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1. Biological Control for Sustainable Disease Management

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Abstract:

It has been thought that biological management of plant diseases is a practical substitute for chemical control. Biological control for conservation, classical, and augmentation is a few of these. Numerous naturally occurring bio-control agents target plant pathogens with vigour and reduce plant disease through diverse mechanisms of action. Bio control agents (BCAs) possess various advantageous traits, including antagonistic potential, rhizosphere competence, and the capacity to generate lytic enzymes, antibiotics, and nutrients and niches. An appealing substitute tactic for managing plant diseases is biological disease control. It also offers methods that are in line with the objective of a sustainable farming system. When determining if a biological system is practical for controlling a certain pathogen, many criteria need to be taken into account. Being able to sustain oneself on the host plant and having an appropriate antagonist available is crucial. Whether or not an adversary can establish effective population levels in competition with the current micro *flora will depend in large part on the environment in which the crop is cultivated. The antagonist chosen may also be influenced by the surroundings. In addition to being safe for farmers and consumers, the use of BCA-based products should also be environmentally friendly. To create formulations that are stable, affordable, simple to make, and straightforward to use, however, a great deal more effort needs to be done. With the goal of creating future biological control methods that work, it will be essential to conduct additional research on a few underdeveloped biocontrol aspects. These include creating novel formulations, comprehending how environmental factors affect biocontrol agents, producing large quantities of biocontrol microorganism, and utilizing biotechnology and nanotechnology to enhance biocontrol mechanism and strategies. With growers' increasing demand for bio-control products, the future of plant disease biocontrol appears bright and promising. Biological control can be used as an efficient way to manage plant diseases, boost yield, protect the environment and biological resources.*

Keywords:

Augmentation, Bio control, Inoculation, microorganisms, microflora, sustainable.

1.1 Introduction:

More and more people are becoming aware of the green agenda, particularly the necessity of emphasizing the sustainable use of the resources found on our planet. Plant pathology can help achieve this goal by increasing agricultural productivity and decreasing its negative effects on the environment. Specifically, it can do this by lowering the 20 percent to 30 percent of losses that are thought to be brought on by diseases and pests (Savary *et al*., 2019) as well as the negative effects of disease and pest control measures.

In order to preserve the quantity and quality of food, feed and fiber produced by farmer worldwide, plant diseases must be managed. Plant diseases can be prevented, mitigated, or control using various strategies.

Beyond appropriate agronomic and horticultural methods, farmers depend extensively on chemical fertilizer and insecticides. Since last century, there have been notable advancements in crop productivity and quality, mostly attributed to the use of such inputs in agriculture.

However, people's perceptions of the use of pesticide in agriculture have significantly changed as a result of the environmental damage brought on by the overuse of agrochemicals, as well as the fear mongering tactics used by certain opponents of the practice.

There is political pressure to take the most hazardous chemicals off the market, and there are stringent limits on the use of chemical pesticides today. Furthermore, because of the dose at which chemicals could need to be made, the proliferation of plant diseases in natural ecosystems may make the successful application of pesticides impossible. As a result, several researchers studying pest management have concentrated on creating substitutes for artificial chemicals in the management of diseases and pests.

An important technological, economic and political discussion aimed at developing sustainable agriculture at a lower ecological cost has been sparked by the concept of biocontrol (O'Brien P.A. 2017). As a result, several countries have put in place a preventative strategy that can reduce pesticide usage by about 50% (Macfadyen *et al.*, 2014).

These measurements clearly demonstrate a significant understanding of the build-up of hazardous residues in the environment and the different connections within the food chain. They also highlight the dearth of options to lessen the agricultural sectors reliance on pesticides.

To increase the effectiveness and application of biocontrols in this situation, it seems imperative that we learn more about them (Barratt *et al.*, 2018). Due to all of these factors, research is moving in the right direction toward a biological control viewpoint that applies microbial inoculum and might be combined with the other methods stated above to create a potent defense against plant diseases.

Since 1980s forward, research into Biological Control (BC) by the use of antagonistic microbes has been ongoing. The use of Biological Control Agents (BCA) has been regarded as a significant sustainable alternative within in the Integrated Management of Pests and Diseases (IMPD) to alleviate the negative consequences related to the production and quality of agricultural crops (Villarreal *et al*., 2018).

Definition:

Several biological disciplines, mostly entomology and plant pathology, have employed the terms "biological control" and its shortened synonym "biocontrol." Within plant pathology, the phrase encompasses both the application of host-specific pathogens and the use of microbial antagonists to inhibit Diseases. The term "biological control agent" (BCA) refers to the organism that inhibits the pest or disease. The utilization of microorganisms for biological control of plant infections has been deemed a more sustainable and eco-friendlier substitute for the current chemical treatment techniques (Prajapati *et al.*, 2020).

Biological control was initially defined “the action of parasites, predators, or pathogens in maintaining another organism’s population density at a lower average than would occur in their absence”. In particular, the biological control that these living things offer is crucial for lowering the populations of diseases, mites, and pest insects. Using natural enemies to reduce or mitigate pests and their consequences is a sustainable and efficient way to manage pest populations (Nafiu *et al.*, 2014).

1.2 Historical Background of Biological Control:

- In order to supplement biological control in the management of insect pests, biological control agents were employed between 200 and 1840 A.D.
- Pest biological control dates back to China in the sixteenth century. In the third century, they used ant nests from *Oecophylla smaragdina*, which was sold close to Canton, to control citrus insect pests like *Tesseratoma papillosa* (Lepidoptera).

