overgrowth of pathogenic fungi in rhizosphere plants. These experiments also show the antagonistic fungal pathogen, promote plant growth, and reduce the infection of pathogenic fungi. The mechanism of biocontrol against plant pathogenic fungus is the subject of several investigations. The primary mechanisms of biocontrol include antibiosis, competition for micronutrients like iron, mycoparasitism, hydrolytic enzyme synthesis, induction of systemic resistance in host plants, and rhizosphere competence. Nonetheless, the pathway that is well understood is the one that is influenced by antifungal chemicals (Haas and Keel 2003) [19]. Below given table 3 shows the different types of antagonism interactions leading to biological control of plant pathogens.

Table 3: Different types of interspecies antagonisms leading to biological control of plant pathogens

Type	Mechanism	Examples
1. Direct antagonism	Hyperparasitization/predation	Lytic/some non-lytic mycoviruses
		Ampelomyces quisqualis
		Lysobacter enzymogenes
		Pasteuria penetrans
		Trichoderma virens
2. Mixed- path antagonism	Antibiotics	2,4-diacetylphloroglucinol
		Phenazines and Cyclic lipopeptides
	Lytic enzymes	Chitinases, Glucanases and Proteases
	Unregulated waste products	Ammonia, Carbon dioxide and Hydrogen cyanide
	Physical/chemical interference	Blockage of soil pores Germination signals consumption Molecular cross-talk confused
3. Indirect antagonism	Competition Exudates/leachates consumption	Exudates/leachates consumption Siderophore scavenging Physical niche occupation

(**Source:** (Pal and McSpadden, 2006) [43]

4.1 Hyperparasitism

In this approach, a specialized biocontrol agent (BCA) attacks the pathogen directly, killing it or its propagules. Hyperparasites can be divided into four categories: obligatory bacterial pathogens, hypoviruses, facultative parasites, and predators. An obligatory bacterial pathogen *Pasteuria penetrans* is a classical example used as a BCA against root-knot nematodes. Hyper parasites are hypo viruses; a well-known example is the virus that infects *Cryphonectria parasitica*, a fungus that causes chestnut blight, and induces hypo virulence, or a decrease in virulence in the pathogen's ability to cause disease. In many cases, the phenomenon has been successful in controlling chestnut blight (Tjamos *et al*., 2010) [61]. Several other fungal pathogens attacks many other pathogens; *Coniothyrium minitans* attacks sclerotia, while *Pythium oligandrum* attacks live hyphae. Many hyperparasites, including *Acrodont Iim Crateriform*, *Gliocladium virens*, *Ampelomyces quisqualis*, *Cladosporium oxysporum*, and *Acremonium alternatum*, can target a single fungal pathogen, which in turn controls powdery mildew diseases (Heydari and Pessarakli, 2010) [23].

4.2 Antibiotics mediated suppression

Antibiotics are microbial toxins that poison or kill other micro-organisms when used at low concentrations. Most microorganisms produces and release one or more antibiotic-active chemicals (Islam *et al*., 2005) [27]. In certain situations, it has been shown that plant pathogens and the diseases they cause can be effectively suppressed by antibiotics produced by microorganisms. Table 4 provides a list of various antibiotic examples that have been implicated in plant pathogen inhibition. The antibiotics have all been found to be very effective in suppressing the target pathogen's growth *in vitro* and/or in situ. For antibiotics to have a biocontrol effect, they must be produced close to the pathogen in sufficient quantities. It has been measured how many different biocontrol agents synthesize antibiotics in situ (Thomashow *et al*., 2002) [60]. However, because of the small quantities produced in comparison to other, less hazardous organic compounds in the phytosphere, the effective quantities are difficult to estimate, and numerous approaches have been devised to determine when and where biocontrol agents produce antibiotics. Because of the heterogeneous distribution of plant-associated microorganisms and possible infection sites, identifying expression in the infection court is difficult.

