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Biological control, an important tool for sustainable agriculture

Abstract

Biological Control (BC) with antagonistic microorganisms is one of the tools within the Integrated Management of Pests and Diseases (MIPE), being an important sustainable alternative to mitigate the negative effects that refer to the quality and productivity of agricultural crops. Therefore, this bibliographic review study reports on the research that needs to be carried out, such as: antagonistic studies on the various phytopathogens, efficacy studies on a wide range of microorganisms, evaluations of specificity between antagonists and phytopathogens, studies of the viability in the introduction of an antagonistic agent in a plant-soil-environment system and of the complex interactions between plants, people, and the environment. It also discusses the uses and types of CB, and the variety of CB strategies available for use.

Keywords: antagonistic microorganisms, phytopathogens, biocontroller

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Introduction

Biological Control (BC) with antagonistic microorganisms began to be constantly investigated from the 1980s.[1] Within the Integrated Management of Pests and Diseases (IMPD), the use of Biological Control Agents (BCA) has been considered an important sustainable alternative to mitigate the negative effects that refer to the quality and productivity of agricultural crops.[2]

Therefore, the BC consists of the control of harmful organisms or microorganisms through beneficial organisms or microorganisms. Baker & Cook[3] idefined it as "the reduction in inoculum density or activity of a pathogen or parasite, in its active or dormant state, achieved naturally or through manipulation of the environment, the host or antagonists of the pathogen or pest to be controlled".[4] Later Eilenberg, Hajek, & Lomer[5] defined it as "the use of living organisms to suppress a pest, to reduce its population or its impact, making it less abundant or harmful."[6]

Results and discussion

For some years now, agriculture has become dependent on the use of chemical pesticides to control phytopathogenic organisms, which causes resistance to pests, variation of the microbial microflora, environmental contamination due to the accumulation of toxins at levels harmful to humans and the ecosystem[1,7,8–10] and affects beneficial organisms and production costs.[10–12] A report from the National Research Council of the USA indicated that chemical products produce 60% of oncogenic risks,[7] the agro-commercial sectors showed great interest in the development of ecological and profitable strategies for the management of plant diseases[10] due to the increased importance of global food security. This led to increased investments in agricultural research and development to improve productivity in the world, especially in developing countries,[9] allowing safe food production and lower agricultural production costs.[2]

By 2050, the world population is expected to reach approximately 9.1 billion people, therefore, it is estimated that agricultural food production needs to be increased by around 70%.[6,10] Likewise, the production of grains is of great importance in world food, but problems such as global warming, environmental pollution and population explosion have repercussions on the productivity of plants, causing both biotic and abiotic stress and resulting in yield losses. Biotic stressors involve fungi, bacteria, viruses, nematodes, weeds, and insects that cause yield losses of up to 31-42%. Among them, phytopathogens of fungal origin are one of the most important since they limit crop production throughout the world,[10] and the search for methods that lead to increased agricultural productivity has led to the increase in populations of other organisms (insects, bacteria, and viruses) that limit crop yields. Soil phytopathogens are of great importance because they affect a wide spectrum of hosts. The disease-causing species mainly belong to the genera: *Fusarium, Pythium, Phytophthora, Rizoctonia, Aphanomyces* and *Verticilium,*[13] (Figure 1), for which it is considered of interest to find alternatives for the control of disease-causing agents that are framed in sustainable agriculture. At present, the use of non-aggressive alternative methods for the environment has gained a great boom, being the BC one of the most promising and it is a substantial component in the initiatives of sustainable agriculture of several institutions and organizations.[11,14–16]

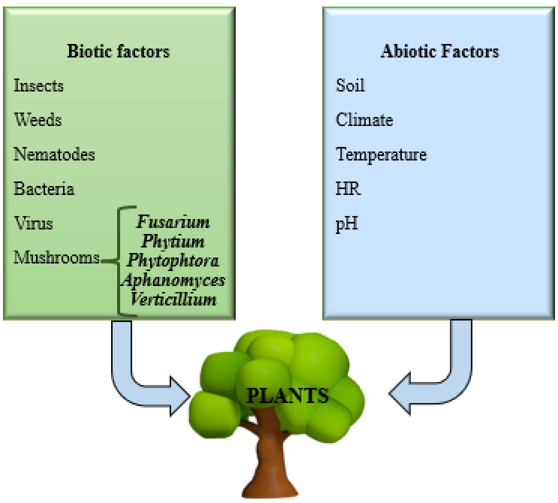

Figure 1 Factors affecting plants.

