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Entomopathogenic Fungi in the Brazilian Amazon: Occurrence and Prospection

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Abstract

Entomopathogenic fungi are often used to control insects, allowing to reduce the use of pesticides. In this scenario, to obtain adequate isolates for formulation of effective products has been the objective of various scientific studies. The Brazilian Amazon is a promising source for the prospection of fungi for this purpose on account of its huge biodiversity. This study aimed to describe the occurrence and bioprospection of entomopathogenic fungi in the Amazon region in Brazil. Thus, the occurrence and bioprospection of entomopathogenic fungi in nine states that comprise the Brazilian Amazon region were identified. Genera of entomopathogenic fungi native to this region were accessed on the Information System for Collections of Biotechnological Interest (SIColNet) using as search terms the genera Acremonium, Aegerita, Akanthomyces, Aschersonia, Ascosphaera, Aspergillus, Atricordyceps, Beauveria, Calonectria, Coelomomyces, Coelomycidium, Conidiobolus, Cordycepioideus, Cordyceps, Couchia, Culicinomyces, Engyodontium, Entomophaga, Entomopththora, Erynia, Funicularis, Fusarium, Gibellula, Hirsutella, Hymenostilbe, Hypocrella, Lagenidium, Leptolegnia, Massospora, Meristacrum, Metarhizium, Myiophagus, Myriangium, Nectria, Neozygites, Nomuraea, Paecilomyces, Paraisaria, Pleurodesmospora, Podonectria, Polycephalomyces, Pseudogibellula, Sorosporella, Sporodiniella, Sporothrix, Stilbella, Tetracrium, Tetranacrium, Tilachlidium, Tolypocladium, Torrubiella, Verticillium combined with the name and abbreviation of each state of the Brazilian Amazon. The prospection studies with isolates from this region were identified from 1995 to 2020 by electronic search on Google Scholar, Portal Embrapa Portal, ScienceDirect, CAPES/MEC Publications Portal and PubMed, using the terms biological control, entomopathogenic fungi, Metarhizium, Beauveria and Paecilomyces, also combined with the

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name and abbreviation of each state of the region. Based on the data of collections of microorganism cultures, 379 isolates were recorded and grouped into 12 genera that contain entomopathogens. The most prevalent genera found are Aspergillus (159), Fusarium (84), Metarhizium (59), Paecilomyces (36) and Beauveria (26), and the regions with the greatest number of records were Amazonas (119), Maranhão (94) and Mato Grosso (66). The fungi Beauveria (43) and Metarhizium (28) were predominant among the 87 native entomopathogenic fungi prospected. The greatest number of prospected isolates of Beauveria were investigated for the control of Rhyzopertha dominica (7), Sitophilus oryzae (7) and Sitophilus zeamais (7), while the greatest number of Metarhizium was tested for the control of Diatraea saccharalis (7), Spodoptera cosmioides (7) and Rhipicephalus microplus (6). Other isolates from the region, such as Paecilomyces (9), Fusarium (2) and Isaria (2), also demonstrated potential for insect control. In addition, entomopathogens of the genus Ophiocordyceps were also found parasitizing insects from this region and should be assessed in prospection studies. Thus, the Brazilian Amazon is a rich and promising source of entomopathogenic fungi that should be considered for improvement of insect control.

Key Words: Brazilian Amazon, Microbial Control of Insects; *Beauveria*; *Metarhizium*.

1. INTRODUCTION

Brazil is one of the top global consumerist countries of pesticides (PIGNATI et al., 2017). A continuous and indiscriminate use of these compounds may pose severe risks to human health, produce deposits of toxic wastes in the soil, reduce biodiversity with loss of environmentally-beneficial species and select resistant populations of pest insects (DEREUMEAUX et al., 2020). In this context, several countries have set policies to limit the use of these products (BRODEUR et al., 2018; MESSING; BRODEUR, 2018), encouraging the development and adoption of containment actions such as biological control (SINGH et al., 2019).

Of the diverse techniques used in biological control, the natural augmentation alternative of control is one of the most commercially used method. This strategy basically consists of mass production and large scale release of natural enemies to control specific pests (CHANDLER et al., 2011; LACEY et al., 2015). The main natural enemies used for this purpose are microbial agents, including bacteria, viruses and entomopathogenic fungi (VAN LENTEREN et al., 2018).

The first practical methods for microbial control of insects were developed in 1880, firstly with fungi of the genus *Metarhizium* to control insects in cereal grains (ROBERTS; LEGER, 2004). Entomopathogenic fungi stand out from other agents used for biological control, with more than 100 genera and about 750 species documented (SAMSON et al., 2013). These microorganisms can overcome the insects' physical and chemical defense barriers by triggering an infective process that ultimately reduces the pest populations in the environment (BUTT et al., 2016).

Insect infection by entomopathogenic fungi takes place through a complex process that includes the invasion of the host tissue, development from nutrient intake, toxin production and dispersal in the environment after sporulation from the cadaver (Figure 1). So, the mechanism that makes infection effective consists of the spore adhesion, its interaction with the host cuticle, resulting in the death of susceptible arthropods (SUJEETHA; SAHAYARAJ, 2014; LACEY et al., 2015).

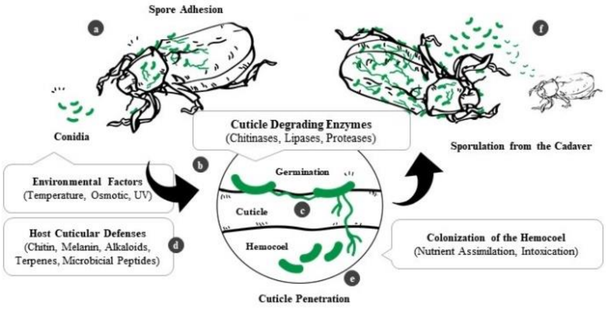

Figure 1. Mechanism of entomopathogenic fungus infection. a. contact and adhesion to the host's cuticle; b. differentiation of infection structures; c. cuticle penetration; d. ability to overcome host defenses; e. hemocoel colonization; f. sporulation in the corpse.

This cuticular invasion depends on physical and enzymatic degradation mechanisms (FERNANDES et al., 2012; GOLO et al., 2015; RAMIREZ et al., 2018). Appressoria are penetration-specialized structures that constitute the main physical mechanism for disrupting the host cuticle (MOMANY; TALBOT, 2017) and are formed by entomopathogens such as *Metarhizium* sp. (LOVETT; LEGER, 2015; LI et al., 2018; WANG et al., 2019). In addition, extracellular enzymes such as chitinases, lipases and proteases are vital for the efficacy of the invasion process (COUTINHO-RODRIGUES et al., 2016; MONDAL et al., 2016).

