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Identification and characterization of endophytic fungi found in plants from northeast Brazilian mangroves: a review

Identificação e caracterização de fungos endofíticos encontrados em plantas de manguezais do nordeste brasileiro: uma revisão

Identificación y caracterización de hongos endofíticos encontrados en plantas de manglares del noreste brasileiro: una revisión

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Abstract
Mangroves constitute an ecosystem formed by different classes of living organisms. Due to its diversity, it has an ecological and environmental value that human activities can threaten. Endophytic fungi, found inside plant tissues, can produce substances of biotechnological value, such as antibiotics and other active principles with pharmacological properties. Therefore, this narrative review of the literature carried out through the analysis of articles found in different databases, such as: 'CAPES Journal Portal,' 'Web of Science,' 'SciElo,' 'Pubmed,' among others, highlights the importance of identifying, characterizing, and isolating endophytic fungi found in Brazilian mangroves and their relevance to the prospection of substances of high biotechnological value to the society. As well as to assist in understanding the ecological dynamics of mangroves in Brazil.
Keywords: Biodiversity; Lasiodiplodia; Pathogenicity; Phylogeny; Sequencing.

Resumo
Os manguezais constituem um ecossistema formado por diferentes classes de organismos vivos. Devido à sua diversidade, possui um valor ecológico e ambiental que as atividades humanas podem ameaçar. Os fungos endofíticos, encontrados no interior dos tecidos vegetais, podem produzir substâncias de valor biotecnológico, como antibióticos e outros princípios ativos com propriedades farmacológicas. Portanto, esta revisão narrativa da literatura realizada por meio da análise de artigos encontrados em diferentes bases de dados, tais como: 'Portal de Periódicos CAPES', 'Web of Science', 'SciElo', 'Pubmed', entre outros, destaca a importância de identificar, caracterizar e isolar fungos endofíticos encontrados em manguezais brasileiros e sua relevância para a prospecção de substâncias de alto

valor biotecnológico para a sociedade. Bem como para auxiliar na compreensão das dinâmicas ecológicas de manguezais no Brasil.
Palavras-chave: Biodiversidade; Filogenia; Lasiodiplodia; Patogenicidade; Sequenciamento.

Resumen
Los manglares constituyen un ecosistema formado por diferentes clases de organismos vivos. Por su diversidad, tiene un valor ecológico y ambiental que las actividades humanas pueden amenazar. Los hongos endófitos, que se encuentran en el interior de los tejidos vegetales, pueden producir sustancias de valor biotecnológico, como antibióticos y otros principios activos con propiedades farmacológicas. Por lo tanto, esta revisión narrativa de la literatura realizada a través del análisis de artículos encontrados en diferentes bases de datos, tales como: ' Portal del diario Capes', 'Web of Science', 'SciElo', 'Pubmed', entre otras, destaca la importancia de identificar, caracterizar y aislar hongos endófitos encontrados en los manglares brasileños y su relevancia para la prospección de sustancias de alto valor biotecnológico para la sociedad. Así como ayudar a comprender la dinámica ecológica de los manglares en Brasil.
Palabras clave: Biodiversidad; Filogenia; Lasiodiplodia; Patogenicidad; Secuenciación.

1. Introduction

The term mangrove is often used to refer to plants and their associated community. The latter comprises a wide range of organisms belonging to different groups, including bacteria, fungi, microalgae, invertebrates, birds, and mammals. It is estimated that the global area of mangroves is 18.1 million hectares, distributed in 112 countries, and Brazil has the second largest mangrove area globally (Silva & Fontgalland, 2021).

Particularly along the coast of northeastern Brazil, due to the semi-arid climate, the oligotrophic conditions of coastal waters, and the importance of artisanal fishing for the coastal population, these mangrove properties are highlighted, making them ecosystems of immense ecological and environmental value. Based on these properties, Brazilian legislation considers mangrove areas as permanent preservation areas. However, despite the efforts for its conservation, the mangroves are permanently threatened by various human activities developed both on the coast and inland (Silva et al., 2022).

Even with the growing threat to mangrove areas of the state of Ceará, much of its territory still preserves the original vegetation cover, usually in areas of difficult access. Thus, it becomes fundamental for the characterization of the effects of deforestation on the local biota, enabling the creation of mitigating measures to this problem, being an essential instrument for the expansion of knowledge about that biodiversity the use of a scientific collection. These can be used as a source of benefits for society, supporting public policies, promoting mitigation of environmental impacts, guiding management and conservation strategies, and promoting the identification of potentially beneficial organisms. Currently, knowledge about biodiversity represents an essential productive resource, and collections are essential in this context (Silva et al., 2022).

