# Occurrence, Biological and Enzymatic Activities of Agaricomycetes from the Brazilian Amazon – A Systematic Review

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**ABSTRACT:** Agaricomycetes are highlighted for producing a variety of compounds and enzymes with nutritional and medicinal properties. However, the knowledge of the diversity of this group of fungi is still insufficient, as well as their biological and enzymatic activities. Thus, the objective of this work is to describe the occurrence, biological and enzymatic activities of Agaricomycetes from the Brazilian Amazon. The present study is a systematic review with the literature search done in the following databases: Scielo, Google Scholar, PubMed and ScienceDirect. The descriptors used were Basidiomycota, Agaricomycetes, mushroom, antimicrobial activity, antitumor activity, antioxidant activity, anti-inflammatory activity, immunomodulator, enzymatic activity, and Brazilian Amazon. We used as inclusion criteria articles in Portuguese and English, published between 2010 and 2021 and that had the full text available and presented relevance to the exposed topic, and as exclusion criteria, works not done in the Brazilian Amazon, duplicate articles in the databases search or outside the topic under study. A total of 40 articles, published between 2010 and 2021, were selected for analysis. 230 species of Agaricomycetes fungi were described for the Brazilian Amazon, with the most frequent orders being Polyporales (52.60%), Agaricales (14.35%), and Hymenochaetales (13.91%). Six studies were found on antimicrobial activity for promising Agaricomycete fungi against the bacteria *Escherichia coli*, *Klebsiella pneumoniae*, *Staphylococcus aureus* and the fungi *Candida albicans*, *C. parapsilosis* and *C. tropicalis*. For the antioxidant activity, a study described the species *Lentinus citrinus* with high amounts of antioxidant compounds. For enzymatic activity, five studies reported Agaricomycete fungi producing protease, cellulase, amylase, pectinase, laccase, and xylanase enzymes. This review shows the scarcity of studies on the description and technological potential of Agaricomycetes from the Brazilian Amazon, highlighting the need to encourage the study of this group of organisms.

**KEY WORDS:** Basidiomycetes, Agaricomycetes, Polyporales, protease, medicinal mushrooms, antimicrobial activity, antitumor activity, antioxidant activity, anti-inflammatory activity, immunomodulatory, enzymatic activity, Brazilian Amazon

## I. INTRODUCTION

Agaricomycetes are fungi that have a wide variety of shapes, textures, and colors and play important roles in nature, such as maintaining ecosystems, ensuring the cycling of nutrients, and acting in the decomposition of organic matter through the production of primary and secondary metabolites.[1]

They have a wide distribution in the Brazilian territory and although the literature presents works that approach the diversity of Agaricomycetes in the North,[2,3] South,[4] Southeast,[5,6] Northeast,[7] and Midwest.[8] However, knowledge of the diversity of this class is still insufficient, as well as studies on biological and enzymatic activity.

Such fungi stand out for producing a variety of compounds with nutritional and medicinal properties, showing anti-inflammatory,[9] antioxidant,[10] immunomodulatory,[11] antitumor,[12] antiparasitic,[13] and antimicrobial,[14] which may be able to inhibit microorganisms that are resistant to common antibiotics.[15]

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In addition to the compounds already mentioned, Agaricomycetes are producers of enzymes, such as amylases, cellulases, proteases, and lipases, which have advantages for large-scale production, with potential application in the replacement of conventional chemical processes and of industrial interest, also presenting uses in environmental recovery, working in the recycling of agricultural and agro-industrial residues.[16]

Thus, the objective of this work was to review the occurrence, biological and enzymatic activities of Agaricomycetes from the Brazilian Amazon.

## II. MATERIAL AND METHODS

The present study is a systematic review with the literature search done in the following databases: Scielo, Google Scholar, PubMed and Science Direct. The descriptors used were Basidiomycota, Agaricomycetes, mushroom, antimicrobial activity, antitumor activity, antioxidant activity, anti-inflammatory activity, immunomodulatory, enzymatic activity, and Brazilian Amazon.

The study included articles in Portuguese and English, published between 2010 and 2021, as well as articles that had the full text available and were relevant to the exposed topic. The exclusion criteria were work not done in the Brazilian Amazon, duplication of articles when found in more than one search base, and outside the topic under study.

## III. RESULTS

A total of 16,686 articles were found in the Google Scholar database, 10 in PubMed, 333 in Science Direct, and 4 in Scielo. Applying the inclusion and exclusion criteria, a total of 40 articles published between 2010 and 2021 were selected for analysis (Fig. 1). All works were organized by descriptors and database (Table 1).