Table 4: Examples of several antibiotics acting specifically against plant pathogens

Antibiotic	Source	Taget Pathogen	Disease	Reference
2,4diacetylphlorog lucinol	*Pseudomonas fluorescens* F113	*Pythium spp*.	Damping off	Shanahan *et al.* (1992) [53]
Agrocin 84	*Agrobacterium radiobacter*	*Agrobacterium tumefaciens*	Crown gall	Kerr (1980) [30]
Bacillomycin D	*Bacillus subtilis*AU195	*Aspergillusflavus*	Aflatoxin contamination	Moyne *et al.* (2001) [41]
Bacillomycin, fengycin	*Bacillus amyloliquefaciens* FZB42	*Fusarium oxysporum*	Wilt	Koumoutsi *et al.* (2004) [36]
Xanthobaccin A	*Lysobacter sp.* strain SB-K88	*Aphanomyces cochlioides* Damping off Islam *et al.* (2005) [27]	Damping off	Islam *et al.* (2005) [27]
Gliotoxin	*Trichoderma virens*	*Rhizoctonia solani*	Root rots	
Herbicolin	*Pantoea agglomerans* C9-1	*Erwinia amylovora*	Fire blight	Sandra *et al.* (2001) [77]
Iturin A	*B.subtilis* QST713	*Botrytis cinerea* and *R. solani*	Damping off	Kloepper *et al.* (2004) [47]
Mycosubtilin	*B. subtilis* BBG100	*Pythium aphanidermatum*	Damping off	Leclere *et al.*(2005) [78]
Phenazines	*P. fluorescens* 2-79 and 30-84	*Gaeumannomyces Graminis var. tritici*	Take-all	Thomashow *et al.* (1988) [59]
Pyoluteorin, pyrrolnitrin	*P. fluorescens* Pf-5	*Pythium ultimum* and *R. solani*	Damping off	
Pyrrolnitrin, Pseudane	*Burkholderia cepacia*	*R. solani* and *Pyricularia oryzae*	Damping off and rice blast	Homma *et al.* (1989) [79]
Zwittermicin A	*Bacillus cereus* UW85	*Phytophthora medicaginis* and *P. aphanidermatum*	Damping off	Smith *et al.* (1993) [55]

(***Source***: Pal and McSpadden, 2006) [43].

4.3 Cell wall degrading enzymes
Several biological control agents (BCA) produce enzymes that hydrolyze chitin, proteins, cellulose, and hemicellulose, allowing direct suppression of plant pathogens. There are several BCAs that can produce enzymes that are useful against specific plant diseases. In a variety of tests, *Serratia marcescens* chitinases and the genes that encode them have been proven to have biocontrol potential. *Botrytis spp*., *Rhizoctonia solani*, and *Fusarium oxysporum* were found to be suppressed by a highly chitinolytic strain of *S. marcescens* (Ningaraju, 2006) [42].

4.4 Competition
Bicontrol agents compete for space and nutrition indirectly inhibit activity of several pathogens. Soil-borne pathogens infecting by mycelial contact, such as *Fusarium* and *Pythium* species, are more susceptible to competition from other soil and plant-associated bacteria than those growing directly on plant surfaces and infecting through appressoria and infection pegs. Biological control agents (BCA) that colonise the rhizosphere or phyllosphere protects the plant by entirely absorbing the limited available substrates, leaving no space for diseases to proliferate. Effective nutrition catabolism in the spermosphere, for example, has been identified as a mechanism contributing to *Pythium ultimum* suppression by *Enterobacter cloacae* (Van Dijk and Nelson, 2000) [63]. The importance of siderophore production as a mechanism of biological control of *Erwinia carotovora* by several plant growth promoting *Pseudomonas fluorescens* strains (Kloepper *et al*., 1980) [35].

4.5 Induction of Host resistance
A range of chemical stimuli produced by biological control agents (BCA) are recognized by plants as responses. These stimuli have the ability to either cause host plant defenses to be induced through biochemical changes that express resistance mechanisms against new pathogen infections or they can cause host plant defenses to be induced through biochemical changes that express resistance mechanisms against new pathogen infections. Host defence induction can be localized or systemic in nature. There exist several mechanisms underlying resistance. The first mechanism, referred to as systemic acquired resistance (SAR), is facilitated by salicylic acid (SA), which induces the production of proteins related to pathogenesis (PR), which encompass a variety of enzymes. A second type of induced systemic resistance (ISR) is mediated by jasmonic acid (JA) and/or ethylene, which are produced after non-pathogenic rhizobacteria are applied. A *Bacillus mycoides* strain capable of producing peroxidase, chitinase, and 1,3-glucanase in sugar beets is one of the most remarkable example of bacterial determinants and kinds of disease resistance (ISR) caused by BCAs (Bargabus *et al*., 2003) [6]. In Arabidopsis, *B. subtilis* GB03 and IN937 produce 2, 3-butanediol (Ryu *et al*., 2004) [47]. *Serratia marcescens* 90-166 produces siderophore in cucumber (Press *et al*., 2001) [44]. Strong host plant defenses