Within the world's biodiversity, fungi represent the second largest group of organisms on our planet, behind only insects. They are crucial elements in tropical ecosystems, being cosmopolitan and occurring in various habitats (psychrophiles to thermophiles) (Flora do Brasil, 2022). One of these groups, called "endophytic," formed a type of association that has been confirmed through fossil records, suggesting that the endophilic-plant association has evolved since the establishment of the first plants on the earth. The term endophytic was created to differentiate them from epiphytic fungi, which occur only on the surface of plants. The most accepted definition is that endophytic fungi are organisms that, during some stage of their development, survive within plant tissues without causing any apparent damage or symptom of disease in the host (Silva et al., 2022).

Despite the importance of these microorganisms, very little of the existing diversity is known, making it imperative to explore microorganisms from ecosystems such as Brazilian mangroves. For this reason, the present work seeks to conduct a bibliographic survey in different databases ('Science Direct,' 'Web of Science,' 'Scielo,' 'Pub Med,' among others) on the fungal community present in the mangroves of the coast of Ceará through the study of the diversity of endophilic fungi associated with the branches, roots, and leaves of three tree species of mangroves (*Rhizophora mangle*, *Laguncularia racemosa*, and *Avicennia nitida*).

2. Methodology

The narrative review of the literature was used as a methodological resource to gather information on the identification, characterization, and possible biotechnological applications of endophytic fungi extracted from Brazilian mangroves, contributing to the synthesis and construction of knowledge on the subject. According to Rother (2007), publications that use a narrative review as a methodology seek to demonstrate a given subject's development or state of the art broadly, theoretically, or contextual.

These data were collected in mid-2019 in different databases, namely: 'CAPES Journals Portal,' 'Google Scholar'; 'SciELO'; 'Web of Science,' among others; Subsequently, the analysis of the title and a thorough reading of the abstracts were performed. The inclusion criteria used for the choice were publications that presented state of the art or fully addressed the topic, containing information on isolation, identification, pathogenicity, characterization, and applications of substances of these microorganisms. Keywords in Portuguese, English, and Spanish related to the topic were adopted, such as: 'Phylogeny,' 'Pathogenicity,' 'Sequencing,' 'Lasiodiplodia,' and 'Endophytic,' excluding articles that did not fall within the scope of this review.

3. Results and Discussion

3.1 History of microbial taxonomy in Brazil

Among the microbial classifications, the classical identification of filamentous fungi considers, mainly, the morphological characteristics of reproductive structures (sexual and asexual). Thus, to identify these structures, the isolates must be cultivated from pure colonies in appropriate culture media and colored with appropriate techniques for maintaining structures (Arx, 1974).

In many cases, the production of reproductive structures may not occur, thus changing the cultivation conditions. To induce sporulation, poor culture medium (water agar), increased culture illumination, and irradiation with reduced doses of ultraviolet light can be used. These actions can only be performed for arable species/isolates. In all cases, preparation for microscopic observation of the structures should be carried out. These should be compared with the standard literature, using identification keys (Barnett & Hunter, 1972).

Biochemical analyses can also be used. For fungi that do not sporulate in synthetic medium, molecular biology techniques should be employed. They are mainly based on sequencing of the spacing regions (ITS) of ribosomal DNA (rDNA) and comparison with a database (http://www.ncbi.nlm.nih.gov/BLAST/). All of this makes the development of a database for DNA sequences necessary for the classification of fungal species, especially for Brazil. This country has substantial biodiversity, which could generate a considerable amount of data to identify fungi.

Currently, there are collections and herbaria of fungi in Brazil, especially those of the ‘University of Brasília – UNB’, related to fungi isolated from Cerrado plants; of the ‘Federal University of Pernambuco - UFPE’ (perhaps the most complete in Brazil); (phytopathogens); of the Botanical Institute (Basidiomycetes) of ‘Embrapa Genetic Resources and Biotechnology – CENARGEN’; in Brasília (fungi used in the biological control of insects), of the ‘School of Agriculture Luiz de Queiroz – ESALQ’ in the ‘Department of Agroindustrial Technology’ (mainly yeasts) and Genetics (especially fungi of genetic interest and endophilic fungi), of the ‘Institute of Technological Research’ of the State of São Paulo (fungi of industrial interest).