In addition to cuticle invasion, the entomopathogenic fungi can also cause infection of insects orally, although rarely reported (MANNINO et al., 2019). These mechanisms of infection also vary according to environmental conditions, mainly those related to temperature changes and UV radiation (MISHRA et al., 2015). These factors together affect the effectiveness of entomopathogens as agents for control of insects. Thus, it is fundamental to evaluate and select fungi of different origins with appropriate characteristics (BRODEUR et al., 2018).

Formulating biopesticides based on microorganisms with these characteristics has been a strategy frequently utilized. In Brazil, there are about 82 biopesticides registered, of which 60% are made with fungi, especially the entomopathogens *Metarhizium anisopliae* and *Beauveria bassiana* (MASCARIN et al., 2019). Examples of these products are Granada® and Boveril WP®, both formulated with *B. bassiana*, and Metarril WP® with *M. anisopliae*, which are indicated for the control of *Mahanarva fimbriolata*, which affects sugarcane yields, and *Bemisia tabaci*, known as whitefly, which causes losses to many cultures, such as common bean and soybean (MASCARIN et al., 2019).

Although promising, growth of this market has some challenges, such as the development of new production strategies, effective enforcement of regulations and laws, selection of isolates resistant to variable environmental conditions and the need for strains with high virulence to specific pests (MASCARIN et al., 2019). According to this logic, identification of new agents is an important step for the improvement of this technique (HOLLAND et al., 2016; VAN LENTEREN et al., 2018).

With about 20% of world's biodiversity, we emphasize the importance of the Brazilian Amazon as a biome suitable for the prospection and identification of new entomopathogenic fungi with desirable characteristics for an effective control of insects. (PYLRO et al., 2014). In this context, studies with entomopathogens from this region have documented promising results in recent years for the control of insects (CHRISTIAN LUZ et al., 2019; BARROS et al., 2020; OLIVEIRA et al., 2020).

So, this study aimed to describe the occurrence and bioprospection of entomopathogenic fungi in the Brazilian Amazon rainforest.

2. METHODS

2.1. Search strategy

The occurrence of entomopathogenic genera native to the Brazilian Amazon region stored in collections of microorganisms was identified through electronic research in the Sistema de Informação de Coleções de Interesse Biotecnológico (SIColNet) available on the network speciesLink (http://sicol.splink.org.br) on June 5, 2021. In this platform, the following fungal genera that contain entomopathogens were used as search terms: *Acremonium*, *Aegerita*, *Akanthomyces*, *Aschersonia*, *Ascosphaera*, *Aspergillus*, *Atricordyceps*, *Beauveria*, *Calonectria*, *Coelomomyces*, *Coelomycidium*, *Conidiobolus*, *Cordycepioideus*, *Cordyceps*, *Couchia*, *Culicinomyces*, *Engyodontium*, *Entomophaga*, *Entomopththora*, *Erynia*, *Funicularis*, *Fusarium*, *Gibellula*, *Hirsutella*, *Hymenostilbe*, *Hypocrella*, *Lagenidium*, *Leptolegnia*, *Massospora*, *Meristacrum*, *Metarhizium*, *Myiophagus*, *Myriangium*, *Nectria*, *Neozygites*, *Nomuraea*, *Paecilomyces*, *Paraisaria*, *Pleurodesmospora*, *Podonectria*, *Polycephalomyces*, *Pseudogibellula*, *Sorosporella*, *Sporodiniella*, *Sporothrix*, *Stilbella*, *Tetracrium*, *Tetranacrium*, *Tilachlidium*, *Tolypocladium*, *Torrubiella*, *Verticillium* (SAMSON et al., 2013). Combined with these terms, the name and acronym of each state that makes up the Brazilian Amazon were used: Acre (AC), Amapá (AP), Amazonas (AM), Maranhão (MA), Mato Grosso (MT), Pará (PA), Rondônia (RO), Roraima (RR) and Tocantins (TO). Information on the prospecting of isolates was obtained from theses and scientific articles published from 1995 to 2020. In this study, the terms were used biological control, entomopathogenic fungi, *Metarhizium*, *Beauveria* and *Paecilomyces* combined with the name and acronym of each state in the Brazilian Amazon: Acre (AC), Amapá (AP), Amazonas (AM), Maranhão (MA), Mato Grosso (MT), Pará (PA), Rondônia (RO), Roraima (RR) and Tocantins (TO), in Google Scholar, Portal Embrapa, ScienceDirect, Portal Periódicos CAPES/MEC and PubMed. Articles outside the selected research area and duplicates were disregarded.

3. RESULTS AND DISCUSSION

3.1. Occurrence and prospection of entomopathogenic fungi

The Amazon Region has distinct characteristics of vegetation, climate, chemical and biological composition that contribute to species biodiversity, housing approximately 20% of the world's biodiversity, standing out as an opportune source for the characterization and obtaining of entomopathogenic fungi (PYLRO et al. , 2014). Regarding the richness of fungal species, this region is the second largest source of records, with about 1,050 species identified, with potential for the identification of new species (MAIA et al., 2015).

The information available on the Sistema de Informação de Coleções de Interesse Biotecnológico (SIColNet) on the collections of microorganism cultures report the occurrence of 379 records of fungi grouped into 12 genera that contain entomopathogens in the nine states of the Amazon region of Brazil (Figure 2). Among these genera, the following stand out as the most frequent: *Aspergillus* (159), *Fusarium* (84), *Metarhizium* (59), *Paecilomyces* (36) and *Beauveria* (26), while among the regions with the highest number of records stands out Amazonas (119), Maranhão (94) and Mato Grosso (66) (Figure 2).

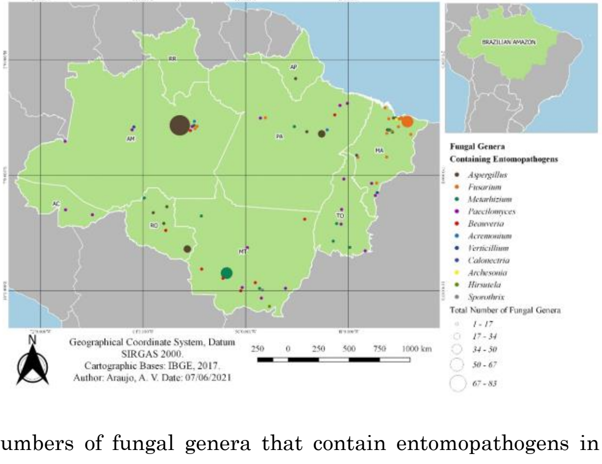

Figure 2. Numbers of fungal genera that contain entomopathogens in collections of microorganisms available in the states of the Brazilian Amazon. AC= Acre, AM= Amazonas, AP= Amapá, MA= Maranhão, MT= Mato Grosso, PA= Pará, RO= Rondônia, RR= Roraima and TO= Tocantins.