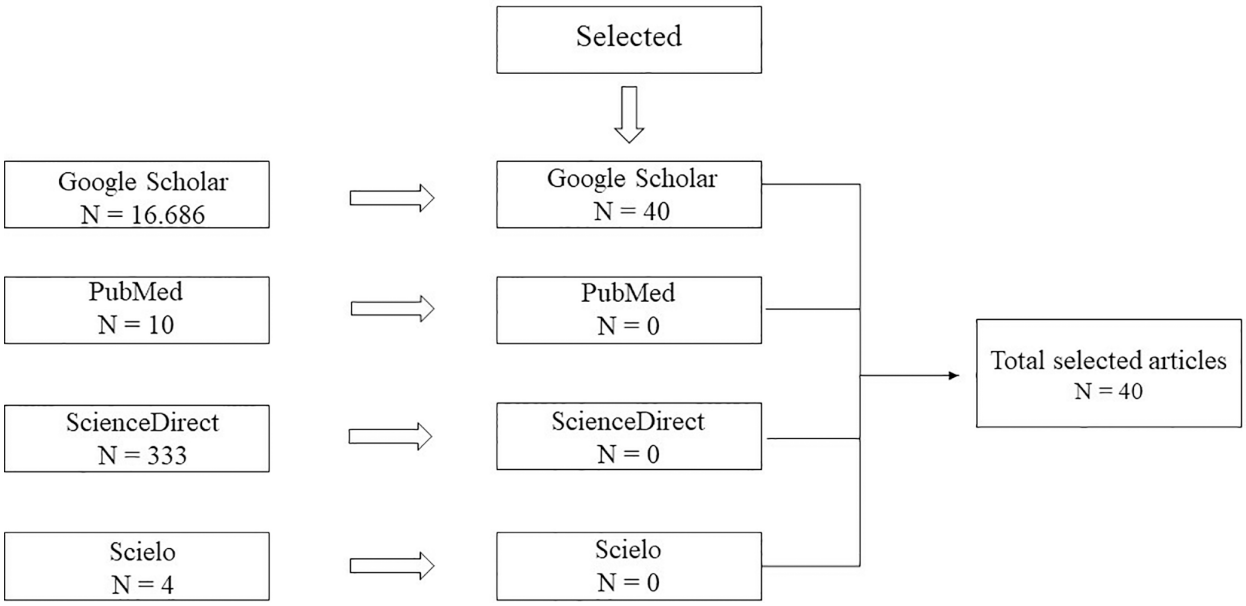


**FIG. 1:** Total number of articles selected for systematic review of occurrence, biological and enzymatic activities of Agaricomycetes from the Brazilian Amazon

**TABLE 1:** List of descriptors and database used to search for occurrence, biological and enzymatic activities of Agaricomycetes in the Brazilian Amazon

| Descriptor | Google Scholar | Science Direct | PubMed | Scielo |
|---|---|---|---|---|
| Basidiomycota + Brazilian Amazon | 1,330 | 38 | 4 | 2 |
| Agaricomycetes + Brazilian Amazon | 443 | 9 | 0 | 1 |
| Mushroom + Brazilian Amazon | 7,880 | 213 | 6 | 1 |
| Antimicrobial activity + Brazilian Amazon + Basidiomycota | 1,610 | 8 | 0 | 0 |
| Antimicrobial activity + Brazilian Amazon + Agaricomycetes | 273 | 2 | 0 | 0 |
| Antitumoral activity + Brazilian Amazon + Basidiomycota | 571 | 0 | 0 | 0 |
| Antitumoral activity + Brazilian Amazon + Agaricomycetes | 117 | 0 | 0 | 0 |
| Antioxidant activity + Brazilian Amazon + Basidiomycota | 822 | 5 | 0 | 0 |
| Antioxidant activity + Brazilian Amazon + Agaricomycetes | 155 | 1 | 0 | 0 |
| Anti-inflammatory activity + Brazilian Amazon + Basidiomycota | 433 | 0 | 0 | 0 |
| Anti-inflammatory activity + Brazilian Amazon + Agaricomycetes | 80 | 0 | 0 | 0 |
| Immunomodulator + Brazilian Amazon + Basidiomycota | 186 | 0 | 0 | 0 |
| Immunomodulator + Brazilian Amazon + Agaricomycetes | 41 | 0 | 0 | 0 |
| Enzymatic activity + Brazilian Amazon + Agaricomycetes | 425 | 1 | 0 | 0 |
| Enzymatic activity + Brazilian Amazon + Basidiomycota | 2,320 | 11 | 0 | 0 |
| Total | 16,686 | 333 | 10 | 4 |

Of the 40 articles selected, 26 (65%) were related to the description of 230 species of Agaricomycetes distributed in 11 orders: Polyporales (52.60%), Agaricales (14.35%), Hymenochaetales (13.92%), Geastrales (5.65%), Russulales (4.34%), Phalales (3.48%), Boletales (1.74%), Corticiales (0.87%), Auriculareales (0.44%), Dacrymycetales (0.44%), and Cantharellales (0.44%) (Fig. 2). There were still four species reported with uncertainty of identification, corresponding to 1.74% of the data collected (Table 2).

