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ENDOPHYTIC MICROORGANISMS AS BIOCONTROL AGENTS: AN ALTERNATIVE FOR THE SUSTAINABLE AGRICULTURAL PRODUCTION SYSTEM

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ABSTRACT
Endophytic microorganisms emerge as a sustainable alternative, offering benefits to plants, such as increased resistance to stress and pathogens. This research aims to carry out a literature review on the potential of endophytic microorganisms in the biological control of pathogens in agricultural systems, as a sustainable alternative to traditional methods. Endophytes can act directly on insects or colonize plants, creating a natural defense against pests. They also hold promise in controlling phytopathogens, aiding in reducing the use of chemical fungicides, and encouraging more sustainable agricultural practices by producing bioactive compounds with effective antifungal activity against pathogens. Additionally, they show potential as natural herbicides, negatively affecting germination and weed development. While more research is needed on the potential of endophytes in agricultural systems, they hold great promise for more sustainable management.

Keywords: Biological Control. Resistance Induction. Endophytic fungus. Endophytic Bacteria.

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INTRODUCTION

The use of pesticides has been the main form of agricultural pest control over the years, due to their effectiveness and rapid action on unwanted organisms. However, the incorrect and indiscriminate use of these chemicals can cause serious consequences for the environment and human health. The intensive use of pesticides promotes the selection of resistant insect populations, making chemical control less and less effective. In addition, pesticides can accumulate in soil and water, harming biodiversity and negatively affecting non-target species such as pollinators, which are essential for agricultural productivity (Cabrera, Guerrero, Batista, 2020; Díaz, Aguilar, 2015; Garrido, Bottom, 2021; Gilden, Huffling and Sattler, 2010; Kim; Kabir; Jahan, 2017; Nauen, Denholm, 2005; Sarwar, 2015). These side effects, along with growing concern about environmental contamination and human health risks, have driven the search for more sustainable alternatives in agricultural management.

In the face of these challenges, the development of new forms of agricultural management, which minimize environmental impact and promote sustainable production, is of paramount importance. Among these alternatives, endophytic microorganisms stand out, which are capable of living within plant tissues without causing any apparent damage to plants, maintain a harmonious relationship with their host (Jaber; Ownley, 2018; Rodriguez *et al*., 2009; Suryanarayanan *et al*., 2009; Vega *et al*., 2008; Veja, 2018). Some start on the surface of the plants, as epiphytics, and others can be latent pathogens, living harmoniously with the plant for long periods, without causing infection. These interactions show how complex the relationship between plants and these organisms is (Petrini, 2012). These symbiotic interactions benefit both plants and microorganisms, creating an ecological balance that can be exploited for the biological control of pests and diseases.

Endophytic microorganisms have aroused great scientific interest due to their ability to contribute to sustainable development in agriculture. Some of these microorganisms, such as fungi and endophytic bacteria, can aid plant growth and health through the production of enzymes, such as chitinases, lipases, cellulases, and proteases, which aid in the degradation of cellular components and promote a healthier environment for plant development (El-Gendi *et al*., 2022). In addition, these microorganisms can increase the uptake of nutrients, such as phosphorus and nitrogen, increase plant resistance to biotic and abiotic stresses, and produce plant hormones that stimulate growth, becoming valuable tools in integrated crop management (Adeleke *et al*., 2022; Anand *et al*., 2023; Sudha *et al.*, 2016; Toghueo, 2019).

An example of success in the application of endophytic microorganisms in biological control can be seen in the work of Toppo *et al*. (2024), which demonstrated that endophytes belonging to the genera *Colletotrichum* and *Fusarium* promoted significant growth in *Azadirachta indica* plants, improving seed germination and vigor, in addition to increasing the growth of the roots and aerial part of the plant. These results indicate the potential of these microorganisms to replace the use of conventional chemicals, providing a more sustainable approach to agricultural management.

Another relevant aspect is the potential of these microorganisms in the production of bioactive compounds, such as alkaloids and enzymes, which can act as biological control agents against pests. Some compounds produced by endophytes have insecticidal action, being able to degrade the cuticle of insects and inhibit their development, which makes them a promising alternative in integrated pest management (Sudha *et al*., 2016; Sugahara; Varéa, 2014). Not only does this reduce reliance on chemical pesticides, but it also promotes greener and safer agriculture for the environment and consumers.

Given the breadth of the potential of endophytic microorganisms, this review aims to explore the recent literature on the use of these organisms in the biological control of pathogens in agricultural systems. The objective is to highlight how these solutions can be a sustainable and efficient alternative to traditional methods, promoting more responsible and sustainable agriculture.

METHODOLOGY

To carry out this literature review, specific criteria were established to ensure the relevance and timeliness of the selected studies. In order to encompass the most recent research on the use of endophytic microorganisms in the biological control of agricultural pathogens, articles published between 2019 and 2024 were included. The searches were carried out in scientific databases, such as Scopus, Capes and Google Scholar, using the keywords "Biological control", "Induction of resistance", "Endophytic fungus" and "Endophytic bacteria", both in Portuguese and English.