- In the 1840s, predators were released to control gypsy moths and garden pests that caused cabbage caterpillars in Italy. This was the first use of natural enemies to control insect pests.
- To control lepidopterous pests, egg parasites known as *Trichogramma* sp. were imported from the United States to Canada in 1882.
- William Roberts first introduced the term "antagonism" in 1874 when he demonstrated the antagonistic action of micro-organisms in liquid culture between *Pencillium glaucum* and bacteria.
- C. F. Von first used the term "biological control" as a workable preposition of plant disease management in 1914.
- Sanford (1926) noted that antagonistic activities of green manuring inhibited the potato scab.
- Weindling (1932) documented that *Trichoderma lignorum* is a parasite on a number of plant diseases.
- Grossbard (1948–1952), Wright (1952–1957), and others showed that *pencilium*, *Aspergillus*, *Trichoderma*, and *streptomyces sp.* generated antibiotics in soil.
- Wright (1952–1957) and Kerr (1980) were the first to report the use of *Agrobacterium radiobacter* strain K–84 for biocontrol of crown gall disease. Other researchers also showed that Pencilium, *Aspergillus*, *Trichoderma*, and *Streptomyces* sp. generated antibiotics in soil.
- The significance of siderophores produced by *Erwinia carotovora* was illustrated by Kloepper (1980).
- Howell (1993) described P and Q strains of *Trichoderma* sp.

1.3 Strategy and Principles of Biological Control:

There are 3 basics strategies in biological control of pests viz:

Classical Biological Control (Importation), Augmentation and Conservation.

- **Classical biological control** is defined by Eilenberg *et al.*, (2001) as the deliberate introduction of an exotic BCA for the long-term pest management, that is typically co-evolved. It is the introduction of natural enemies of pests from other nations to a new area in which they are not native. Figure1 depicts the basic idea of bacterial biological control. When an organism is unintentionally or purposely brought into a previously uninhabited area, it can occasionally reach a high population density and develop into a significant hazard. This increase in population is primarily the result of the pest being introduced without its natural enemies. The objective of classical biological control is to locate beneficial natural enemies, introduces them in to the target pest's area, and establish them permanently so that they will provide ongoing pest control, resulting in a decrease in the pest population density, below the level of economic injury that the pest causes. The time scale on figure 1 can be years (Nafiu *et al.*, 2014).

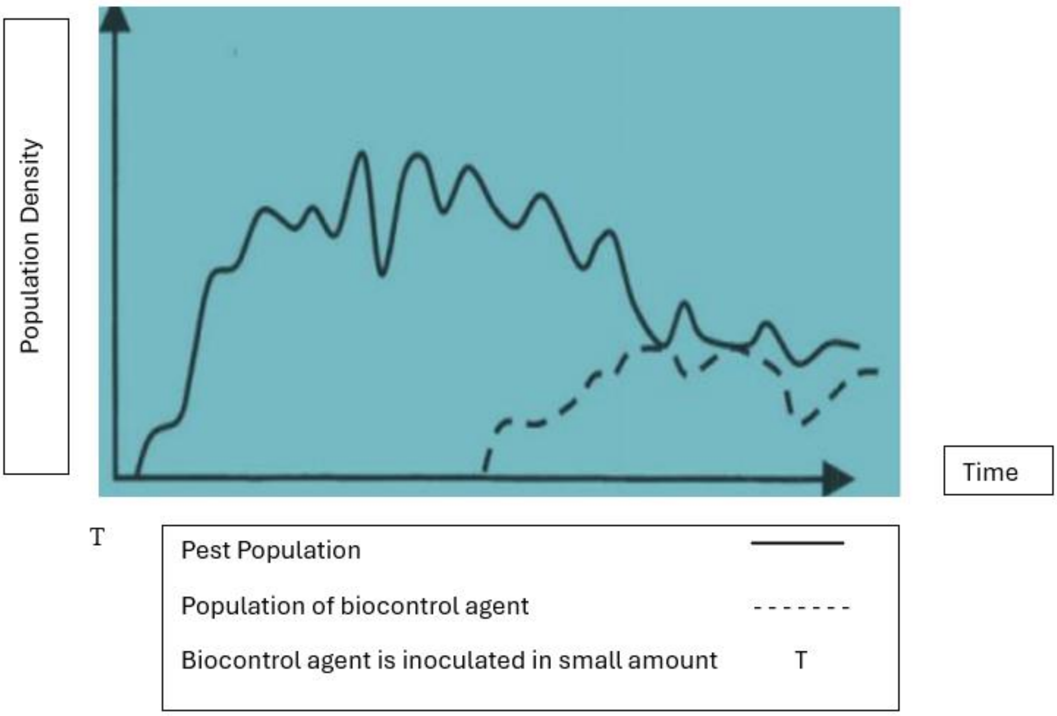

Figure 1.1: Classical Biological Control (Source: Tsegaye *et al*., 2018)

- **Augmentation** is the other strategy of BC is also defined by **Eilenberg *et al.*, (2001)** as:

The intentional release of a living organism as a bioloigical control agent with the idea that it will multiply and control the pest for an extended period but not permanently. In order to keep a pest below harmful levels, it involves periodically releasing a natural adversary that does not exist naturally in large enough numbers.

The practice of augmentation is based on the knowledge or premise that in some instances that are not adequate numbers or species of natural enemies to achieves optimal biological control, but that the numbers can be raised by releases. This relies on a capacity to mass-produce enormous numbers of the natural enemy in a laboratory or by firms to make and sell them.