Source: Collection of Cultures of Microorganisms of the Department of Food Science/UFLA (CCDCA), Collection of Entomopathogenic Fungi Oldemar Cardim Abreu (CFEOCA), Collection of Entomopathogenic Fungi of the Laboratory of Agricultural Biotechnology (CFEUnioeste), Collection of Cultures of Entomopathogenic Fungi (CG), Microbiological Collections of the Paraná Network – Taxonline (CMRP), Filamentous Fungi Culture Collection (Fiocruz-CCFF), Amazon Fungi Collection (Fiocruz-CFAM), Micoteca "Prof. Gilson Soares da Silva" (MGSS), URM Micoteca (URM-Micoteca) available on the speciesLink network (http://sicol.splink.org.br) on June 5th, 2021 at 18:20.

The topography of the Amazon Region contributes to the maintenance of climatic conditions with areas with high humidity that can favor the sporulation and transmission of entomopathogens between their hosts, ensuring the prevalence of these microorganisms in the environment (CARDOSO NETO et al., 2019). Thus, the climatic and geomorphological varieties of this region can directly interfere in the taxonomic composition of entomopathogens, providing an opportunity for the discovery and bioprospecting of new agents for pest control (CERQUEIRA et al., 2018).

Although there are more than 750 species of entomopathogenic fungi described, defining opportunistic genera is still a challenge, requiring careful laboratory testing to ensure the pathogenic status of these fungi (SAMSON et al., 2013). In this sense, publications that assess the potential of fungi native to the Amazon Region have registered promising results for the control of insects (Table 1).

Table 1. Prospection for entomopathogenic fungi in the Brazilian Amazon.

Evaluated isolates	Identification	Target Arthropod	Mortality (%)	Concentrations	Home State	Source Substrate	Author
ESALQ 484	*Beauveria bassiana*	*Sitophilus oryzae*	100	1×10^{9} conidia mL^{-1}	MT	*Solenopsis invicta*	1
ESALQ 572	*B. bassiana*	*Sitophilus zeamais*	100	1×10^{9} conidia mL^{-1}	MT	*Solenopsis* sp.	1
ESALQ 604	*B. bassiana*	*S. zeamais*	100	1×10^{9} conidia mL^{-1}	MT	Solo	1
ESALQ 484	*B. bassiana*	*Rhyzopertha dominica*	100	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	1
ESALQ 529	*B. bassiana*	*R. dominica*	100	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	1
ESALQ 532	*B. bassiana*	*R. dominica*	100	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	1
ESALQ 548	*B. bassiana*	*R. dominica*	100	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	1
ESALQ 604	*B. bassiana*	*R. dominica*	100	1×10^{9} conidia mL^{-1}	MT	Solo	1
CG 1061	*B. bassiana*	*Cosmopolites sordidus*	100	2×10^{8} conidia mL^{-1}	RO	-	2
CG 425	*B. bassiana*	*Rhammatocerus schistocercoides*	100	5000 conidia/ insects	MT	*R. schistocercoides*	3
ESALQ 447	*Beauveria* sp.	*Diatraea saccharalis*	100	1×10^{8} conidia mL^{-1}	MT	*S. invicta*	4
B 46	*Beauveria* sp.	*D. saccharalis*	100	1×10^{8} conidia mL^{-1}	MT	Solo	4
B 47	*Beauveria* sp.	*D. saccharalis*	100	1×10^{8} conidia mL^{-1}	MT	Solo	4
B 48	*Beauveria* sp.	*D. saccharalis*	100	1×10^{8} conidia mL^{-1}	MT	Solo	4
ESALQ 532	*B. bassiana*	*S. oryzae*	96.7	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	1
ESALQ 573	*B. bassiana*	*S. zeamais*	96.7	1×10^{9} conidia mL^{-1}	MT	*Solenopsis* sp.	1
ESALQ 572	*B. bassiana*	*R. dominica*	96.7	1×10^{9} conidia mL^{-1}	MT	*Solenopsis* sp.	1
CG 1067	*B. bassiana*	*C. sordidus*	95	2×10^{8} conidia mL^{-1}	RO	-	2
ESALQ 529	*B. bassiana*	*S. oryzae*	93.3	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	1
ESALQ 548	*B. bassiana*	*S. oryzae*	93.3	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	1
ESALQ 573	*B. bassiana*	*S. oryzae*	93.3	1×10^{9} conidia mL^{-1}	MT	*Solenopsis* sp.	1
ESALQ 573	*B. bassiana*	*R. dominica*	93.3	1×10^{9} conidia mL^{-1}	MT	*Solenopsis* sp.	1
CG 1059	*B. bassiana*	*C. sordidus*	90	2×10^{8} conidia mL^{-1}	RO	-	2
ESALQ 548	*B. bassiana*	*S. zeamais*	86.7	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	1
CG 1229	*Beauveria* sp.	*Bemisia tabaci*	85	1×10^{7} conidia mL^{-1}	MA	*Rupela albinella*	5
ESALQ 1288	*B. bassiana*	*Helicoverpa armigera*	84	1×10^{8} conidia mL^{-1}	MT	*R. palmarum*	6
UNIOESTE 57	*B. bassiana*	*Dermanyssus gallinae*	78.1	1×10^{8} conidia mL^{-1}	MT	Pentatomidae	7
ESALQ 532	*B. bassiana*	*S. zeamais*	76.7	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	1
ESALQ 572	*B. bassiana*	*S. oryzae*	76.6	1×10^{9} conidia mL^{-1}	MT	*Solenopsis* sp.	1
ESALQ 529	*B. bassiana*	*S. zeamais*	60	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	1
ESALQ 447	*B. bassiana*	*B. tabaci*	58	1×10^{7} conidia mL^{-1}	MT	*S. invicta*	8
ESALQ 484	*B. bassiana*	*S. zeamais*	56.7	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	1
ESALQ 908	*B. bassiana*	*B. tabaci*	56	1×10^{7} conidia mL^{-1}	MT	*Solenopsis* sp.	8
CG 451	*B. bassiana*	*C. sordidus*	53.30	1×10^{9} conidia mL^{-1}	MT	*S. invicta*	9
ESALQ 480	*B. bassiana*	*H. armigera*	48	1×10^{8} conidia mL^{-1}	MT	*S. invicta*	6
AM 09	*Beauveria* sp.	*Atta sexdens*	45	1×10^{8}; 1×10^{9} conidia mL^{-1}	AM	*D. incompleta*	10