An effort to gather all this data was carried out in the 1980s by Wanderley Perez Cantos and his group, organizing catalogs that gathered all the data on collections of cultures of microorganisms in Brazil, including (Canhos & Lange-Canhos, 1989). The classification work continues to be carried out based on morphological aspects, especially in UFPE. More recently, especially after programs financed, first by Research Support Foundation of the State of São Paulo - FAPESP and then by federal government agencies, aiming at the establishment of genomic sequencing techniques of different microbial species, several laboratories are employing molecular techniques in the taxonomy of fungi, as was the ‘Laboratory of Phytopathology’ of ‘Embrapa Agroindústria Tropical’, which, in partnership with UFPE, conducted a taxonomic study of endophytic fungi from Caatinga cearense (Gonçalves et al., 2016), four. Some of these studies can be portrayed in Figure 1.

Figure 1: Taxonomic investigation studies of endophytic fungi from the Caatinga cearense.

Article	Aspect analyzed	Reference
New species and new records of cercosporoid hyphomycetes from Brazil, New Zealand and Venezuela.	Identification of new fungal species	(Braun et al., 2010; Coutinho et al., 2016)
Diversity of genus Lasiodiplodia associated with perennial tropical fruit plants in northeastern Brazil.		
The microbiological diversity of caatinga cearense.	Characterization of regional species	(Freire & Gonçalves, 2012; Freire & Berndt, 2013)
An updated list of plant fungi from Ceará State (Brazil) II. Rusts.		
Endophytic fungi: a source of bioactive products of importance to humanity.	Discoveries of fungi producing metabolites potentially used by the pharmacological industry	(Freire et al., 2014)
Production of *Aspergillus flavus* aflatoxins in liquid medium.	Identification of compounds harmful to health	(Rocha et al., 2013, 2014; Vieira et al., 2007)
Determination of aflatoxins in cashew kernels by thin-layer chromatography.		
Mycotoxins and their effects on human and animal health.		
Phytophthora nicotianae occurrence in *Lilium speciosum* in Brazil.	Identification of pathogens in regional cultivars.	(Freire et al., 2002; Freire, 2012; Freire, 2014; Freire et al., 1996; Freire & Martins, 2010; Freire & Mosca, 2009; Martins et al., 2014)
Confirmation of the occurrence of bleeding from the coconut stem in the state of Ceará.		
Fungi associated with cashew inflorescences in Brazil.		
Microbiological deterioration of cashew almonds: a problem of difficult solution.		
Pathogens associated with ornamental plant diseases in the state of Ceará		
Diseases of cashew nut (*Anacardium occidentale* L.) plants in Brazil.		
Fungal deterioration of cashew almonds in northeastern Brazil.		
The ultrastructure of peeled and shelled cashew nuts.	Differentiation between species through chemotaxonomy, among others	(Muniz et al., 2013)
Occurrence of internal papaya rot in the state of Ceará.		(Santos et al., 2001)
Characterization of *aspergillus flavus of* Brazilian chestnuts and cashew by RAPD and analysis of ribosomal DNA.		(Midorikawa et al., 2008)
Evaluation of resistance in cashew snare snoot to gumsome in northeastern Brazil.		(Cardoso et al., 2006)
Diseases of cashew nut (*Anacardium occidentale* L.) plants in Brazil.		(Freire et al., 2002)
New species of *Phakopsora* (Basidiomycota, Uredinales) from Cameroon, South Africa, and Brazil.		(Berndt et al., 2007)
Some cercosporoid hyphomycetes from Brazil.		(Braun et al., 1999)

Source: Authors (2022).

In one of Freire and Gonçalves's, a great fungal diversity was identified, as well as species of the oomycota class associated with plants of caatinga cearense, where 332 specimens (320 fungi and 12 Oomycetes) were identified, with the appearance of 6 new species of fungi causing rust in plants, one species of coelomycete and 49 species of hyphomycetes (Freire & Gonçalves, 2012).

Knowledge of this diversity is essential not only for the knowledge and preservation of the environment but also as good sources of biotechnological products, as Freire et al. (2014), when reporting the possibilities of using metabolites from endophilic fungi, mainly as powerful drugs against human and plant pathogens. The authors report that many compounds with antimicrobial properties have been isolated from endophilic fungi of soil plants, mangroves, and fungi from marine animals and plants.