There are 2 general ways to augmentation Inoculative release and inundative release. The main idea behind inoculation BC is illustrated in Figure (1.2). As a pest population grows, a BCAs is gradually injected in small to moderate amount time Ton figure 1.2, before the population density reaches its potential maximum. The objective is to increase the size of the natural enemy populations in order to control the pest over time; the inoculated bio-control organism will not establish permanently at a sufficiently high population density, so after some time the pest will increase in size and a new inoculation would be required. Since the events in inoculation BC are frequently restricted to a single cropping season, the time scale on figure (1.2) is weeks or months.

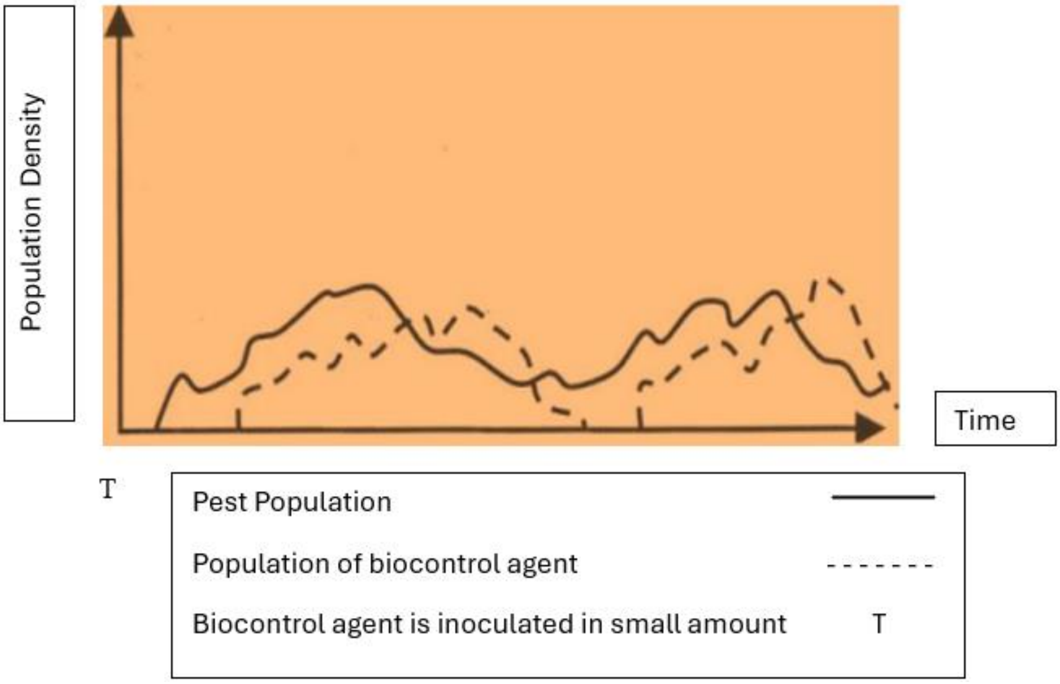

Figure 1.2: Inoculation Biological Control (Source: Tsegaye *et al*., 2018)

- **Inundation biological control** is type of augmentation bio control and defined by **Eilenberge *et al*., (2001)** as:

The process of using living organism to control Pest when the organisms themselves are the only ones capable of doing so. The main idea behind inundation biological control is depicted in figure (1.3).

Initially, the pest population grows, but after a certain amount of time (Time T) for example, after the economic injury level has been reached a biological control organism is applied in large is applied in large quantities (inundated), and the pest population is quickly controlled, and both the pest population and the biocontrol agent's population density decrease over time.

Eventually, the pest population will grow again, necessitating a new application of biocontrol agent. These events in inundation biological control are frequently restricted to a single cropping season. So, the time scale on figure 3 is weeks or months. A Typical example of BC is the widespread use of Bacillus thuringiensis to control epidopteran and dipteran insects.

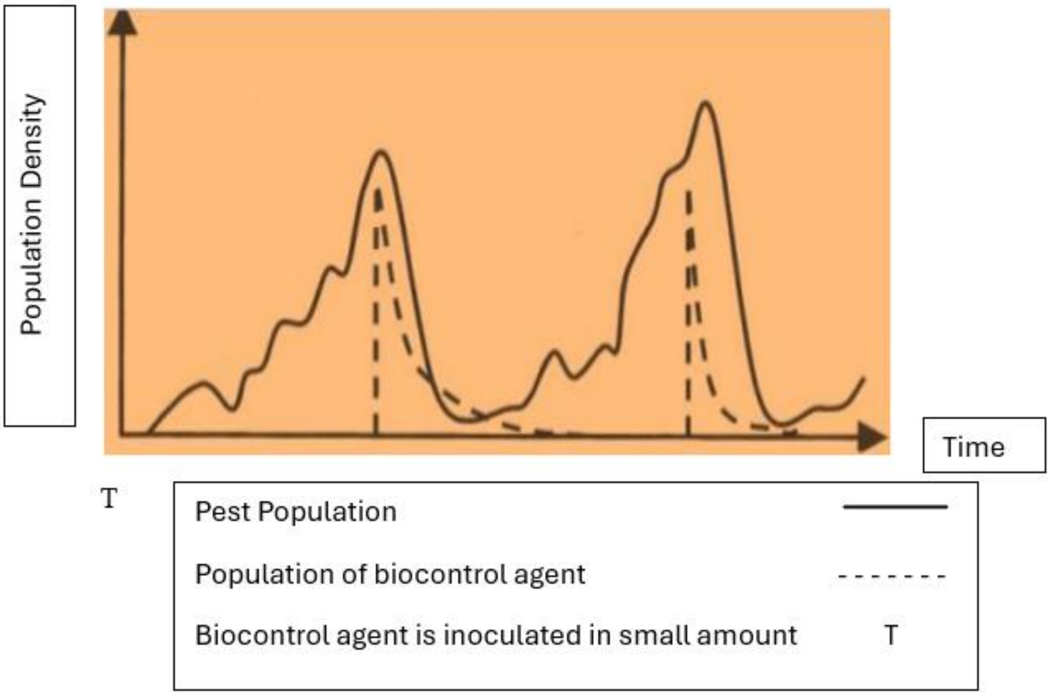

Figure 1.3: Inundation Biological Control (Source: Tsegaye *et al*., 2018)