UNIOESTE 47	*B. bassiana*	*D. gallinae*	34	1×10^{8} conidia mL^{-1}	MT	Pentatomidae	7
ESALQ 604	*B. bassiana*	*S. oryzae*	33.3	1×10^{9} conidia mL^{-1}	MT	Solo	1
CG 1066	*B. bassiana*	*C. sordidus*	33	2×10^{8} conidia mL^{-1}	RO	-	2
ESALQ 1197	*B. bassiana*	*B. tabaci*	26	1×10^{7} conidia mL^{-1}	MT	Solo	8
ARSEF 2402	*B. bassiana*	*Myzus persicae.*	5.1	947 conidia/ mm^{2}	MT	*S. invicta*	11
ARSEF 2402	*B. bassiana*	*Aphis gossypii*	3	947 conidia/ mm^{2}	MT	*S. invicta*	11
ESALQ 1195	*B. bassiana*	*B. tabaci*	2	1×10^{7} conidia mL^{-1}	MT	Solo	8
Ma 283	*Metarhizium anisopliae*	*D. saccharalis*	100	1×10^{8} conidia mL^{-1}	MT	Solo	4
CG 835	*M. anisopliae*	*D. saccharalis*	100	1×10^{8} conidia mL^{-1}	MT	*Scaptocoris castanea*	4
CG 59	*M. anisopliae*	*D. saccharalis*	100	1×10^{8} conidia mL^{-1}	MT	*Deois flavopicta*	4
CG 581	*M. anisopliae*	*D. saccharalis*	100	1×10^{8} conidia mL^{-1}	TO	*D. flavopicta*	4
CG 29	*M. anisopliae*	*D. saccharalis*	100	1×10^{8} conidia mL^{-1}	AM	*D. flavopcta*	4
UFMS 03	*M. rileyi*	*Spodoptera cosmioides*	96	1×10^{9} conidia mL^{-1}	MT	*R. palmarum*	12
UFMG 11444	*Metarhizium* sp.	*Mahanarva spectabilis*	90	1×10^{4} conidia mL^{-1}	MA	*M. spectabilis*	13
UFMS 07	*M. rileyi*	*S. cosmioides*	88	1×10^{9} conidia mL^{-1}	MT	*R. palmarum*	12
UFMS 06	*M. rileyi*	*S. cosmioides*	86	1×10^{9} conidia mL^{-1}	MT	*R. palmarum*	12
LPP 133	*M. anisopliae*	*Aedes aegypti*	85	1×10^{8}; 1×10^{9} conidia mL^{-1}	RO	Solo	14
LPP 45	*M. anisopliae*	*A. aegypti*	83	1×10^{8}; 1×10^{9} conidia mL^{-1}	RO	Solo	14
CG 148	*M. anisopliae*	*Rhipicephalus microplus*	83	1×10^{8} conidia mL^{-1}	MT	*Deois* sp.	15
UFMS 04	*M. rileyi*	*S. cosmioides*	82	1×10^{9} conidia mL^{-1}	MT	*R. palmarum*	12
UFMS 05	*M. rileyi*	*S. cosmioides*	80	1×10^{9} conidia mL^{-1}	MT	*R. palmarum*	12
UFMS 02	*M. rileyi*	*S. cosmioides*	78	1×10^{9} conidia mL^{-1}	MT	*R. palmarum*	12
MT	*M. anisopliae*	*D. saccharalis*	77	1×107 conidia mL-1	MT	*Deois* sp.	16
AF5D9B3	*M. rileyi*	*S. frugiperda*	74.5	1×10^{7} conidia mL^{-1}	MT	*C. includens*	17
UFMS 08	*M. rileyi*	*S. cosmioides*	62	1×10^{9} conidia mL^{-1}	MT	*R. palmarum*	12
AF5D9B3	*M. rileyi*	*Chrysodeixis includens*	58	1×10^{7} conidia mL^{-1}	MT	*C. includens*	17
CG 1313	*M. anisopliae*	*Bactrocera carambolae*	54	1×10^{8} conidia mL^{-1}	AP	Solo	18
MT	*M. anisopliae*	*R. microplus*	35	1×10^{8} conidia mL^{-1}	MT	*Deois* sp.	19
CRM 530	*M. anisopliae*	*A. sexdens*	30	1×10^{7} conidia mL^{-1}	TO	*A. sexdens*	20
CG 1314	*M. robertsii*	*B. carambolae*	30	1×10^{8} conidia mL^{-1}	AP	Solo	18
CG 34	*M. anisopliae*	*Callosobruchus maculatus*	26.7	$2{,}9\times10^{8}$ conidia mL^{-1}	AM	*Conotrachelus* sp.	21
CG 579	*M. anisopliae*	*R. microplus*	10.9	1×10^{5}; 1×10^{8} conidia mL^{-1}	TO	*Zulia entreriana*	22
CG 578	*M. anisopliae*	*R. microplus*	4.4	1×10^{5}; 1×10^{8} conidia mL^{-1}	TO	*Z. entreriana*	22
CG 580	*M. anisopliae*	*R. microplus*	2.3	1×10^{5}; 1×10^{8} conidia mL^{-1}	TO	*Z. entreriana*	22
CG 37	*M. anisopliae*	*R. microplus*	2	1×10^{5}; 1×10^{8} conidia mL^{-1}	TO	Solo	22
MGSS 136	*Paecilomyces lilacinum*	*Aleurocanthus woglumi*	100	1×10^{7} conidia mL^{-1}	MA	*A. woglumi*	23
ESALQ 832	*P. lilacinus*	*Meloidogyne paranaenses*	99	10^{9} conidia g^{-1} de arroz	MT	*S. invicta*	24
CG 402	*P. lilacinus*	*M. paranaenses*	94	10^{9} conidia g^{-1} de arroz	PA	Solo	24
CG 184	*P. lilacinus*	*M. paranaensis*	88	10^{9} conidia g^{-1} de arroz	MT	Solo	24
CG 266	*P. lilacinus*	*M. paranaenses*	85	10^{9} conidia g^{-1} de arroz	MT	Solo	24
CG 175	*P. lilacinus*	*M. paranaenses*	77	10^{9} conidia g^{-1} de arroz	PA	*Meloidogyne* sp.	24
ESALQ 623	*P. fumosoroseus*	*B. tabaci*	40	1×10^{7} conidia mL^{-1}	MT	Solo	8
4.145	*Paecilomyces* sp.	*R. microplus*	35.5	1×10^{7} conidia mL^{-1}	AC	Solo	25
MGSS 61	*Fusarium proliferatum*	*A. woglumi*	97	1×10^{7} conidia mL^{-1}	MA	*A. woglumi*	23
UFMG 11443	*Fusarium* sp.	*M. spectabilis*	90	1×10^{4} conidia mL^{-1}	MA	*M. spectabilis*	13
CG 1228	*Isaria fumosorosea*	*B. tabaci*	95	1×10^{7} conidia mL^{-1}	MA	*R. albinella*	5
IBCB 367	*Isaria* sp.	*Thaumastocoris peregrinus*	87	1×10^{8} conidia mL^{-1}	MT	Solo	26
-	*Aschersonia* sp.	*A. woglumi*	17	$2{,}3\times10^{4}$ - $\times10^{8}$ conidia mL^{-1}	AM	*A. woglumi*	27