## A. Biological Activity

Seven studies about the antimicrobial activity and one of antioxidant of Agaricomycetes from the Brazilian Amazon were identified. The Agaricomycetes tested were positive against the bacteria *Escherichia coli*, *Klebsiella pneumoniae*, and *Staphylococcus aureus*, and the fungi *Candida albicans*, *C. parapsiolosis*, and *C. tropicalis* (Table 3).

## B. Enzymatic Activity

Five studies developed with Agaricomycetes from the Brazilian Amazon, producers of xylanase, pectinase, cellulase, protease, amylase, and laccase enzymes were found (Table 4).

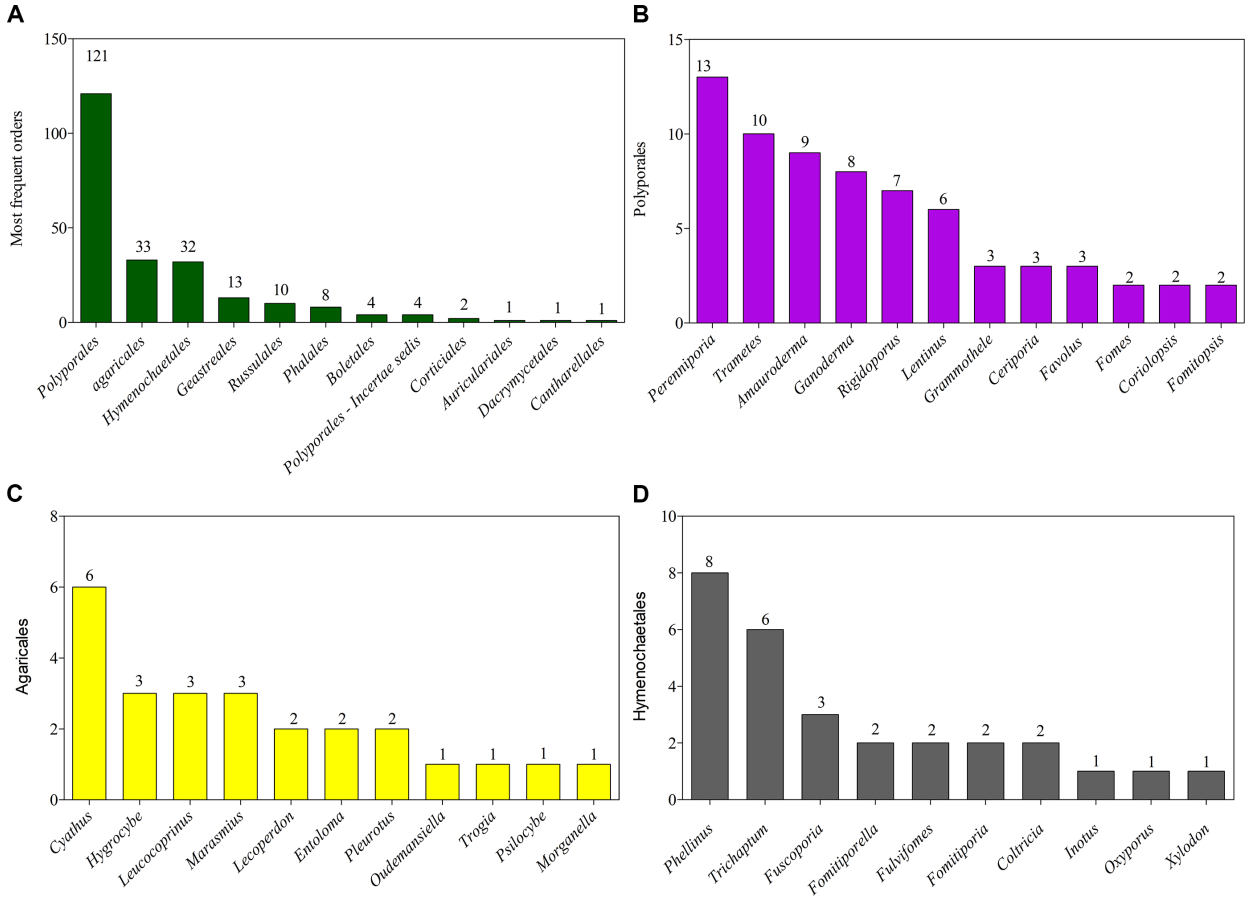


**FIG. 2:** Distribution of taxas of the Class Agaricomycetes from the Brazilian Amazon. (A) Most frequent orders. (B) Most frequent genera of the order Polyporales. (C) Most frequent genera of the order Agaricales. (D) Most frequent genera of the order Hymenochaetales.