In recent years, the search for biocontrol microorganisms that inhibit or kill phytopathogens has acquired great importance, especially those that develop in the same ecological niche, with prolonged persistence and the possibility of effective inoculation through the development of a formulation that can subsequently be produced on a large scale.[17]

The importance of BC is that it modifies the traditional way of controlling diseases, with the use of agrochemicals. In addition, it is a strategy that is giving good results against infectious agents by displacing them naturally,[18] or as Ruano Rosa et al.,[19] for the success of pathogen management, the implementation of integrated disease control strategies is recommended, combining tools of a physical, cultural, chemical, and biological nature, since it would provide a more sustainable use of chemical-based phytosanitary products. when it is not possible to resort to alternatives that exclude them in a significant way, bearing in mind that its success depends on the complex and subtle balance of interactions between pathogen, host, BCA, and the environment.[20] Application of BCA with low chemical concentrations stimulates disease suppression like high-dose chemical fungicide treatments.[10]

For the use of BC in soil diseases, there are recognition mechanisms and interactions between the BCA, the host plant, the phytopathogen and the microorganisms of the rhizosphere that are subject to variations in different periods of time (rain, drought, concentrations of salts, pH, among others), so knowing the ecology of the BCA is important to understand the relationship between antagonists and the components of the rhizosphere, this being of great importance for the implementation of the biocontroller (Figure 2).

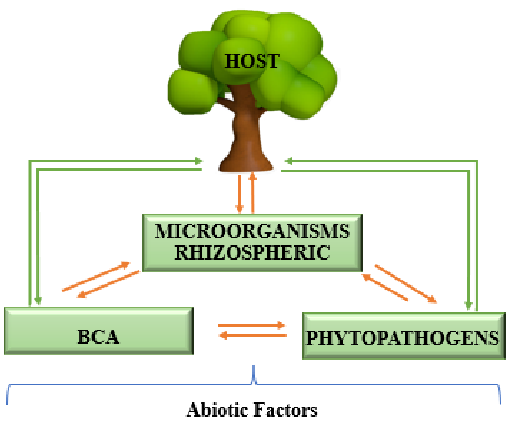

Figure 2 Interaction plant – phytopathogen – BCA – rhizospheric microrganisms vs. abiotic factors.

In the study of BC, it is necessary to carry out antagonistic studies on the various phytopathogens, without generalizing or extrapolating their efficacy to a wide range of fungi, since between the antagonists and the phytopathogens there is a certain specificity to be evaluated.[21] There are several ways to achieve an effective BC, sometimes it can occur naturally, without human intervention, while it can also occur through man, using cultural practices (crop rotation, solarization and post storage conditions). –harvest to favor natural antagonists and disfavor the phytopathogen at the site of action. It can also occur by applying previously selected antagonistic microorganisms in a massive way, it is sought that these antagonists are not foreign, but that they are part of the microflora normally present in those places. Therefore, it is preferred to use as biological controllers, native strains that have been isolated from sites like the application site, ensuring rapid adaptation to the place where biocontrol is expected to occur.[22] The colonization of BCA in roots can be both endophytic and superficial, they can induce both systemic and localized responses by the host, which limit the entry of phytopathogens.[23] This is a dynamic process in which different factors act: availability of water, temperature, pH, type of soil, composition of root exudates, presence of other microorganisms, host plant, BCA, etc.[24] (Figure 3). The mentioned parameters determine how soil microorganisms can establish themselves in the rhizosphere and/or within the root of the plant,[20] where they exert control over phytopathogens since the rhizosphere represents the first line of defense of the plant. plant against edaphic phytopathogenic organisms, thus avoiding their establishment in the root.[2]

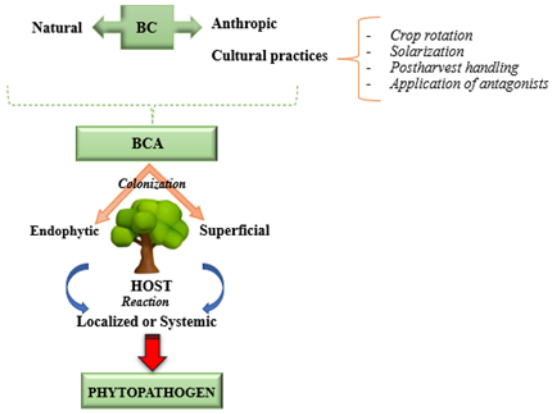

Figure 3 Action of BCA on host plants.