AC= Acre, AM= Amazonas, AP= Amapá, MA= Maranhão, MT= Mato Grosso, PA= Pará, RO= Rondônia, RR= Roraima e TO= Tocantins.

1. MOINO JUNIOR et al., 1998. **2.** COSTA et al., 2010. **3.** MAGALHÃES et al., 2000. **4.** BOVI, 2012. **5.** MASCARIN et al., 2013. **6.** SOUZA, 2020. **7.** OLIVEIRA et al., 2020. **8.** RAMOS, 2001**. 9.** LOPES et al., 2011. **10.** LOUREIRO; MONTEIRO, 2004. **11.** JANDRICIC et al., 2014. **12.** LOUREIRO et al., 2020. **13.** CAMPAGNANI et al., 2017. **14.** PAULA, 2007. **15.** PERINOTTO, 2013. **16.** SCHNEIDER et al., 2013. **17.** BARROS et al., 2020. **18.** SILVA et al., 2016. **19.** FRAZZON et al., 2000. **20.** DORNELAS et al., 2017. **21.** MURAD et al., 2006. **22.** QUINELATO et al., 2012. **23.** MEDEIROS et al., 2018. **24.** SANTIAGO et al., 2006. **25.** ARAÚJO, 2017. **26.** LORENCETTI et al., 2018. **27.** PENA, 2007.

The entomopathogens *Beauveria* and *Metarhizium* are present in about 80% of commercially available products for microbial pest control (MASCARIN et al., 2019). These fungi have essential characteristics to be used for this purpose, such as mass growth for release into the environment, compatibility with other products to be implemented in an integrated way and the ability to infect different pest arthropods (BUTT et al., 2016). Therefore, among the native isolates from the Amazon region prospected in theses and articles (84) there was a preponderance of *Beauveria* sp. (43) and *Metarhizium* sp. (28) (Figure 3).

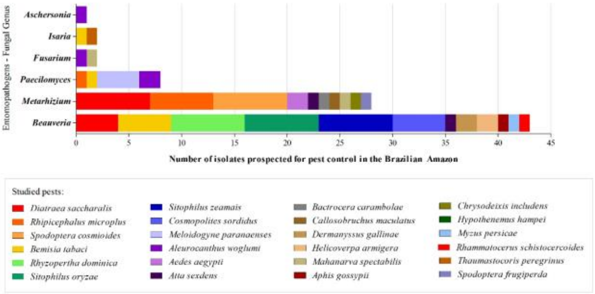

Figure 3. Number of entomopathogenic isolates prospected in the Amazon of Brazil published in theses and scientific articles.

Regarding the genus *Beauveria*, the largest number of isolates prospected were for the control of grain pests *Rhyzopertha dominica* (7), *Sitophilus oryzae* (7) and *Sitophilus zeamais* (7) (Figure 3). Other isolates of this genus were also promising for the control of the whitefly *Bemisia tabaci* (5) and the *Cosmopolites sordidus* borer (5). As for the genus *Metarhizium*, there was a greater record of isolates evaluated for the control of the sugarcane borer *Diatraea saccharalis* (7) and the carthusian caterpillar *Spodoptera cosmioides* (7), followed by the bovine tick *Rhipicephalus microplus* (6). The largest number of isolates of *Paecilomyces* sp. tested was for the control of root-knot nematodes *Meloidogyne paranaenses* (5) and blackfly *Aleurocanthus woglumi* (2) (Figure 3).

In addition, other species from the Amazon are also pathogenic and should be considered for prospective studies. Species of the entomopathogen *Ophiocordyceps* sp. are identified in this region as parasitizing insects, mainly ants (IMIRZIAN et al., 2020). Other studies have also been prospecting different isolates from the region, such as *Fusarium* sp. for the control of *A. woglumi* (MEDEIROS, 2016), such as *Isaria fumosorosea* for the control of *B. tabaci* (LOURENÇÃO et al., 2001; MASCARIN et al., 2013).

3.2. *Beauveria bassiana*

The entomopathogens of the genus *Beauveria* sp. are cosmopolitan and parasitize more than 700 insect species, and are widely used to control pests (IMOULAN et al., 2017). About 13 biopesticides are made with these microorganisms in Brazil, and are mainly used in the control of whitefly, *Bemisia tabaci*, coffee berry borer, *Hypothenemus* *hampei,* and banana root borer, *Cosmopolites sordidus* (MASCARIN et al., 2019).

Under this perspective, studies have examined the occurrence of these fungi in different regions of the Brazilian Amazon. Entomopathogens of the genus were isolated in wasps in the state of Amazonas (FERNANDES et al., 2008) and in *Simulium goeldii* insects (FONSECA et al., 2008), while in the state of Mato Grosso they were found in soils (BOVI, 2012) and as natural enemies of the insects *Chalcodermus*, *Diabrotica paranoense* (COATES et al., 2002) and *Solenopsis invicta* (BOVI, 2012). *Beauveria* sp. was also identified in the state of Pará, parasitizing the insect *Lymantria dispar,* known as gypsy moth (COATES et al., 2002).

The coffee borer, *H. hampei*, above cited, is an important pest that affects coffee plantations in different regions of the Brazilian Amazon (CURE et al., 2020). In search of natural enemies for the control of this pest, investigations reported the parasitism by *Beauveria* sp. in specimens collected in the state of Rondônia (COSTA et al., 2002; GAMA et al., 2005; GAMA, 2006). Also in this state, a reduction of the borer was observed in coffee fruits onto which a conidial suspension of *B. bassiana* isolated from the region was sprayed (COSTA, 2006).