This study demonstrates the importance of microbiological diversity studies in underexplored biomes, confirming the need for measures that rapidly reduce the degradation of these biomes, such as the caatinga, a genuinely Brazilian biome, and mangroves, so exploited by real estate and industrial speculation.

Analyzing the set of 18S, 5,8S, and 25-28S genes of rDNA are widely used to evaluate phylogenetic relationships between fungi. The variable regions ITS1 and ITS2 are found among these genes and are transcribed and processed, giving rise to ribosomal RNA. These ITS regions evolve rapidly and are used to discriminate related species and varieties of the same species (Guarro et al., 1999; Larena et al., 1999).

ITS regions are used in the molecular identification of fungi for three main reasons: the gene grouping encoding rDNA is repeated hundreds of times, facilitating amplification; its fragments are short (600 to 800bp); these ITS regions present high variability discriminating fungal species, and even isolated from some species. Analyses of the 18S rDNA sequence are also used in taxonomic studies of fungi (Kuninaga et al., 1997; Lee & Taylor, 1992; Woese et al., 1990)

Various molecular techniques can be employed to assess the diversity of fungi, such as ARDRA (Amplified Ribomic DNA Restriction Analysis), ARISA (Automated Intergenic Intergenic Analysis), DGGE/TGGE (Denaturing/Temperature Gradient Gel Electrophoresis), Gene Cloning, SSCP (Single Wire Conformation Polymorphism), T-RFLP (Terminal Restriction Fragment Fragment Length Polymorphism) and RAPD (Random Amplified Polymorphic DNA) (Amann et al., 1995; Anderson & Cairney, 2004; Pang & Mitchell, 2005; Schloss & Handelsman, 2003).

3.2 Mangroves and their importance

Mangrove plants are among the most productive in the ocean. The leading representative in the tropical regions of the American continent is the red mangrove *(Rhizophora mangle* L.), while the black mangrove (*Avicennia germinans* (L.) L.) and the white mangrove (*Laguncularia racemosa* (L.) C.F. Gaertn.) are the most abundant in the estuaries of Mexico, west India, Barramas and Florida (Miles *et al*., 1998). These plants synthesize bioactive compounds used in the medical, agronomic, and cosmetic areas, such as minerals, organic acids, carbohydrates, hydrocarbons, benzoquinones, naphthofurans, sesquiterpenes, triterpenes, alkaloids, flavonoids, polymers, sulfur derivatives and tannins (Li et al., 2009; Miles et al., 1998; Sharaf et al., 2000; Wu et al., 2008).

Mangroves are located at the interface between land and sea, environments well adapted to the conditions of natural stresses such as temperature, salinity, anoxia, and ultraviolet radiation. However, this ecosystem has certain tolerance limits, being sensitive to the changes created by human activities (Walters et al., 2008). Its proximity to urban centers favors its exploitation. In addition, industrial effluents have contributed to the contamination of sediments with heavy metals. Many mangroves have also been contaminated with oils due to oil spills. These events have generated adverse effects in the same (Kathiresan & Bingham, 2001; Pena et al. 2020; Walters et al., 2008).

According to the Federative Constitution of Brazil of 1988 (Brasil, 1988), the protection of the environment is a constitutional right guaranteed in article 225, namely: "Everyone has the right to an ecologically balanced environment, a good common use of the people and essential to a healthy quality of life, imposing on the Public Power and the collective the duty to defend it and preserve it for present and future generations." Federal Law 12.651/2012, which establishes the ‘Brazilian Forest Code’, presents as permanent protection areas (Apps) the mangroves throughout its extension and the sandbank areas as dunes or stabilizers of the mangrove, promoting the preservation and conservation of this vital ecosystem (Albuquerque et al., 2015).

Maintaining mangroves is a challenge of economic importance for most tropical countries. In the last 50 years, approximately one-third of mangrove forests have been lost (Alongi, 2002). Mangroves worldwide have been destroyed mainly due to aquaculture, wood production, and urban development. This destruction generates significant losses of fish, birds, plants, and microorganisms, as mangroves are among the three most productive environments of the global ecosystem, alongside coral reefs and tropical forest (Al-sayed et al., 2005). Mangroves serve as refuge and shelter, favoring the creation and feeding of numerous marine species necessary for the economy and ecology. They are also the habitat of the main sanctuary of birds and many insects, some reptiles, a few mammals, and many invertebrates (Al-sayed et al., 2005; Holguin et al., 2006; Nagelkerken et al., 2008).