**TABLE 2:** List of Agaricomycetes species from the Brazilian Amazon reported in the literature

| Order | Species | Ref. |
|---|---|---|
| Polyporales 52.60% | *Abundisporus roseoalbus* (Jungh.) Ryvarden | Soares et al.[3] Xavier et al.[17] |
| | *Abundisporus violaceus* (Wakef.) Ryvarden | Medeiros et al.[18] |
| | *Amauroderma boleticeum* (Pat. & Gaillard) Torrend | Soares et al.[3] |
| | *Amauroderma calcigenum* (Berk.) Torrend | Soares et al.[3] |
| | *Amauroderma camerarium* (Berk.) JS Furtado | Xavier et al.[17] Soares et al.[3] |
| | *Amauroderma exile* (Berk.) Torrend | Soares et al.[3] |
| | *Amauroderma omphalodes* (Berk.) Torrend | Soares et al.[3] |
| | *Amauroderma praetervisum* (Pat.) Torrend | |
| | *Amauroderma schomburgkii* (Mont. & Berk.) Torrend | Xavier et al.[17] Soares et al.[3] |

**TABLE 2:** (*continued*)

| | |
|---|---|
| *Amauroderma trichodermatum* J.S Furtado | Cavalcante et al.[19] |
| *Amauroderma subrugosum* (Bres. & Pat.) Torrend | |
| *Antrodiella murrillii* (Lloyd) Ryvarden | Xavier et al.[17] |
| *Ceriporia amazônica* A.MS Soares, Sotão & Ryvarden | |
| *Ceriporia purpúrea* (Fr.) Donk | |
| *Ceriporia xylostromatoides* (Berk.) Ryvarden | |
| *Cerrena caperata* (Berk.) Zmitr. | Xavier et al.[17]<br>Medeiros et al.[18]<br>Soares et al.[3]<br>Costa et al.[20] |
| *Cerrena hydnoides* (Sw.) Zmitr. | Cavalcante et al.[19]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| *Coriolopsis brunneoleuca* (Berk.) Ryvarden | Xavier et al.[17]<br>Soares et al.[3] |
| *Coriolopsis byrsina* (Mont.) Ryvarden | Soares et al.[3] |
| *Cristataspora coffeata* (Berk.) Robledo, Costa-Rezende & de Madrignac Bonzi | Soares et al.[3]<br>Gomes-Silva et al.[22] |
| *Cubamyces lactineus* (Berk.) Lücking | Medeiros et al.[18]<br>Soares et al.[3]<br>Xavier et al.[17] |
| *Daedalea dochmia* (Berk. & Broome) T. Hatt | Xavier et al.[17] |
| *Diplomitoporus allantosporus* Ryvarden & Iturr | Xavier et al.[17] |
| *Earliella scabrosa* (Pers.) Gilb. & Ryvarden | Soares et al.[3]<br>Xavier et al.[17]<br>Medeiros et al.[18] |
| *Echinochaete brachypora* (Mont.) Ryvarden | Soares et al.[3]<br>Medeiros et al.[18] |
| *Fabisporus sanguineus* (L.) Zmitr. | Xavier et al.[17]<br>Soares et al.[3] |
| *Favolus grammocephalus* (Berk.) Imazeki | Soares et al. [3] |
| *Favolus ianthinus* (Gibertoni & Ryvarden) Zmitr. & Kovalenko | Xavier et al.[17]<br>Soares et al.[3] |
| *Favolus tenuiculus* P. Beauv | Pinto et al.[21] |
| *Flaviporus hydrophilus* (Berk. & MA Curtis) Ginns | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| *Flaviporus liebmannii* (Fr.) Ginns | Xavier et al.[17]<br>Soares et al.[3] |
| *Fomes extensus* (Lév.) Cooke | Xavier et al.[17] |
| *Fomes fasciatus* (Sw.) Cooke | Soares et al.[3] |
| *Fomitella supina* (Sw.) Murrill | |
| *Fomitopsis roseoalba* A.M.S. Soares, Ryvarden & Gibertoni | Xavier et al.[17] |