Interaction plant – pathogen – biocontroller

Plants are subject to changing environmental conditions, sometimes they can be unfavorable and must adapt to survive, in the same way as against potentially harmful microorganisms (viruses, bacteria, fungi, among others) even with insects and nematodes. However, when the plant is a natural host, an interaction between the plant and the pathogen is established, which can lead to the development of the disease. The opposite occurs when in nature the most frequent situation is one in which the plant is not a natural host of a pathogenic organism, which does not cause any detrimental effect due to the presence of self-regulation mechanisms.[4,25] This self-regulation of populations of living beings is another way of calling BC.[4]

BC refers to the use of beneficial microorganisms that can reduce the effects of pathogens on plants. For a disease to occur, a phytopathogenic organism must compete with other microorganisms to secure a suitable site on the susceptible plant. Therefore, a good antagonist or biocontroller should be able to prevent the phytopathogen from colonizing the host and starting the infection or it could also destroy the phytopathogen preventing the disease. Therefore, different mechanisms are involved: competition with the pathogen for nutrients or space at the site of infection, inhibition or destruction of the pathogen by production of toxic substances at the site of action, and induction of the resistance response. of the plant (Figure 4).[22]

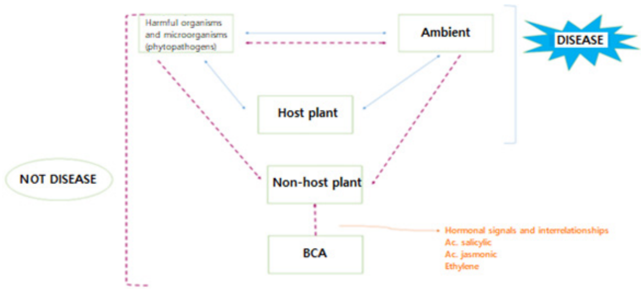

Figure 4 Predisposing factors for the plant to become ill or healthy.

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The BC of soil phytopathogens is complicated since it is regulated by the biocontroller-pathogen-plant interaction.[23] The plant can select its colonizers through exudates (sugars, amino acids, volatile compounds: ethanol, polyacetylene hydrocarbons, aldehydes and butyl and isopropyl alcohols, as well as non-volatile: sulfoxides) that it produces.[23,26] However, the feasibility of introducing an antagonistic agent in a plant-soil-environment system does not guarantee the same results and survival in another type of soil or genotype.[23]

Microbial colonization in plants is regulated by hormonal signals and intercommunications. The plant defense system recognizes molecular patterns emitted by the pathogen (PAMPs: Pathogen Associated Molecular Patterns) and emits its defense PTI (PAMP-triggered immunity), so that the pathogen, to evade the PTI, secretes defective molecules which are overcome by plants resistant and emits a greater defense, which can lead to cell death or programmed tissue necrosis (Effector Triggered Immunity or ETI). They also have extracellular receptors on the membranes, such as RLK (receptor like kinase) that recognize PAMPs, and intracellular receptors such as NBS – LRR (Nucleotide-binding siteleucine-rich repeats) that recognize effectors. Among the plant hormones involved in the defense of plants against the attack of phytopathogens are salicylic acid (SA), which acts against bio or hemibiotropic organisms, while jasmonic acid (JA) and ethylene (ET) they are activated against necrotrophic microorganisms, with SA and JA being mutually antagonistic (Figure 5). The opposite occurs in the relationship biocontrollers and the host that is not well defined, such is the case of Trichoderma. Where microorganisms obtain sucrose from plants in exchange for having the ability to promote plant growth and protect it from pathogens. A protein, Tsp1, that acts as an effector and is negatively regulated by T. virens after 96 h in contact with the root was recently detected.[27]

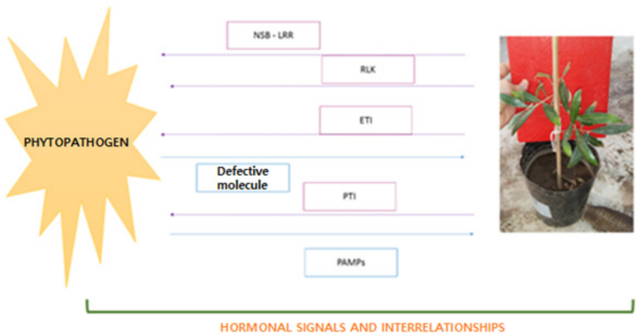

Figure 5 Molecular action mechanisms of phytopathogenic agents vs. molecular defense reaction of the host plant.