During the last three decades, mangroves have received enormous attention, reflecting an exponential increase in the number of publications (Gopal & Chauhan, 2006). However, knowledge about this ecosystem is still incipient. With the continuous degradation of this environment, it is imperative to evaluate the diversity and biotechnological potential of the microorganisms that inhabit it since these species can be extinct.

Among marine ecosystems, mangroves are the second most productive and rich ecosystem, being surpassed only by coral reefs (Sridhar, 2004). Mangrove plants are morphologically and physiologically adapted to this environment with high salinity, floods (tides), strong winds, high temperature, and anaerobic soil. Mangroves present organic matter from plants, which forms the basis of the food chain in tropical estuaries (Sarma et al., 2001).

3.3 Fungi present in mangroves and their genetic diversity

Several articles have been published on tropical mangrove marine fungi in the last two decades. However, these aspects have been little explored in the Brazilian mangroves (Cavalcante et al., 2009; Gilbert et al., 2008; Harvey & Goff, 2010; Kumaresan & Suryanarayanan, 2001; Tremblay et al., 2007). Marine fungi play an essential role in the nutrient regeneration cycle to deform dead organic matter. The study of the diversity of the marine fungal community, covering genetic diversity and species richness, is the first step towards dynamic modeling of the fungal community in terms of abundance and spatial and temporal distribution of species, and nutrient cycling. Such models are essential for the efficient management and conservation of marine, forest, and rural environments, which are economically significant (Pang & Mitchell, 2005).

Among the 900 marine fungi already identified, 358 belong to mangrove ecosystems (Maria & Sridhar, 2002). These fungi perform essential processes such as transforming polymeric compounds into dissolved organic matter, used by other consumers in the food chain (Hyde et al., 1998). In view of a few studies on endophilic fungi of Brazilian mangroves, the importance of assessing diversity in mangroves in the state of Ceará is emphasized in search of the determination of the genetic structure and identification of the species present.

3.4 Endophotic microorganisms

Endophytic microorganisms are bacteria or fungi that colonize the interior of plant tissues without presenting a pathogenic effect on the host (Owen & Hundley, 2004; Tan & Zou, 2001). Thus, there is a symbiotic association between the host plant, which protects and feeds it, and the endophytic microorganism, a producer of bioactive metabolites that aid the growth and protection of the plant against the attack of phytopathogens (Owen & Hundley, 2004; Tan & Zou, 2001; Zhang et al., 2006).

However, since the discovery of endophytic microorganisms in Darnel (Germany) in 1904, many researchers have differently defined the term (Hallmann et al., 1997; Petrini, 1991; Tan & Zou, 2001). A definition proposed by Azevedo and

Araújo (2006), considers an endophyte as anyone who may or may not grow in culture media, that is, arable or not, and who inhabits the interior of tissues and plant organs without causing damage to their host and without producing external structures emerging from vegetables. However, this definition excludes rhizobium and mycorrhizas. Thus, Mendes and Azevedo (2007) proposed the redefinition of this term, considering the previous definition proposed by Azevedo and Araújo (2006), adding the division of endophilic microorganisms into two types: Type I, those that do not produce structures external to the plant; and Type II, those that produce structures external to the plant.

Each of the 300,000 existing plant species is host to one or more endophytic microorganisms, but few have been thoroughly studied in relation to their endophytic biology. The ease of isolation of these microorganisms in a culture medium makes this group a promising source of biotechnological products. Consequently, the opportunity to discover new and exciting endophilic microorganisms of host plants from different ecosystems becomes excellent (Strobel et al., 2004).

Among all producers of natural bioactive compounds, microorganisms represent a rich source of biologically active metabolites that have a wide application, such as antibiotics, antiparasitics, antifungals, and antitumors, among many other compounds. It is estimated that only 1% of bacteria species and less than 7% of fungal species are known (Hawksworth, 2004; Gunatilaka, 2006), suggesting that millions of microbial species may provide essential biomolecules.