**TABLE 2:** (*continued*)

| Order | Species | Ref. |
|---|---|---|
| | *Fomitopsis scalaris* (Cooke) Ryvarden | |
| | *Foraminispora rugosa* (Berk.) Costa-Rez., Drechsler-Santos & Robledo | Soares et al.[3] |
| | *Funalia aspera* (Jungh.) Zmitr. & Malysheva | Xavier et al.[17] |
| | *Funalia floccosa* (Jungh.) Zmitr. & Malysheva | Medeiros et al.[18]<br>Soares et al.[3] |
| | *Ganoderma amazonense* Weir | Gomes-Silva et al.[22] |
| | *Ganoderma australe* (Fr.) Pat. | Gomes-Silva et al.[22]<br>Xavier et al.[17]<br>Medeiros et al.[18] |
| | *Ganoderma citriporum* Ryvarden & Iturr | Gomes-Silva et al.[22] |
| | *Ganoderma multiplicatum* (Mont.) Pat. | Gomes-Silva et al.[22]<br>Soares et al.[3] |
| | *Ganoderma orbiforme* (Fr.) Ryvarden | Gomes-Silva et al.[22]<br>Xavier et al.[17] |
| | *Ganoderma resinaceum* Boud | Gomes-Silva et al.[22] |
| | *Ganoderma stipitatum* (Murrill) Murrill | Xavier et al.[17]<br>Gomes-Silva et al.[22]<br>Medeiros et al.[18] |
| | *Geesterania carneola* (Bres.) Westphalen & Rajchenberg | Xavier et al.[17]<br>Soares et al.[3] |
| | *Ganoderma zonatum* Murrill | Gomes-Silva et al.[22] |
| | *Grammothele fuligo* (Berk. & Broome) Ryvarden | Xavier et al.[17]<br>Soares et al.[3] |
| | *Grammothele lineata* Berk. & MA Curtis | Xavier et al.[17]<br>Soares et al.[3] |
| | *Grammothele subargentea* (Speg.) Rajchenb. | Xavier et al.[17]<br>Soares et al.[3] |
| | *Gloeoporus thelephoroides* (Hook.) G. Cunn. | Costa et al.[20] |
| | *Haddowia longipes* (Lév.) Steyaert | Gomes-Silva et al.[22]<br>Soares et al.[3] |
| | *Junghuhnia subundata* (Murrill) Ryvarden | Soares et al.[3]<br>Xavier et al.[17] |
| | *Lentinus articularius* (Batsch) Zmitr. | Da Silva Soares et al.[23] |
| | *Lentinus berteroi* (Fr.) Fr. | Cavalcante et al.[19] |
| | *Lentinus crinitus* (L.) Fr. | |
| | *Lentinus tricholoma* (Mont.) Zmitr. | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18]<br>Cavalcante et al.[19] |
| | *Lentinus swartzii* Berk | Xavier et al.[17] |
| | *Lentinus velutinus* Fr. | Cavalcante et al.[19] |

**TABLE 2:** (*continued*)

| | |
|---|---|
| *Magasporia amazonica* (Gomes-Silva, Ryvarden & Gibertoni) CRS Lira & Gibertoni | Xavier et al.[17] |
| *Megasporoporia setulosa* (Henn.) Rajchenb. | Soares et al.[3] |
| *Megasporoporiella cavernulosa* (Berk.) CRS Lira & TB Gibertoni | Soares et al.[3]<br>Xavier et al.[17] |
| *Microporellus dealbatus* (Berk. & MA Curtis) Murrill | Soares et al.[3] |
| *Microporellus obovatus* (Jungh.) Ryvarden | Soares et al.[3]<br>Xavier et al.[17]<br>Medeiros et al.[18] |
| *Navisporus sulcatus* (Lloyd) Ryvarden | Xavier et al.[17] |
| *Nigrofomes melanoporus* (Mont.) Murrill | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| *Nigroporus rigidus* Ryvarden | Soares et al.[3] |
| *Nigroporus vinosus* (Berk.) Murrill | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| *Pachykytospora alabamae* (Berk. & Cooke) Ryvarden | Xavier et al.[17] |
| *Panus similis* (Berk. & Broome) TW May & AE Wood | Cavalcante et al.[19] |
| *Panus strigellus* (Berk.) Overh. | |
| *Perenniporia medulla-panis* (Jacq.) Donk | |
| *Perenniporia aurantiaca* (A. David & Rajchenb.) Decock & Ryvarden | Soares et al.[3] |
| *Perenniporia brasiliensis* C. RS de Lira, MAS Soares, Ryvarden & Gibertoni | Xavier et al.[17] |
| *Perenniporia centrali-africana* Decock & Mossebo | |
| *Perenniporia contraria* (Berk. & MA Curtis) Ryvarden | Xavier et al.[17]<br>Soares et al.[3] |
| *Perenniporia cremeopora* Decock & Ryvarden | Xavier et al.[17]<br>Soares et al.[3] |
| *Perenniporia inflexibilis* (Berk.) Ryvarden | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| *Perenniporia martia* (Berk.) Ryvarden | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| *Perenniporia parvispora* Decock & Ryvarden | Xavier et al.[17] |
| *Perenniporia ohiensis* (Berk.) Ryvarden | Medeiros et al.[18] |
| *Perenniporia roseoisabellina* (Pat. & Gaillard) Ryvarden | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| *Perenniporia sprucei* Decock & Ryvarden | Soares et al.[3]<br>Medeiros et al.[18] |