The selection of articles was based on the application of endophytic microorganisms that promote resistance against pathogens, such as insects, fungi and weeds, in addition to evaluating the efficacy of these organisms in promoting plant health. Studies that did not present clear experimental data on the potential of endophytes in pathogen control, as well as those focused on microorganisms other than endophytes or biological control methods not applicable to agriculture, were excluded.

Finally, the selected articles were analyzed in terms of methodology, results and conclusions, with emphasis on those that demonstrated a positive impact on the control of pathogens and the reduction of the use of chemical inputs.

RESULTS AND DISCUSSION

41 articles were selected, but only 18 articles were used, as they addressed endophytic microorganisms applied to agriculture, for the control of insects, in the control of phytopathogens and in the control of weeds, in which they are presented as an alternative or potential use for more sustainable agricultural systems.

ENDOPHYTIC MICROORGANISMS IN INSECT CONTROL

The literature has several studies that used the fungus *B. bassiana* in the mortality of insect larvae, especially in *Aedes aegypti* larvae. The crude extracts of this endophyte, in high concentrations, provide high mortality rates in larvae of different stages of the insect and also in adult individuals (De Paula *et al.*, 2008; Quintero-Zapata *et al.*, 2021). This efficacy of *B. bassiana* is indicative of the potential of endophytic fungi as natural insecticides.

In addition to direct use in insects, endophytic fungi can colonize plants, providing a natural defense against pests, as in the study by Agbessenou *et al.* (2020), which colonized tomato and nightshade plants with endophytic fungi and evaluated the survival of Tuta absoluta. They evaluated that the endophytic fungi *T. asperellum, B. bassiana* and *H. lixii* stood out by improving the defense of tomato and nightshade against *T. absoluta*, reduced oviposition, pupation and emergence of adults, thus becoming a new strategy that can be developed for sustainable pest management.

Chebet *et al.* (2021) complements these observations by evaluating the potential of *Hipocrea lixii* and *Beauveria bassiana* to endophytically colonize and produce active compounds in Phaseolus vulgaris. The results indicated a significant reduction in the percentage of pupation of 2nd instar leaf miner larvae and in the emergence of adult flies. In addition, the survival of 1st instar fall armyworm larvae was considerably affected,

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indicating the high potential of these fungi to produce specific defense compounds that can be used to combat pests such as pea miner and fall armyworm.

Regarding the diversity of endophytic fungi, Hazaa *et al.* (2022) analyzed 69 isolates of endophytic fungi, in which 17 showed larvicidal potential and 3 isolates with anti-food potential of Spodoptera littoralis. Among these strains, *A. sydowii, A. flavus* and *L. theobromae* stood out, with their activities intensified by exposure to gamma rays.

Another endophytic fungus of interest is *Aspergillus sojae*, which has demonstrated efficacy against *Spodoptera litura*. The extract showed 66.0% mortality at the highest concentration. In addition, it showed activity for the four enzymes amylase, cellulase, lipase and laccase. And antibacterial activity, especially against *E. coli* (Elango *et al.*, 2020).

Pathogenic fungi of insects have been an interesting alternative in the biological control of pests. However, they have some limitations, such as a relatively slow mortality rate and the need for a large amount of conidia to be effective. Despite these challenges, recent research conducted by Parveen and Rashtrapal (2024) has opened up new possibilities by suggesting that these fungi can act as endophytes. By establishing themselves on plants, they not only protect against phytopathogens but can also contribute to higher agricultural productivity. In addition, fungi of the genus Beauveria, known for their entomopathogenic action, can also behave as endophytes, as indicated by Canassa *et al.* (2019) and Lelio *et al.* (2022). This innovative approach can result in more efficient pest control and promote more sustainable agricultural practices, benefiting both farmers and the environment.

ENDOPHYTIC MICROORGANISMS IN THE CONTROL OF PHYTOPATHOGENS

Phytopathogenic fungi are responsible for causing several diseases in plants, causing great damage to agricultural systems. One of the promising alternatives to combat these pathogens is the use of endophytic microorganisms, which can produce substances with antibiotic action, efficiently protecting plants. These bioactive compounds, generated by endophytes, have the potential to replace or complement the use of chemicals, favoring more sustainable agricultural practices.

In the research by Lykholat *et al.* (2022) endophytic fungi extracted from the fruits of Chaenomeles speciosa, demonstrated a strong ability to fight phytopathogens. The endophytic isolates showed antifungal activity against strains of the genus *Fusarium*, inhibiting the growth of *Fusarium culmorum* between 51.5% and 81.3%, and of *Fusarium* *oxysporum* between 68.4% and 86.6%. These results show the great potential of endophytic fungi for the development of biocontrol agents and the discovery of new bioactive compounds.