- **Conservation biological control** is also other strategy of the BC can be defined is as altering the surroundings or current procedures to safeguard and strengthen particular enemies or other creatures in order to lessen the impact of pest (Eilenberg *et al*., 2001). Increasing the species richness and structural complex city of agro-ecosystem is a common method of habitat management. By enhancing natural enemies, habitat alteration techniques can lower pest concentrations by giving natural enemies access to resources including nectar, pollen, physical refuges, and substitute hosts. Figure (1.4) illustrates the fundamental idea of biological control in conservation. Because the natural enemies' impacts are insufficient, a pest arises at high population levels. Natural enemies comprise all forms of biological regulation, such as weeds, plant diseases, and antagonistic microorganisms that cause suppressive soils. They also include macro and microorganisms that govern invertebrates. The practice or the environment are altered at time T in figure 1.4 to strengthen the natural adversaries that are already there. Their population grows, and as a result, there are fewer pests overall. Figure (1.4) shows a possible time scale in years.

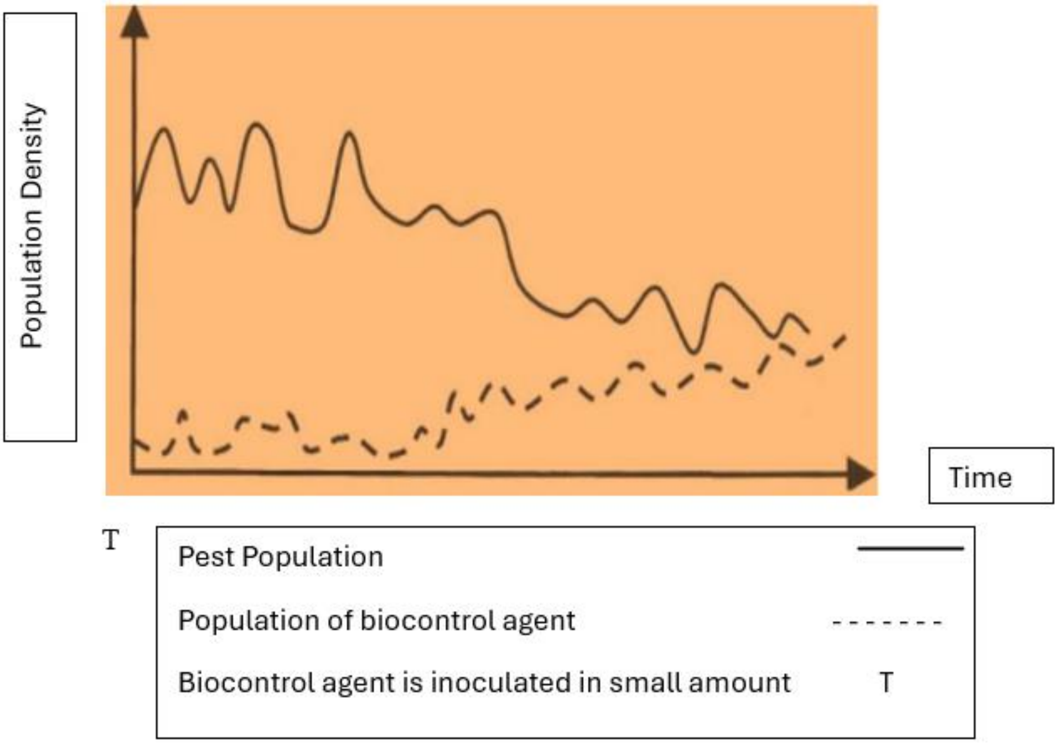

Figure 1.4: Conservation Biological Control (Source: Tsegaye *et al*., 2018)

1.4 Mechanisms of Biological Control:

Because a wide range of interactions between organisms can lead to biological control, scientists have concentrated on describing the mechanisms at work in various experimental scenarios. Pathogens are always agitated by the existence and behaviour of other organisms they come into contact with.

Here, we claim that the various mechanism of antagonism arises along a directionality spectrum associated with the degree of interspecies contact and interaction specialization (Table 1.1). Physical contact and/or a high level of pathogen selectivity by the mechanism expressed by the BCA (s) cause direct antagonism. Under such a model, the most direct form of antagonism would be hyper parasitism by the obligate parasite of plant pathogen as no other organism actions would be necessary to exert a suppressive effect

Table 1.1: Types of interspecies antagonisms leading to biological control of plant pathogens (Nega A. (2014)

Types	Mechanism	Examples
Direct antagonism	Hyperparasitism/predation	Lytic/some nonlytic mycovirues
		Ampelomyces quisqualis
		Lysobacter enzymogenes