**TABLE 2:** (*continued*)

| Order | Species | Ref. |
|---|---|---|
| | *Perenniporia stipitata* Ryvarden | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| | *Phaeodaedalea incerta* (Curr.) Tura et al. | Medeiros et al.[18] |
| | *Picipes dictyopus* (Mont.) BK Cui, Xing Ji & JL Zhou | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| | *Podofomes millia* (Sommerf.) Gorjón | Cavalcante et al.[19] |
| | *Polyporus guianensis* Mont. | Xavier et al.[17]<br>Soares et al.[3] |
| | *Polyporus leprieurii* Mont. | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18]<br>Cavalcante et al.[19] |
| | *Porogramme albocincta* (Cooke & Massee) Gibertoni | Xavier et al.[17] |
| | *Pyrofomes lateritius* (Cooke) Ryvarden | Xavier et al.[17]<br>Soares et al.[3] |
| | *Ranadivia modesta* (Kunze: Fr.) Zmitr. | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18]<br>Costa et al.[20] |
| | *Rigidoporus amazonicus* Ryvarden | Xavier et al.[17]<br>Soares et al.[3] |
| | *Rigidoporus biokoensis* (Bres. ex Lloyd) Ryvarden | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| | *Rigidoporus lineatus* (Pers.) Ryvarden | Soares et al.[3]<br>Medeiros et al.[18] |
| | *Rigidoporus microporus* (Sw.) Overeem | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| | *Rigidoporus ulmarius* (Sowerby) Imazeki | Soares et al.[3] |
| | *Rigidoporus undatus* (Pers.) Donk | Xavier et al.[17] |
| | *Rigidoporus vinctus* (Berk.) Ryvarden | Xavier et al.[17]<br>Soares et al.[3] |
| | *Rhodofomitopsis cupreorosea* (Berk.) BK Cui, ML Han & YC Dai | Soares et al.[3] |
| | *Sanguinoderma rude* (Berk.) YF Sun, DH Costa & BK Cui | Xavier et al.[17]<br>Soares et al.[3] |
| | *Tinctoporellus epimiltinus* (Berk. & Broome) Ryvarden | Xavier et al.[17]<br>Soares et al.[3] |
| | *Tomophagus colossus* (Fr.) Murrill | Gomes-Silva et al.[22] |
| | *Trametes cotonea* (Pat. & Har.) Ryvarden | Medeiros et al.[18]<br>Soares et al.[3] |

**TABLE 2:** (*continued*)

| | | |
|---|---|---|
| | *Trametes cubensis* (Mont.) Sacc. | Medeiros et al.[18]<br>Soares et al.[3] |
| | *Trametes elegans* (Spreng.) Fr. | Xavier et al.[17] |
| | *Trametes hostmannii* (Berk.) Zmitr., Wasser & Ezhov | Medeiros et al.[18] |
| | *Trametes membranacea* (Sw.) Kreisel | Xavier et al.[17] |
| | *Tametes maxima* (Mont.) A. David & Rajchenb. | Medeiros et al.[18] |
| | *Trametes nivosa* (Berk.) Murrill | Xavier et al.[17]<br>Soares et al.[3] |
| | *Trametes psila* (Lloyd) Ryvarden | Xavier et al.[17]<br>Medeiros et al.[18]<br>Soares et al.[3] |
| | *Trametes supermodesta* Ryvarden & Iturr. | Xavier et al.[17]<br>Soares et al.[3] |
| | *Trametes variegata* (Berk.) Zmitr., Wasser & Ezhov | Soares et al.[3]<br>Medeiros et al.[18]<br>Costa et al.[20] |
| | *Truncospora tephropora* (Mont.) Zmitr. | Xavier et al.[17] |
| | *Trullella dentipora* (Ryvarden & Iturr.) Zmitr. | |
| | *Trullella meridae* (Miettinen & Ryvarden) Zmitr. | |
| Hymenochaetales 13.92% | *Coltricia barbata* Ryvarden & de Meijer | Xavier et al.[17]<br>Soares et al.[3] |
| | *Coltricia hamata* (Romell) Ryvarden | Soares et al.[3] |
| | *Fomitiporella cavicola* (Kotl. & Pouzar) T. Wagner & M. Fisch. | Xavier et al.[17] |
| | *Fomitiporella coruscans* (Bres.) Salvador-Montoya & Popoff | Medeiros et al.[18]<br>Soares et al.[3] |
| | *Fomitiporia baccharidis* (Pat.) Decock, Robledo & Amalfi | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| | *Fomitiporia punctata* (P. Karst.) Murrill | |
| | *Fulvifomes membranaceus* (JE Wright & Blumenf.) Baltazar & Gibertoni | Xavier et al.[17] |
| | *Fulvifomes merrillii* (Murrill) Baltazar & Gibertoni | Soares et al.[3] |
| | *Fuscoporia callimorpha* (Lév.) Groposo, Log.-Leite & Góes-Neto | Xavier et al.[17] |
| | *Fuscoporia contigua* (Pers.) G. Cunn | |
| | *Fuscoporia undulata* (Murrill) Bondartseva & S. Herrera | Xavier et al.[17]<br>Soares et al.[3] |
| | *Hymenochaete iodina* (Mont.) Baltazar & Gibertoni | Xavier et al.[17]<br>Soares et al.[3] |
| | *Inonotus calcitratus* (Berk. & MA Curtis) Gomes-Silva & Gibertoni | Xavier et al.[17]<br>Soares et al.[3]<br>Medeiros et al.[18] |
| | *Oxyporus corticola* (Fr.) Ryvarden | Cavalcante et al.[19] |
| | *Phellinus anchietanus* Decock & Ryvarden | Xavier et al.[17] |