Historically, of all microorganisms studied, actinomycetes and fungi have been the largest producers of secondary metabolites. It is also suggested that fungi are fundamental to the health and prosperity of many terrestrial ecosystems, being essential for the sustainability and biodiversity of the same (Gunatilaka, 2006; Owen & Hundley, 2004; Sridhar, 2004). Fungi typically exert a mutualistic, antagonistic, or neutral association with a multitude of heterotrophic and autotrophic organisms. These relationships present varying degrees of association and healthy interdependence. Fungi that live outside their hosts are called epiphytes, while those that live entirely inside are called endophytes. Endophytic, in contrast to epiphytic, live entirely within the host plant and may have a parasitic or symbiotic association with the host (Sinclair & Cerkauskas, 1996).

In the simplest definition, endophytic refers to the site of the organism in relation to the plant, where 'endo' (inside) and 'phyte' (plant) describe all organisms that live within plants. However, the term has evolved not only to indicate the location of the organism in relation to the plant but also to describe the type of association of fungus or bacteria with its hosts.

The nature of the interaction described by the endophilic term shows that organisms are within the plant but do not cause symptoms of diseases; that is, infection is asymptomatic (Wilson, 1995).

It was proposed that there is an evolutionary change between parasites, mutualists, and/or saprophytes and that this evolutionary change is multidirectional. The fungus can evolve from mutualist to saprophyte and pathogen from pathogen to mutualist and saprophyte (Carroll, 1988; Rodriguez & Redman, 2008). The proposition is that the change from mutualism to parasitism may be due to some balanced antagonism or balance in host-endophilic interaction. If this balance is altered occurs, the development of the disease (Kogel et al., 2006).

It is essential to highlight that product of biotechnological value, such as antibiotics and other active ingredients, with numerous pharmacological properties, have been synthesized by endophytic fungi, making them an essential target in studies applied in the medical and agronomic areas. The 'taxol,' a potent antitumor agent synthesized by the endophilic fungus Taxomyces andreanae of the host plant Taxus brevifolia, has been studied for its production on an industrial scale (Yuan et al., 2006). Fungi have been a source of antibiotics widely used in clinical practice, such as penicillin produced by the fungus Penicillium notatum and 'cephalexin' synthesized by the fungus *Cefalosporium acremonium* (Owen & Hundley, 2004).

Endophytic fungi can contribute to the growth of the host plant directly or indirectly. The direct mode of promoting plant growth is related to the production of active compounds by endophytes, facilitating the host plant's absorption of nutrients and water (Zhang et al., 2006). Studies have suggested that endophytes alter water flow in plants by producing watersoluble chemical compounds such as alkaloids, which increase the osmotic flow in the roots of the host plant (Bacon, 1993; Owen & Hundley, 2004; Tan & Zou, 2001).

The indirect form of the endophyte to improve plant growth and development is made by protecting against the attack of pests and pathogens (Azevedo & Araújo, 2006). Endophytes can protect plants by producing compounds such as alkaloids and terpenes, which have an insect-repelling effect and make the plant less susceptible to insect attack. Another mechanism found in the literature is the natural control of insects through the production of cytotoxic metabolites by entomopathogenic fungi (Redman et al., 2001; Schulz & Boyle, 2005; Stone et al., 2004).

Various classes of secondary metabolites such as alkaloids, pyrrolizidines, steroids, terpenoids, sesquiterpenes, isocoumarins, quinones, flavonoids, phenylpropanoids, polyketides, lactone, among others, are produced by endophytic fungi, which makes them a promising source for studies exploring the biotechnological potential of products applied in clinical practice (Zhang et al., 2006).

4. Conclusion

Endophytic fungi, found in plants extracted from Brazilian mangroves, have taxonomic, ecological, and environmental importance, and their preservation has been continuously threatened through the exploration and anthropic activities in this ecosystem.

Research that seeks to identify, characterize and isolate these microorganisms through different molecular biology techniques, as well as the analysis of their interaction with different living organisms, are relevant since they allow the investigation of the compounds and secondary metabolites produced by them, capable of being used in a range of biotechnological applications, such as the production of substances against human pathogens of plants and/or animals; the production of compounds with biological activity (antibiotics, antiparasitic, antifungals, antitumor, insecticides, among others).

Future research should emphasize the interaction between endophytes as controlling agents of numerous plant pathogens (assisting in research dealing with biological control); promoting plant growth and development; isolation of enzymes, and phytoremediation of plants in polluted areas.

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