Types	Mechanism	Examples
		Pasteuria penetrans
		Trichoderma virens
Mixed-path antagonism	Antibiotics	2,4- diacetylphloroglucinol
		Phenazines
	Lytic enzymes	Chitinase
		Glucanases
	Unregulated waste products	Ammonia
		Carbon dioxide
	Physical/chemical interference	Blockage of soil spores
		Germination signals consumption
Indirect antagonism	Competition	Exudates/leachates consumption
		Siderophore scavenging
	Induction of host resistance	Contact with fungal cell walls
		Detection of pathogen–associated

- **Hyperparasites and predation** in hyper parasitism, a particular BCA targets the pathogen directly in order to destroy it or its propagules. The four main groups of hyperparasites, include facultative parasites, obligatory bacterial pathogen, hypoviruses, and predators. One obligatory bacterial pathogen root-knot nematodes that has been employed as a BCA is Pasteuria penetrans. Hyperperasites are called hypoviruses. A well-known virus that infects the fungus *Cryphonectria parasitica*, which causes chestnut Blight. This virus reduces the pathogen's ability to produce disease, a condition known as hypovirulence. In many locations, the phenomena have managed the chestnut blight (Milgroom and Cortesi 2004). Microbial predation, as opposed to hyper parasitism, is more widespread, non-specific to pathogens, and typically results in less consistent disease control levels. When nutrients are scarce, certain BCAs behave in a predatory manner. Under normal growth conditions, however, this kind of activity is usually not displayed. For instance, a variety of enzymes produced by certain *Trichoderma* species target the cell walls of fungus. Nevertheless, *Trichoderma* spp. does not directly target *Rhizoctonia solani*, a plant disease, when fresh bark is added to composts. However, when bark decomposes, the amount of cellulose that is easily available diminishes, activating *Trichoderma* spp.'s chitinase genes to create chitinase that parasitizes *R. solani* (Benhamou and Chet 1997).
- **Antibiotic-mediated suppression:** At low concentrations, antibiotics are microbial poisons that can poison or kill other microbes. The majority of Microorganisms generate and release one or more substances with antimicrobial properties. It has occasionally been demonstrated that plant pathogen and the disease they induce are especially vulnerable to the adverse effects of antibiotics made by microbes; some examples of these antibiotics are given in Table 1.2. The antibiotics have all been shown to be especially successful in preventing the target pathogen's growth in vitro or in situ.

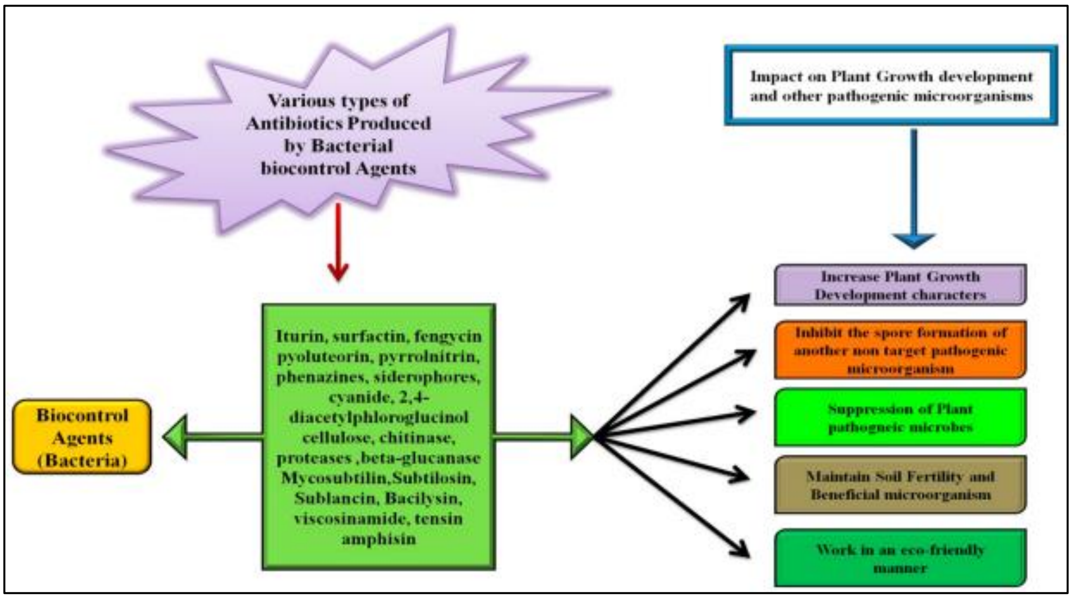

Figure 1.5: The Synthesis of Antibiotics by Bacterial BCAs And Their Effect on The Growth of Plants and Other Harmful Microorganisms (Source- Tariq *Et Al.*, 2020)

Table 1.2: Some of antibiotics Obtained from BCAs

Sr. No.	Antibiotic	Source	Disease	Reference
1	2,4 diacetylphloroglucinol	*Pseudomonas fluorescens* F113	Damping off	Shanahan *et al*. (1992)
2	Gliotoxin	*Trichoderma virens*	Root rots	Wilhite *et al.* (2001)
3	Xanthobaccin A	*Lysobacter* sp. strain SBK88	Damping off	Islam *et al*. (2005)
4	Bacillomycin and Fengycin	*Bacillus amyloliquefaciens* FZB42	Fusarium wilt	Koumoutsi *et al*. (2004)
5	Bacillomycin D	*Bacillus subtilis* AU195	Aflatoxin Contaminaion	Moyne *et al*. (2001)

1.5 Lytic Enzymes and Other Byproducts of Microbial Life:

Many polymeric compounds, such as chitin, protein, cellulose, hemicellulose and DNA, can be degraded by lytic enzymes that various microorganisms manufacture and release. There are times when the development and production of such enzymes by certain microorganisms directly suppresses the activity of plant pathogens; for example, control of *Sclerotium rolfsi* by Serratia marcescens appeared to be mediated by chitinase expression (Ordentlich *et al*., 1988).