**TABLE 2:** (*continued*)

| Order | Species | Ref. |
|---|---|---|
| | *Phellinus caryophylleus* (Cooke) Ryvarden | Soares et al.[3]<br>Medeiros et al.[18] |
| | *Phellinus gilvus* (Schwein.) Pat. | Soares et al.[3] |
| | *Phellinus grenadensis* (Murrill) Ryvarden | Soares et al.[3]<br>Medeiros et al.[18]<br>Cavalcante et al.[19] |
| | *Phellinus rimosus* (Berk.) Pilát | Soares et al.[3]<br>Medeiros et al.[18] |
| | *Phellinus fastuosus* (Lév.) S. Ahmad | Xavier et al.[17]<br>Medeiros et al.[18]<br>Soares et al.[3]<br>Cavalcante et al.[19] |
| | *Phellinus griseoporus* D.A. Reid | Soares et al.[3] |
| | *Phellinus shaferi* (Murrill) Ryvarden | Xavier et al.[17]<br>Soares et al.[3] |
| | *Phylloporia spathulata* (Hook.) Ryvarden | Xavier et al.[17]<br>Soares et al.[3] |
| | *Pyrrhoderma lamaoense* (Murrill) LW Zhou & YC Dai | Xavier et al.[17] |
| | *Trichaptum abietinum* (Pers. ex JF Gmel.) Ryvarden | Nascimento et al.[24] |
| | *Trichaptum biforme* (Fr.) Ryvarden | Xavier et al.[17] |
| | *Trichaptum byssogenum* (Jungh.) Ryvarden | Soares et al.[3] |
| | *Trichaptum griseofuscum* (Mont.) Ryvarden & Iturr. | Soares et al.[3]<br>Xavier et al.[17] |
| | *Trichaptum perrottetii* (Lév.) Ryvarden | Medeiros et al.[18]<br>Soares et al.[3]<br>Xavier et al.[17] |
| | *Trichaptum sector* (Ehrenb.) Kreisel | Medeiros et al.[18]<br>Soares et al.[3]<br>Xavier et al.[17] |
| | *Tropicoporus dependens* (Murrill) LW Zhou, YC Dai & Vlasák | Xavier et al.[17]<br>Soares et al.[3] |
| | *Tropicoporus linteus* (Berk. & MA Curtis) LW Zhou & YC Dai | Xavier et al.[17] |
| | *Xylodon flaviporus* (Berk. & MA Curtis ex Cooke) Riebesehl & Langer | Xavier et al.[17]<br>Soares et al.[3] |
| Agaricales 14.35% | *Clavaria* cf. *zollingeri* Lév. | Nascimento et al.[24] |
| | *Cyathus albinus* Accioly, R. Cruz & Baseia | Accioly et al.[25] |
| | *Cyathus amazonicus* Trierv.-Per. & Baseia | |
| | *Cyathus earlei* Lloyd | |
| | *Cyathus limbatus* Tul. & C. Tul. | |
| | *Cyathus morelensis* C.L. Gómez & Pérez-Silva | Cruz et al.[26] |
| | *Cyathus triplex* Lloyd | Accioly et al.[25] |
| | *Entoloma azureoviride* E. Horak & Singer | Wartchow et al.[27] |

**TABLE 2:** (*continued*)

| | | |
|---|---|---|
| | *Entoloma guyanense* Blanco-Dios | Coimbra; Gibertoni[28] |
| | *Gymnopus montagnei* (Berk.) Redhead | Cavalcante et al.[19] |
| | *Hygrocybe firma* (Berk. & Broome) Singer | |
| | *Hygrocybe occidentalis* (Dennis) Pegler | |
| | *Hygrocybe miniata* (Fr.) P. Kumm. | Nascimento et al.[24] |
| | *Leucoagaricus rubrotinctus* (Peck) Singer | Cavalcante et al.[19] |
| | *Leucocoprinus fragilissimus* (Ravenel ex Berk. & MA Curtis) Pat. | |
| | *Leucocoprinus* cf. *brunneoluteus* Capelari & Gimenes | |
| | *Leucocoprinus birnbaumii* (Corda) Singer | Cavalcante et al.[19]<br>Nascimento et al.[24] |
| | *Lycoperdon albostipitatum* (Baseia & Alfredo) Baseia, Alfredo & MP Martín | Alfredo et al.[29] |
| | *Lycoperdon fuligineum* Berk. & MA Curtis | Cabral et al.[30] |
| | *Marasmius haematocephalus* (Mont.) Fr. | Cavalcante et al.[19]<br>Nascimento et al.[24] |
| | *Marasmius rotalis* Berk. & Broome | |
| | *Marasmius guyanensis* Mont. | |
| | *Morganella rimosa* Baseia & Alfredo | Alfredo et al.[29] |
| | *Pleurotus djamor* (Rumph. ex. Fr.) Boedijn | Cavalcante et al.[19] |
| | *Pleurotus cornucopiae* (Paulet) Quél. | |
| | *Psilocybe cubensis* (Earle) Singer | Nascimento et al.[24] |
| | *Ramariopsis kunzei* (Fr.) Corner | |
| | *Rectipilus stromatoides* Gorjón | Gorjón et al.[31] |
| | *Schizophyllum* cf. *umbrinum* Berk. | Nascimento et al.[24] |
| | *Tricholoma equestre* (L.) P. Kumm. | Cavalcante et al.[19] |
| | *Trogia cantharelloides* (Mont.) Pat. | Costa et al.[20] |
| | *Tulostoma pusillum* Berk. | Trierveiler-Pereira et al.[32] |
| | *Oudemansiella cubensis* (Berk. & MA Curtis) RH Petersen | Costa et al.[20] |
| Geastrales 5.65% | *Geastrum achinulatum* T.S. Cabral, BDB Silva & Baseia | Da Silva et al.[23] |
| | *Geastrum albonigrum* Calonge & M. Mata | Trierveiler-Pereira et al.[32] |
| | *Geastrum entomophilum* Fazolino, Calonge & Baseia | Leite et al.[33] |
| | *Geastrum fimbriatum* Fr. | |
| | *Geastrum hyalinum* Freitas-Netousa et al. | Assis et al.[34] |
| | *Geastrum inpaense* T.S. Cabral, BDB Silva & Baseia | Cabral et al.[30] |
| | *Geastrum javanicum* Lév. | Leite et al.[33] |
| | *Geastrum lageniforme* Vittad. | Gomes-Silva et al.[22]<br>Trierveiler-Pereira et al.[32]<br>Cabral et al.[30] |