Studies such as the one by Mota *et al.* (2021) reinforce the effectiveness of endophytic fungi in the control of agricultural diseases, as in the case of common beans. Fungi of the genus Induratia were able to inhibit the growth of pathogens such as *Colletotrichum lindemuthianum* and *Sclerotinia sclerotiorum*, using bioactive volatile compounds. The application of these fungi contributed to the reduction of the severity of diseases, pointing to a more sustainable alternative with less use of chemical fungicides.

In addition, some pathogens can also behave as endophytes in some cases, as in the work of De Lamo and Tekken (2020) who show the two sides of *Fusarium oxysporum*, as it is a pathogen that causes disease in plants, but it can act as an endophyte in some cases, promoting resistance, through the activation of the plant's immune response. This promotes a more sustainable approach to agriculture.

Rajani *et al.* (2021) presented relevant findings on the interaction between endophytic fungi of the genus Trichoderma and fungal pathogens. They demonstrated that Trichoderma inhibits the growth of pathogens such as *Fusarium oxysporum* and *Macrophomina phaseolina*, through volatile organic compounds. The results suggest that Trichoderma may be a viable alternative for the biological control of fungal diseases, promoting more sustainable agricultural practices and highlighting the importance of these fungi in plant protection.

The use of endophytic fungi in the control of agricultural pathogens has shown to be a promising strategy to promote more sustainable and efficient agriculture. Research indicates that these microorganisms can reduce reliance on chemical fungicides, as well as provide new opportunities for the development of effective biocontrol agents.

ENDOPHYTIC MICROORGANISMS IN WEED CONTROL

Endophytes can also act as herbicides, as in Silva *et al.*, (2023), in which endophytic fungi found on the leaves of *Copaifera oblongifolia* negatively affected weed seed germination and survival, in addition to impairing seedling development. The secondary metabolites of these fungi show an interesting potential for the control of invasive species, since they can inhibit plant growth. According to this study, these fungi can be used as a

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tool in the management of invasive plants, thanks to their direct impact on seedling development.

Endophytic fungi isolated from the medicinal plant *Lafoensia pacari* have the potential to completely inhibit the germination of seeds of *Lactuca sativa* and *Allium schoenoprasum* (Amorim *et al.*, 2021).

The endophytic fungus *Fusarium venenatum* isolated from *Phelipanche ramosa* (L.) Pomel, has the potential to necrose plants, without affecting tobacco crops, and inhibit the germination of P*. ramosa seeds*, demonstrating the herbicidal potential of this isolate (Gibot-Leclerc *et al.*, 2021).

Camargos *et al.* (2024), in their study with endophytic microorganisms isolated from the Mastic tree (*Myracrodruon urundeuva*), found that metabolites produced by endophytic fungi such as *Phomopsis* sp., *Bacillus* sp., and *Brevilacillus* sp. reduce the vigor of weed seeds such as *U. brizantha Stapf cv. Piatã, B. pilosa* and *Stylosanthes* sp.. These metabolites showed potential for use as bioherbicides, directly interfering in the germination and development of these species.

The bioherbicide Di-Bak Parkinsonia® contains three endophytic fungi endemic to Australia (Lasiodiplodia pseudotheobromae, Macrophomina phaseolina and Neoscytalidium novaehollandiae), is used in capsule form and implanted by the stem, has been shown to be effective in eliminating invasive plants, inducing death and preventing the emergence of new ones. This provides effective control on a large scale, in addition to contributing to more sustainable management (Galea, 2021).

There is still a lack of studies on the application of endophytes in weed control, especially because these microorganisms can also affect crops of economic interest. However, a promising opportunity would be the use of endophytes during the period of sanitary vacuum or between harvests, when there is no presence of plants of economic interest in the agricultural areas. In this interval, weed control could be done efficiently with the use of endophytes, due to their potential to inhibit germination and affect seed vigor. This approach would have the benefit of reducing competition with future crops, promoting more sustainable management and reducing reliance on chemical herbicides.

CONCLUSION

The use of endophytic microorganisms in agriculture emerges as a promising alternative to reduce or eliminate the use of chemicals that are harmful to human health and

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the environment. This literature review analyzed scientific articles that investigate the potential of these microorganisms in biological control, evidencing the growing interest and biodiversity associated with endophytes, in addition to their various applications in the agricultural sector.

Endophytes play an essential role in promoting plant health and preserving biodiversity. They can increase plant resistance to biotic and abiotic stresses, pests, and harsh environmental conditions, favoring the sustainability of ecosystems. Recent research has demonstrated the vast biotechnological potential of these microorganisms, which are promising sources of bioactive compounds.

Despite the advances, there are still challenges in endophytic fungi research, such as the complexity of the interactions between these organisms and their hosts, the need for more efficient methods of isolation, and the characterization of the substances produced. Understanding these interactions is crucial to maximizing the use of endophytes in practical applications.

Thus, endophytic microorganisms represent an untapped and sustainable source of bioactive compounds with great potential for various applications. The continuity of research in this area is essential to take advantage of these resources in an innovative and responsible way.

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