Uses of biological control

The use of BCA began in the early nineteenth century, using living organisms or their metabolites to mitigate diseases in agricultural crops.[2] The use of BCA can be a preventive measure applied before or after sowing, palliative. Also given its qualities, the BC can be combined with other control tools to achieve integrated management. Among the traditional methods to control post-harvest decay is the use of refrigeration, chemical products and recently the use of integrated management or BC. The latter, in post-harvest, has the possibility of maintaining control of factors (such as temperature, humidity, etc.), benefiting biocontrol agents, which means a great possibility and ease of handling.[7,28] The possible fungicides to be used in post-harvest are very limited and the restrictions in the hygienic-sanitary order are increasing, since they are potential oncogenic agents when applied to fruits and vegetables, this led to the establishment of maximum residue limits in the Food Code, so BC is an appropriate and safe practice for human beings, since it does not leave a residual effect on fruits and vegetables, unlike agrochemicals.[1]

Types of biological control

There are a variety of BC strategies available for use, but further development and effective adoption will require greater understanding of the complex interactions between plants, people, and the environment.[28] More broadly, the term BC has also been applied to the use of extracted or fermented natural products, from various sources. They can be very simple mixtures of natural ingredients with specific activities or complex mixtures with multiple effects on the host, as well as the target pest or pathogen. Example of these are:

Biocontrol with plant extracts

Plant extracts are considered bio-inputs, obtained from plants, and have a beneficial effect on the growth and health of crops, minimizing the damage caused by phytopathogenic agents. This is also a sustainable practice that allows the conservation of natural resources and the care of human health. As described by Kuklinski,[29] extracts can be obtained through various methods: mechanical extraction, distillation, extraction with supercritical fluids and solvent extraction.[30]

From strawberry leaves (*Fragaria vesca*), an extract was made that has phenols with antimicrobial properties and inducers of plant defense against phytopathogens.[31] The effect exerted by *Moringa oleifera* (Moringa), *Persea americana* (Avocado), *Equisetum hymale* (Horsetail), *Larrea tridentata* (Governor), *Gnaphalium semiamplexicaule* (Gordolobo), *Peumus boldus* (Boldo), *Brickellia squarrosa* (Prodigiosa), was also evaluated. *Rosmarinus officinalis* (Romero) and *Physalis coztomatl* (Costomate), on fungi: *Fusarium oxysporum, Fusarium solani* and *Rhizoctonia solani*, and the results show an excellent alternative to the control and management of phytopathogens.[32] López Benítez et al.[33] evaluated the inhibition exerted by aqueous extracts of garlic (*Allium sativum*), governor (*Larrea tridentata*), leaves (*Flourensia cernua*), clove (*Syzygium aromaticum*), cinnamon (*Cinnamomum zeylanicum*) and mango (*Mangifera indica*) on the soil fungi of *Fusarium oxysporum* f. sp. *lycopersici, Rhizoctonia solani* and *Verticillium dahliae*, and found that the extracts with the best inhibition results were clove, garlic, and governor.

Biocontrol with microorganisms

Most of the BCA are from species of the genera *Pseudomonas, Trichoderma* and *Bacillus*, the latter has characteristics such as growth stimulant and biocontroller with high survival due to its ability to form endospores.[23] 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 (Table 1).[23] Both *Trichoderma spp.* such as *Bacillus spp.* and *Pseudomonas spp.,* are known as biocontrollers of soil phytopathogens, among them: *Pythium oligandrum, Coniothyrium minitans, Sporidesmium sclerotivorum* and *Fusarium oxysporum*.[23]

Rhizobacteria (*Bacillus, Pseudomonas, Serratia, Arthrobacter* and *Stenotrophomonas*), promoters of plant growth, also have efficient use in the production of volatile compounds and can prevent plant diseases. These can have direct action on the pathogenic organism or act by stimulating systemic resistance in plants.[34]

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Table 1 Characteristics of biocontrol microorganisms

Microorganisms	Characteristic
Pseudomonas	Colonizes the root system
	Produces siderophores
	Plant growth promoter
	Adapts to stress conditions
Trichoderma	Colonizes the root system
	Mycoparasite
	Competition for nutrients
	Antibiosis
	Plant resistance inducer
Bacillus	Plant growth stimulant
	Biocontroller
	Endospores

Conclusion

The use of Biological Control as a tool in agroecological management for sustainable agriculture will greatly influence the economy of farmers. Given that with the application of this biotechnology it is expected to achieve high yields per surface unit, improve the health of the crops and increase the quality of their productions. The application of this tool will allow farmers to obtain harvests of products with differential and desirable characteristics for consumers due to their quality and safety.

In addition, it is important to disseminate, raise awareness and convince about the benefits of BC and the application of this biotechnology will allow satisfying the growing demand for food, due to the sustainability of production, technical feasibility, and economic profitability.

BC can be considered as the solution for organic and sustainable agriculture, since it allows to reduce production costs and reduce the use of agrochemicals, so it is important to increase its application to achieve sustainable agricultural practices, due to its benefits in agriculture and as a strategy to control diseases and improve the agronomic performance of crops. BC in agricultural production would bring great benefits without exerting a detrimental impact on the environment.

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None.

Conflicts of interest

Author declares there is no conflict of interest.

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