Other investigation with prospected isolates of *B. bassiana*, also in the state of Rondônia, determined a 30-100% mortality rate of the banana rhizome borer, *Cosmopolites sordidus*a (COSTA et al., 2010). This pest was also susceptible to infection by an isolate of red imported fire ant, *Solenopsis invicta*, in the state of Mato Grosso, causing 46.7 to 53.3% death of the population tested (LOPES et al., 2011).

These entomopathogens from the Brazil Amazon also have potential to control pests in stored cereal grains. Strains of *B. bassiana*, isolated from ants of the genus *Solenopsis* sp. from soils in Mato Grosso, were tested against *Sitophilus oryzae; Sitophilus zeamais; Rhyzopertha dominica*, important grain insects (MOINO JUNIOR et al., 1998). The isolate 604 obtained from the soil, exhibited one of the most effective results, with a death rate of 86% for *S. oryzae*, 98% for *S. zeamais* and 98% for *Rhyzopertha dominica* (MOINO JUNIOR et al., 1998).

Other pest that affects seriously pastures and crops is the grasshopper, *Rhammatocerus schistocercoides*. Against this insect, the isolate *B. bassiana* (CG 425), native to Mato Grosso, caused 100% reduction in the population when tested in laboratory (MAGALHÃES et al., 2000). Two isolates from *B. bassiana*, from this same region, were assessed against mites of the species *Dermanyssus gallinaei*, one of the major hematophagous parasites of laying-egg chickens. These two isolates were pathogenic and caused death of 34 to 78.1% of the population (OLIVEIRA et al., 2020).

An experiment carried out with *B. bassiana* isolated from soils and *Solenopsis* insects, also in the state of Mato Grosso, had pathogenic effect against the pest known as whitefly, *Bemisia tabaci* biotype B (RAMOS, 2001). This pest was also controlled by *B. bassiana* (CG 1229)*,* originally isolated from *Rupela albinella* from the state of Tocantins, with a >77% lethal rate of nymphs and >50% of adults, when used at the concentration of 1 x 10^7conidia mL^{-1} (MASCARIN et al., 2013).

Other experiment with isolates from this region identified a mortality rate over 80% in *Helicoverpa armigera* bollworms when treated with a strain of *Beauveria bassiana* (ESALQ 1288), primarily isolated from *Rhynchophorus palmarum* (SOUZA, 2020). The entomopathogen *Metarhizium* (B48) from soils in the state of Mato Grosso was virulent to *D. saccharalis* pupae, causing 100% death (BOVI, 2012).

In the state of Amazonas, an isolate named *B. bassiana* (AM 09) obtained from *D. incompleta*, a spittlebug (froghopper), when tested against *Atta sexdens* workers caused a confirmed mortality of 66.7 and 62.5% after treatment with 1×10^8 and 1×10^9 mL^{-1} conidia concentrations, respectively (LOUREIRO; MONTEIRO, 2004). This entomopathogen exhibited a higher tolerance to insecticides, herbicides and ripeners compared with other fungi of this genus found in the state of São Paulo (FREGONESI et al., 2016).

The diversity of climate conditions in this region offers opportunities for the selection of entomopathogens resistant to stress conditions such as radiation and temperature. In this respect, fungi of the genus *Beauveria bassiana* isolated from insects of the families Chrysomelidae and Vespidae collected in Amazonas, exhibited conidia with variable susceptibility to stress conditions, such as the isolate CG 222, which is resistant to exposure to UV-B (FERNANDES et al., 2007).

3.3. *Metarhizium* sp.

The entomopathogens of the genus *Metarhizium* are the main focus of numerous researches in Brazil. These microorganisms are distributed worldwide, have variants adapted to the most diverse environmental conditions, are easily cultivated and have a large variety of hosts (LOUREIRO et al., 2020). In Brazil, there are about 24 biopesticides formulations with *Metarhizium anisopliae* isolates commercially available, which are used in this country in 20% of sugarcane fields for the control of *M. fimbriolata* and *M. spectabilis* spittlebugs (MASCARIN et al., 2019).

With this purpose, nine isolates of this entomopathogen from Mato Grosso caused a mortality rate of *M. fimbriolata* nymphs that ranged from 16 to 50% (FABRICE et al., 2013). Additionally, two isolates from this region also exhibited proteolytic activity, producing essential enzymes for the infective process (COSTA et al., 2020). With respect to the species *M. spectabilis*, known as spittlebug, an isolate of *Metarhizium* sp. (UFMG 11444), from the state of Maranhão, exhibited >90% virulence in the eggs of this insect nine days after treatment and >50% in nymphs after 24 hours (CAMPAGNANI et al., 2017).

The identification of these entomopathogens in different environments offers opportunities for the selection of new variants for the control of pests. In this regard, *Metarhizium* sp. is one of the most studied entomopathogens, found in different regions of the Amazon, such as in the state of Rondônia in *Coffea canephora* (coffee) fruits collected in the soil (GAMA et al., 2005), parasitizing *M. fimbriolata* (TIAGO; SILVA, 2007) and *Deois flavopicta* in Mato Grosso (LUBECK et al., 2008). In addition, the species *M. humberi*, known for its activity against arthropods in different life stages, was already identified in soils and parasitizing insects in the state of Mato Grosso (CHRISTIAN LUZ et al., 2019).

Diversity and distribution of these entomopathogens in soils from different Brazilian biomes (Atlantic Forest, Cerrado [savannas and grasslands], Caatinga [desert and xeric shrubland], Pampa [Brazilian plains] and the Amazon) was investigated in a detailed study, where the greatest diversity of *Metarhizium* species was found in the samples from the Amazon region, when compared with other biomes (BOTELHO et al., 2019). Specifically in the state of Mato

Grosso, the species *M. robertsii*, *M. anisopliae* and *M. pingshaense* were identified (BOTELHO et al., 2019).

This entomopathogen was also isolated in the state of Amazonas originally in larvae of the mosquito *Simulium goeldii*, known in the region as *borrachudo* or *piúm* (FONSECA et al., 2008). Isolates from the region were also investigated for the control of *Aedes aegypti*, the vector of dengue, zika and chikungunya viruses. A previous study identified virulence in adult females of this mosquito in two strains of *Metarhizium*, from the state of Rondônia (PAULA, 2007). One of these strains, isolate LPP 133 caused 90% mortality in a three-day period after spraying (PAULA, 2007).