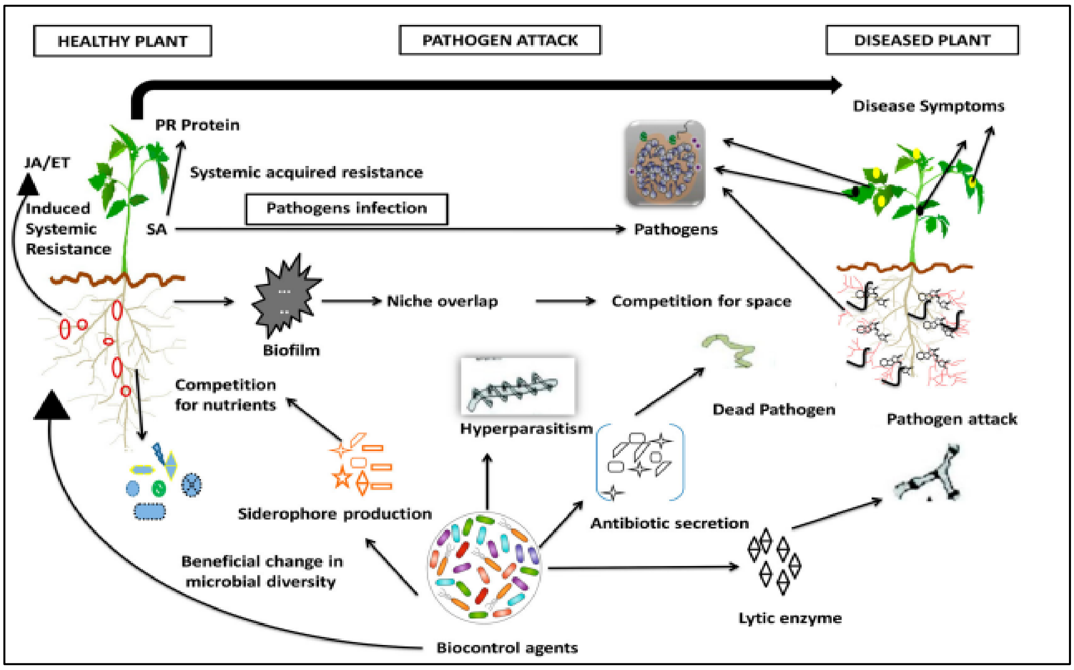

Figure 1.6: Mechanism of Biocontrol Agent Against Pathogenic Microorganism (Source- Tariq *et al.*, 2020)

- **Competition:**

Soils and living plant surfaces are often nutrient- limited environments when viewed through the lens of microbes. A bacterium must successfully compete for the available nutrients in order to colonize the phytosphere. Nutrients given by the host on plant surfaces can be exudates, leachates, or senesced tissue. Furthermore, the waste product of other species, like as insect and dirt, can provide nutrients. Although it is challenging to prove directly, a wealth of indirect data points to the importance of pathogen-non-pathogen competition for food resources in reducing the occurrence and severity of disease.

1.5.1 Induction of Host Resistance:

Many environmental cues, such as gravity, light, temperature, physical stress, and the availability of water and nutrients, cause plants to actively react. Additionally, plants react to a range of chemical stimuli generated by bacteria linked with the soil and plants.

These stimuli have the ability to either initiate or condition plant host defence through biochemical modifications which strengthen resistance to certain pathogen infections later on. Based on the kind, source, and quantity of stimuli, host defence may be induced locally or systemically. BCA and other non-pathogenic bacteria can drive the development of resistance, and phytopathologists have just started to identify the factors and mechanisms of this resistance.

1.6 Types of Biological Control:

Many BC can be used, but more research and comprehension of the intricate relationships between people, plants, and the environment will be necessary for their efficient development and adoption (pal *et al.*, 2006). Using naturally occurring ingredients that have been extracted or fermented from various source has also been included in the broader definition of BC. They might be extremely basic concoctions of natural components with particular functions, or they can be complicated concoctions that affect the target pest or pathogen and the host in different ways. Example of these is:

Utilizing plant extract for biocontrol, which are derived from plants and are regarded as bio-inputs, improve crop health and growth while reducing the harm that phytopathogenic agents can do. Additionally sustainable, this approach promotes both human health and the preservation of environmental resources. Kuklinski outlined several techniques for obtaining extracts, including solvent extraction, mechanical extraction, distillation, and extraction using supercritical fluids (Amaguana *et al.*, 2018)

Biocontrol with micro-organisms: The majority of bacteria that cause BCA are found in the genera Pseudomonas, Trichoderma, and Bacillus; the latter possesses traits like growth stimulant and bio controller with high survival because of its capacity to generate endospores (Moreno *et al.*, 2018).

On the other hand, Trichoderma is of great use due to its stability in root colonization, being endophytic, with the capacity to mycoparasitize, compete for nutrients, generate antibiosis, and induce resistance in plants, while Pseudomonas has great metabolic versatility, is capable of colonize the root endophytically and produce siderophores and growth promoters, as well as adapt to stress conditions.