have been observed to be induced by certain biocontrol strains of Trichoderma spp. and Pseudomonas sp. Salicylic acid, siderophore, lipopolysaccharides, 2, 3-butanediol, and other volatile compounds are among the chemical elicitors of SAR and ISR that the PGPR strains may produce following inoculation (Van *et al*., 1998) [64].

5. Advantages and Disadvantages of Biological Control

The biological control has many advantages as compared to other methods employed in the management of diseases. The advantages of Biological control are given under the following points:

6. Advantages

1. Biological control is less costly and cheaper than any other methods.
2. Biocontrol agents provides protection to crop throughout the crop period.
3. They act specifically against plant diseases.
4. They do not cause toxicity to the plants.
5. Application of biocontrol agents is environment friendly and safer to the person who applies them.
6. They can easily multiply in soil and leave no residual effect.
7. Biocontrol agents have capability to eliminate pathogens from site of infection.
8. By enhancing the beneficial soil microorganisms, biocontrol agents not only control disease but also improve root and plant growth, which in turn boosts agricultural yield. Certain inorganic nutrients are volatilized and sequestered with its aid. Bacillus subtilis, for example, solubilizes phosphorus and makes it available to plants.
9. Biocontrol agents are easy to handle and apply to the target.
10. Biocontrol agents can be used as a combination with biofertilizers.
11. They can be easily manufactured.

7. Disadvantages

Although biological control is advantageous in many aspects, it has following disadvantages:

1. Biocontrol agents are limited to use against particular diseases.
2. In comparison to fungicides, they are not as effective.
3. Plant diseases were slowly controlled by biocontrol agents.
4. Currently, there are very few biocontrol agents that can be used and they are only found in a few locations.
5. Currently, there is a decrease in their quantity available.
6. This method is only a preventive measure and not a curative measure.
7. Biocontrol agents should be multiplied and supplied without contamination and this requires skilled persons for their multiplication, production.
8. The shelf life of biocontrol agents is short. Antagonists, Trichoderma viride is viable for four months and Pseudomonas fluorescens is viable for 3 months only.
9. The optimum amount of population of biocontrol agents should be checked at periodical interval and should be maintained at required level for effective use.
10. Biocontrol agents efficiency is mainly decided by environmental conditions.
11. A biocontrol agent under certain conditions may become a pathogen.

8. Future prospects

Some of the research criteria that will help us to learn more about biological control and the circumstances in which it is effectively applied must be looked into. Biocontrol-active microorganisms' effectiveness and activity are influenced by a variety of ecological parameters. However, there are still some areas that should be explored and developed in order to improve the effectiveness of biocontrol microorganisms. Introducing new strains and mechanisms of fungal/bacterial plant pathogens are quite diverse, and their pathogenicity on host plants varies, thus it's critical to look for new and novel biocontrol microorganisms with a number of different mechanisms.

9. Conclusion

Plant pathogens are one of the most significant cause of severe plant damage and loss. Chemical pesticides have been shown to have harmful effects on the environment and non-target microorganisms. So, there is need of hour to develop and find out non-chemical alternatives to protect the environment and prevent plants against diseases including those caused by fungal pathogens. Biological control of plant diseases utilizing microbial antagonists appears to be a potential alternative approach which has been successfully applied to a variety of plants and crops. Biotic and abiotic elements, method of application, formulation of bio-control microorganisms, and time of application are some of the major elements that determine the efficacy of microbial bio-control agents in managing plant diseases should be carefully studied. One of the most significant tasks will be to understand the mechanisms or activities of antagonist-pathogen interactions, as this will give a reasonable basis for the selection and development of more effective bio-control agents. Biological control does not leave any residual effects in the environment and is not harmful to humans, livestock, or other beneficial living organisms. As a result of these important features, biological control is one of the best alternative for sustaining agricultural production and productivity while avoiding environmental harm.

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