Cowpea is largely used by families living in the Brazilian Amazon as a staple food, but the development of this cultivar can be seriously affected by larvae of C*allosobruchus maculatus*, known as cowpea weevil (LOPES et al., 2018). To control this pest, entomopathogens of the *M. anisopliae* species were also investigated, and 26.7% mortality was found for a population treated with the isolate CG 34, native to the state of Amazonas, at a concentration of 2.9×10^{9}conidia ml^{-1} (MURAD et al., 2006).

Bactrocera carambolae, carambola fly, is a species with high economic importance and considered one of the greatest phytosanitary barriers for exportation of this fruit (CASTILHO et al., 2020). To control immature specimens of this pest, two *Metarhizium* species native to soils from the state of Amapá were tested (SILVA et al., 2016). As a result, the *M. anisopliae* isolate (CG 1313) caused a death rate varying from 36 to 54%, while mortality by *M. robertsii* (CG 1314) was 14 to 30% (SILVA et al., 2016).

In addition, a study carried out in Tocantins describes parasitism of the fungus *M. anisopliae* in leaf-cutting ants, *Atta sexdens*, a relevant pest in agricultural ecosystems (DORNELAS et al., 2017). In this study, under laboratory conditions, the entomopathogen *M. anisopliae* (CRM 530) controlled *A. sexdens*, especially when combined with the immunosuppressor Sandimmun Neoral, boosting the mortality rate to 80% within six days of treatment (DORNELAS et al., 2017).

Significant results for the control of larvae of cattle tick *Rhipicephalus microplus* have also been found with the use of these entomopathogens. A previous study that assessed thirty isolates of *M. anisopliae* from different regions in Brazil found that the isolate

CG37, from the state of Tocantins, was a major entomopathogen determinant of a high mortality rate of larvae (83.6%) 20 days after treatment with a suspension of 10^7conidia ml^{-1} (QUINELATO et al., 2012).

The isolate CG 148, from Mato Grosso, when formulated in mineral oil was effective for the control of cattle tick engorged females, with 73.34% control with a concentration of 10^8 conidia.mL^{-1} (PERINOTTO, 2013). Also in the control of these parasites, other study with *M. anisopliae* isolate (MT) from the region of Mato Grosso, originally isolated from the *Deois* sp. insect, a spittlebug species, accounted for 100% mortality after two weeks of treatment (FRAZZON et al., 2000).

This *M. anisopliae* isolate (MT) also exhibited activity against sugarcane borer, *Diatraea saccharalis*, causing diverse alterations in the cuticle and in the internal tissues of this pest, and a lethal rate ranging from 77.8 to 100% (SCHNEIDER et al., 2013). Detailed studies with this MT isolate demonstrated compatibility, at low concentrations, with the thiophanate-methyl fungicide (FABRICE et al., 2013) and lufenuron, used for pest control (ALVES, 2011), suggesting its implementation for integrated control with other compounds.

Also against sugarcane borer, *D. saccharalis*, isolates of the genus *Metarhizium* sp., from different Amazon regions, were capable of parasitizing eggs, larvae, pupae an adults of this insect (BOVI, 2012). In this study, the isolates Ma 283 and CG 59 from Mato Grosso caused an average parasitism (relating to infection in all life stages) of 56.8 and 98.4%, respectively (BOVI, 2012). In addition, the isolate CG 125 from Pará determined an parasitism average of 71.2%, CG 581 from Tocantins, 88.8%, and CG 29 from Amazonas caused an average of 56.8% (BOVI, 2012). Pathogenic isolates against this pest also promoted plant growth and protection against nematodes (SIQUEIRA, 2016).

Spodoptera frugiperda, known as fall armyworm, and *Chrysodeixis includens*, soybean looper, can also be parasitized by fungi of this genus. These two insects were susceptible under laboratory conditions to the fungus *M. rileyi* originally isolated from the *C. includens* caterpillars from the state of Mato Grosso, exhibiting a mortality rate over 50% for both classes of insects tested (BARROS et al., 2020). Other experiment with seven isolates of *M. rileyi* of this region found that all were pathogenic against *Spodoptera cosmioides* caterpillars with mortality rates between 62 and 96% (LOUREIRO et al., 2020).

3.4. *Paecilomyces*

The fungal genus *Paecilomyces* sp., which contains entomopathogens, was also identified in the Amazon Region (INGLIS; TIGANO, 2006). The taxonomic identification and correct distribution of these microorganisms in the environment are essential for bioprospection studies. In this regard, entomopathogens of the species *P. lilacinus* were identified in soils in the region of Mato Grosso, Tocantins and Maranhão, and *P. fumosoroseus* was also confirmed in soils of Mato Grosso and in the arthropods *Spaethiella* sp. and *Simulium goeldii* in Amazonas (MILANI et al., 1995; INGLIS; TIGANO, 2006; FONSECA et al., 2008).

In Mato Grosso, entomopathogens of the species *P. lilacinus* were found in soil samples (CG 266) infecting *Solenopsis invicta* ants (ESALQ 832), and in Pará there was occurrence of parasitic nematodes of plants of the genus *Meloidogyne* sp. (CG 177) as well as in soil (CG 402) (SANTIAGO et al., 2006). An experiment carried out with these isolates concluded that all of them ensured a decreased nematode population of *Meloidogyne paranaenses* galls in tomato roots (SANTIAGO et al., 2006).

In this same logic, experiments conducted with strains of this entomopathogen from different regions demonstrated pathogenicity against some crop pests. The soil isolate *P. lilacinus* (CG 332) from Mato Grosso was virulent to eggs of *Diabrotica speciosa*, commonly known as cucurbit beetle, and to eggs of nematodes *Meloidogyne javanica* (TIGANOMILANI et al., 1995). Other studies showed that the species *P. fumosoroseus* isolated from soil in Mato Grosso was also pathogenic against *Bemisia tabaci* biotype B, responsible for soybean and cotton yield losses (RAMOS, 2001).

In the state of Acre, a soil isolate of the genus *Paecilomyces* sp. (UFAC 4.145) was pathogenic against larvae of cattle tick, *R. microplus*, with 35.5% mortality rate at a concentration of 1.0×10^7 conidia mL^{-1} (ARAÚJO, 2017). Also in Acre, fungi of this genus were also identified parasitizing insects in broccoli plantations (THOMAZINI et al., 2007).

In addition to this analysis, other study carried out in Maranhão confirmed the presence of a *P. lilacinus* isolate (MGSS 136) infecting the insect *Aleurocanthus woglumi*, known as blackfly (MEDEIROS et al., 2018). In this study, there was 100% mortality of nymphs seven days after treatment with a suspension of the entomopathogen at a concentration of 1×10^7 conidia mL^{-1} (MEDEIROS et al., 2018). These data illustrate the distribution and opportunity of isolation of these fungi in different regions of the Amazon.