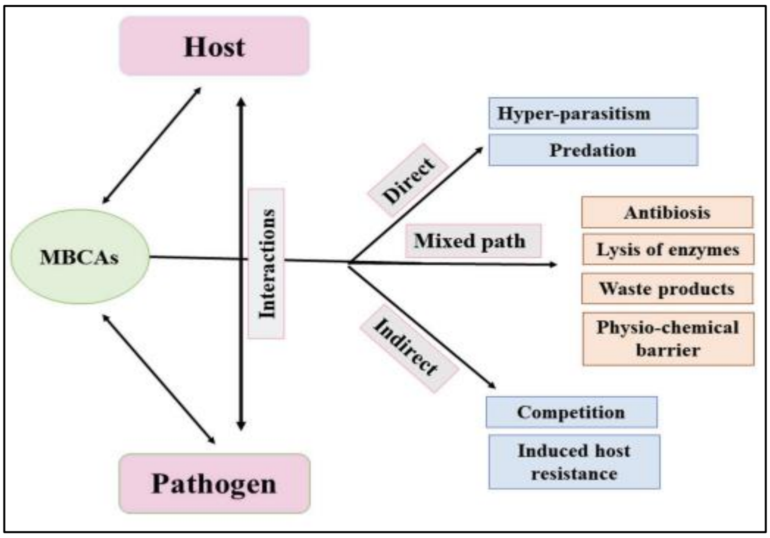

Figure 1.7: Pathways of Microbial Biocontrol Agents (MBCAs) (Source El-Saadony *et al.*, 2022)

1.7 Characteristics of The Successful Biological Agents:

1. Highly successful BCA need to meet the requirements.

- Have the capacity to proliferate and colonize.
- Have the ability to compete and survive longer in soil and host tissue; and
- Have no harmful effects on the environment or host plant.

2. The development of affordable production and agent formulation is necessary.

- Production must yield biomass with a long shelf life.
- The agricultural agent must be successful in maintaining viability, being affordable, and being able to produce in big amounts.

3. Delivery and application must allow for the agent's complete expression; they also need to guarantee that agents will develop and fulfil their mission.

1.8 Approved Techniques for Using BCAs:

For biological control to be applied successfully, more knowledge-intensive management is needed. Inputs derived from biology, like microbial fungicides, can be employed to impede the actions of pathogens.

- **Seed Treatment:** The best ways to treat seeds are to use bacterial cultures, which will protect the plants from phythopathogens and increase plant production and productivity. Rabindra and Vidhyasekaran (1996) reported that rice blast and sheath blight disease was reduced by seed bacterization with a peat-based formulation of *P. fluorescens* strain at a rate of 10 g/kg seed; Meena *et al*. (2001) reported that groundnut root rot incidence was significantly reduced when groundnut seeds were treated with *P. fluorescens* powder formulation; Gamliel and Katan (1993) reported that tomato root inoculated with *P. alkaligenes* reduced the wilt caused by *F. oxysporum* f. sp. *Vasinfectum*.
- **Seedling dipping** Sheath blight on rice can be controlled by applying a *P. fluorscens* mixture, which involves immersing rice seedlings in a pail of water containing a talc-based formulation mixture (20g/lt.) for two hours and then transplanting them in the field.
- **Seed Bio-Priming:** Biopriming is the process of treating seeds with bio-control chemicals and then letting them sit in warm, humid conditions until just before the radicals appear. This method produces a consistent and quick emergence of seedlings, which may be advantageous over only covering the seeds. Around bio-primed seeds, a coating of Trichoderma conidia forms when they germinate on the seed surface. These seeds are more resilient to a range of unfavourable soil conditions. Reducing the amount of biocontrol chemicals applied to the seed could also be achieved through biopriming. In the Tarai region of Uttaranchal, seed biopriming is successfully applied to tomato, brinjal, soybean, and chickpea. Three rhizosphere competent microbial strains, viz., P. fluorescens OKC, *Trichoderma asperellum* T42 and Rhizobium sp. RH4, individually and in combination in bioprimed seeds of chickpea and rajma in pots and fields showed

higher germination percentage, and better plant growth in both the crops compared to non bioprimed control plants.

- **Soil application** Trihoderma can be applied as granules as well as drench. Trichoderma 2.5 kilogram per hectare. Pre incubated in 50 kg FYM used as Soil application. Soil application of peat-based formulation *Pseudomonas fluorscens* at the rate 2.5 kg formulation mixed with 25 kilograms of FYM helps in reducing chickpea wilt.
- **Foliar spray** Foliar spray of *Pseudomonas fluorscens* on beet leaves help in inhibiting spore germination of Botrytis and Cladosporium. Spraying with 0.2 percent Trichoderma helps in reducing Alternaria blight and white rust infection in mustard. (Kumar and Godika, 2011).
- **Applying to the Infection Site:** Application directly to the infection court at a high population level to swamp the pathogen (inundate application), seed coating and treatment with antagonistic fungi and bacteria, e.g., *Trichoderma harzianum* and *Psudomonas fluorescens*, antagonists applied to fruit for protection in storage, e.g., *Pseudomonas fluorescens* (Janisiewicz and Korsten, 2002). These kinds of treatments are the most widely employed techniques that have effectively controlled a number of fungal plant diseases.

1.8.1 Commercialization of Biocontrol:

The sluggish commercial adoption and implementation of biological disease management can be attributed mostly to their inconsistent field performance in varying environmental conditions (Fravel, 2005).

Many biocontrol agents work well in greenhouse and laboratory settings, but they don't work as well in actual field settings.

Only by having a deeper comprehension of the environmental factors influencing biocontrol agents can this issue be resolved.

Aside from this issue, there has also not been a lot of money invested in the creation and manufacturing of commercial formulations of biocontrol-active microorganisms, most likely because these products are expensive to create, test, register, and market.

The process of commercializing bio-control products involves several steps and a variety of tasks, including:

i. Isolation of micro- organism from the natural ecosystem.
ii. Evaluation of bio –agent both in vitro and under glass house condition.
iii. Testing of the best isolate under field conditions.
iv. Mass production
v. Formulation
vi. Delivery
vii. Compatibility
viii. Registration and release

Table 1.3: Some Commercially Exploited Microbes as Biological Control

Sr. No	BCAs	Product	Targetdisease organism	Crop	Manufacturer
1	*Pseudomonas fluorescene* strain A506	Frostban	Fire blight bunch rot	Fruit crop, Tomato, Potato	Plant Health Technologies
2	*Trichoderma harzianum* T22	Root shield plant shield	Soil borne pathogens	Green house nurseries	Bio work USA
3	*Trichoderma harzianum* T39	Trichodex	*Botrytis cinerea*	Most of the food crops	Bio Works USA
4	*Gliocladium catenulatum* strain JI446	Prima stops soil guard	Soil Borne pathogen	/egetables, Herbs, Species	Kemira Agrooy Finland
5	*Pseudomonas aureofaciens* strain TX-1	Bio jet spot less	Pythium *Rhizoctonia solani*	Vegetables and Ornamentals ingreen houses	Eco Soil system

1.8.2 Benefits and Drawbacks of BCAs (Chandrashekara e*t al*., 2012):

Benefits of bio control agents:

a. Steer clear of contamination to the environment.
b. Prevent negative effects on creatures that are helpful.
c. Less costly than insecticides and avoids concerns of resistance.
d. While fungicide requires regular applications, BCAs require only a single application to remain effective.
e. When using fungicides to combat soil-borne diseases is not practical, BCAs are incredibly effective.
f. BCAs are resilient, long-lasting, and eco-friendly.
g. BCAs assisted in creating systemic resitance among the crop species.
h. There is no risk of water contamination.
i. By promoting the healthy soil microbiota, BCAs not only prevent disease but also improve plant and root growth. Additionally, it raises crop yields. It facilitates the sequestration and volatilization of several inorganic nutrients. For instance, phosphorus is soluble and made available to plants by *Bacillus subtilis*.
j. Biofertilizers and biocontrol agents can be mixed.

1.8.3 The Drawbacks of Bio-Control Agents':

While biological control offers numerous benefits, it also has the following drawbacks.

a. The use of BCAs presents significant challenges in terms of getting them to the appropriate location at the correct time in enough amount to make a difference, and then keeping them there.

b. Another issue is the growers' doubts over the effectiveness of BCAs.
c. High labour requirements.
d. BCAs are host-specific and can only be employed against specific diseases.
e. Bio-control agents have a very slow response when it comes to controlling plant diseases.
f. At this time, they are not available in larger quantities.
g. Effected by environment.
h. Compared to fungicides, they are not as efficient.
i. Only a small number of bio-control agents are currently usable and accessible in a limited number of locations.
j. The biocontrol method is not a treatment; it is merely a preventive measure.

1.8.4 Future Outlook:

One of sustainable agriculture's most potential applications is biological control, which is an environmentally friendly agricultural pest management technique. It is a strategy of managing pest populations that is ecologically friendly, safe, and conservative because it makes use of living things. A sustainable biological control program that uses certain biocontrol agents should be able to identify and manage plant-pathogenic bacteria. In the industrialized world, biological control is another strategy that can be used to manage pests sustainably. In comparison to the synthetic control technique, it is thought to be the most environmentally safe, affordable, and sustainable pest management method, offering additional benefits to breeders and customers. The general mechanisms of action of antagonistic bacteria, which are thought to be effective substitutes for synthetic fungicides, have been described in this review along with the success of some of these bacteria in lab settings, which has led to creation of biological products derived from antagonistic bacteria that can be applied after harvest.

The antagonistic association and action of biocontrol microorganisms are significantly influenced by ecological variables. The following standards must be clarified and thought about:

1. The spread of bacterial, nematode, and fungal pathogens as well as the enemies of these organisms in the surroundings.
2. The perfect situation in which biocontrol bacteria employ their restraint powers.
3. The reaction of local and familiar demographics under different supervision.
4. The key elements that influence prosperous settlement and the development of biocontrol characters.
5. The host defense is induced by the components and dynamics of plants.

1.9 Conclusions:

An appealing substitute tactic for managing plant diseases is biological disease control. It also offers methods that are in line with the objective of a sustainable farming system. Effective biocontrol requires a deep comprehension of the cropping system, disease epidemiology, the biology, ecology, and population dynamics of the biocontrol species, as well as the interactions among these elements.

Understanding the processes underlying interactions between pathogens and antagonists will be essential as it could offer a justifiable foundation for the identification and development of more potent biocontrol drugs.

Farmers' livelihoods will be significantly impacted by the employment of biological control as a technique for sustainable agriculture. Given that high productivity, robust crop, and higher-quality agricultural productions are anticipated with the application of this biotechnology. By using this technology, farmers will be able to harvest goods that are unique and appealing to consumers because of their safety and quality.

Due to BC's advantages in agriculture, including its ability to control diseases and enhance crop productivity, is crucial to expand the use of it in order to achieve sustainable agricultural practices. BC can be viewed as the answer for organic and sustainable agriculture, as it lowers production costs and a reduced use of agrochemicals. Using BC in agricultural production would have a positive impact on the environment without causing harm to it.

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