3.5. *Ophiocordyceps*

Species of the fungus *Ophiocordyceps* parasitize insects, especially ants, causing alterations in their behavior and often death (CARDOSO NETO et al., 2019). Investigations and collections carried out in the Amazon region confirmed the presence of parasitized ants, usually in large amounts. The species, *Ophiocordyceps camponoti-atricipis*, *O. camponotibispinosi* and *O. camponoti-indiani* were described parasitizing ants of the genus *Camponotus* in the state of Roraima and in the city of Manaus in Amazonas (ARAÚJO et al., 2015).

Other investigations, also conducted in Manaus, identified ants of the genus *Camponotus* spp. infected by entomopathogens of the genus *Ophocordyceps*, mainly by the species *O. kniphofioides*, *O. australis* and *O. unilateralis* (CARDOSO NETO et al., 2019) and ants of the species *Cephalotes atratus* parasitized by the fungus *O. kniphofioides* (IMIRZIAN et al., 2020). These results indicate the frequent distribution of these entomopathogens in the region.

This parasitism was also found in wasps. A study carried out in Amazonas detected the presence of the entomopathogen *O. humbertiii* in wasps of the genus *Larra*, *Liris* and *Epysiron* (SOMAVILLA et al., 2019), and in adult wasps of the genus *Agelaia*, *Polybia* and *Pseudopolybia* in the regions of Roraima and Amazonas (SOMAVILLA et al., 2020). Accordingly, with such inherent potential to be used as agents for the natural control of insects, some species have been studied in detail with this purpose.

The physiological behavior of parasitized insects can often be modified by these entomopathogens. In insects, the nervous system can be affected by the mycelium of the fungus *O. humbertiii*, causing alterations in the behavior, such as adhering to the axial surface or the tip of the leaf (SOMAVILLA et al., 2019) or aggregating on tree trunks (IMIRZIAN et al., 2020). These strategies are applied by fungi to favor their development and dispersion (SOMAVILLA et al., 2020). Furthermore, although these fungi are often found as parasites, their infective structures remain in the soil while hosts are missing. Molecular analysis conducted in black soils in the state of Amazonas detected sequences of rRNA 18S similar to the species *Ophiocordyceps clavata* and *Ophiocordyceps nutans* (LUCHETA et al., 2016).

In this region, a great quantity of genetic material of the entomopathogen *Cordyceps confragosa* (LUCHETA et al., 2016) was also recorded. These fungi were detected parasitizing *Palpada vinetorum* insects, one of the coffee pollinators in plantations grown in the state of Rondônia. About this, the authors point to the importance of studies that also investigate damages to pollinating species by entomopathogens of this genus (COSTA et al., 2015).

3.6. Other species

Larvae of insects of the family Culicidae are also hosts of diverse species of fungus, and the study of such interactions can provide key information for discovering new agents for microbial control. In this context, fungi of the genus *Acremonium kiliense*, *Fusarium sacchari* var. *sacchari* and the entomopathogen *Paecilomyces* sp. were identified in larvae of insects of the species *Aedes aegypti*, *Aedes fluviatilis, Mansonia titillans, Anopheles darlingi* and *Trichoprosopon digitatun* collected from forest areas in the state of Amazonas and Roraima (PEREIRA et al., 2009).

Furthermore, an analysis with isolates of *Fusarium proliferatum* and *Purpureocillium lilacinum* from the state of Tocantins detected pathogenicity against nymphs of *A. woglumi*, the citrus blackfly (MEDEIROS, 2016). An isolate of *Fusarium* sp. (UFMG 11443) from insects in the state of Maranhão was pathogenic against *M. spectabilis* (CAMPAGNANI et al., 2017). This isolate was the most virulent to nymphs of spittlebug both under laboratory and greenhouse conditions compared with other fungi analyzed in this study, including a commercial strain of *M. anisopliae*, (CAMPAGNANI et al., 2017).

The bronze bug, *Thaumastocoris peregrins*, is an important pest in eucalyptus in Brazil. An experiment with an entomopathogen *Isaria* sp. (IBCB 367), isolated from pasture soils in Mato Grosso, found that the confirmed mortality rate of this pest in humid chamber was 87% (LORENCETTI et al., 2018). Regarding the mortality time, in this study, 100% of the bed bugs were dead by the fourth day of assessment (LORENCETTI et al., 2018). In this case, the small size of the insect, of about 1.3 mm, allows that the infection process by the fungus occurs more rapidly (LORENCETTI et al., 2018).

Similarly, an isolate of the this genus also exhibited pathogenicity against whitefly, *B. tabaci* biotype B. Under laboratory conditions, the fungus of the species *Isaria fumosorosea* (CG 1228) caused >77% death of nymphs, and >93% of adults, thus being a promising agent for the control of this insect (MASCARIN et al., 2013). Furthermore, it was also observed in these pests the epizootic occurrence of the entomopathogen *Verticillim lecanii* in commercial soybean crops in the state of Maranhão, causing a reduction of whitefly populations to extremely low levels (LOURENÇÃO et al., 2001).

Other study carried out with a *Aschersonia* sp. isolate from Amazonas determined an efficiency for control of blackfly, *Aleurocanthus woglumi*. In laboratory, this fungus caused variable mortality at different stages of this pest, specifically 98.75% in eggs and 83% in nymphs 2 (PENA, 2007). Such mortality began at the fourth day after treatment (PENA, 2007). In the state of Acre, *Aschersonia* was reported as a natural enemy of nymphs of *Aleurodicus* sp., a genus of whiteflies (THOMAZINI et al., 2007).

4. CONCLUSIONS

In this study, the occurrence of entomopathogenic fungal genera native to the Brazilian Amazon was identified, mainly *Aspergillus*, *Fusarium*, *Metarhizium*, *Paecilomycese* and *Beauveria*. Regarding the prospected isolates, there was a predominance of *Beauveria* evaluated to control *Rhyzopertha dominica*, *Sitophilus oryzae* and Sitophilus *zeamais*, while *Metarhizium* was tested against *Diatraea saccharalis*, *Spodoptera cosmioides* and *Rhipicephalus microplus*. Other genera such as *Paecilomyces*, *Fusarium*, *Isaria* and *Verticillium* also have pathogenic potential, as well as *Ophiocordyceps*, usually infecting ants. Thus, the Amazon Region of Brazil constitutes a rich and promising source of entomopathogenic fungi that should be considered for the improvement of insect control.

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