**TABLE 2:** (*continued*)

| Order | Species | Ref. |
|---|---|---|
| | *Geastrum lilloi* L.S. Domínguez | Gomes-Silva et al.[22] |
| | *Geastrum saccatum* Fr. | Gomes-Silva et al.[22]<br>Cabral et al.[30] |
| | *Geastrum schweinitzii* (Berk. & MA Curtis) Zeller | Cabral et al.[30] |
| | *Geastrum triplex* Jungh. | |
| | *Geastrum verrucoramulosum* T.S. Cabral, JO Sousa & Baseia | |
| Russulales 4.34% | *Gloeodontia halocystidiata* Górjon | Górjon et al.[35] |
| | *Gloiothele incrustata* Górjon | |
| | *Gloiothele larssonii* Górjon | |
| | *Lactifluus guttulatus* Silva-Filho, DL Komura & Wartchow | Silva-Filho et al.[36] |
| | *Lactifluus spathuliformis* Silva-Filho, DL Komura & Wartchow | |
| | *Lactifluus piperogalactus* Silva-Filho, Sá & Wartchow | |
| | *Lactifluus lepus* Delgat & Courtec. | |
| | *Larssoniporia tropicalis* (Cooke) YC Dai, Jia J. Chen & BK Cui | Xavier et al.[17]<br>Soares et al.[3] |
| | *Peniophora wallacei* Górjon | Górjon et al.[35] |
| | *Wrightoporia avellanea* (Bres.) Pouzar | Xavier et al.[17] |
| Phalales 3.48% | *Phallus atrovolvatus* Kreisel & Calonge | Cabral et al.[30] |
| | *Phallus denigricans* T.S. Cabral, BDB Silva & Baseia | |
| | *Phallus purpurascens* T.S. Cabral, BDB Silva & Baseia | |
| | *Phallus indusiatus* Vent. | Cabral et al. [30]<br>Santana et al.[37]<br>Nascimento et al.[24] |
| | *Phallus merulinus* (Berk.) Cooke | Cabral et al.[30] |
| | *Mutinus caninus* (Schaeff.) Fr. | Trierveiler-Pereira et al.[32] |
| | *Mutinus fleischeri* Penz. | Cabral et al.[30] |
| | *Staheliomyces cinctus* E. Fisch. | |
| Boletales 1.74% | *Scleroderma anomalosporum* Baseia, BDB Silva & MP Martín | Baseia et al.[38]<br>Almeida et al.[39] |
| | *Scleroderma camassuense* M.P. Martín, Baseia & BDB Silva | Baseia et al.[38] |
| | *Scleroderma duckei* B. DB Silva, MP Martín & Baseia | |
| | *Scleroderma minutisporum* Baseia, Alfredo & Cortez | Alfredo et al.[29] |
| Polyporales – Incertae sedis 1.74% | *Cubamyces lactineus* (Berk.) Lücking | Xavier et al.[17] |
| | *Junghuhnia subundata* (Murrill) Ryvarden | Soares et al.[3] |
| | *Lentinus swartzii* Berk. | Xavier et al.[17] |
| | *Trametes elegans* (Spreng.) Fr. | Soares et al.[3] |
| Corticiales 0.87% | *Dendrothele nakasoneae* Górjon | Górjon et al.[35] |

**TABLE 2:** (*continued*)

| | | |
|---|---|---|
| | *Dendrothele ornata* Górjon | |
| Auriculariales 0.44% | *Auricularia delicata* (Mont. ex Fr.) Henn. | Cavalcante et al.[19] Nascimento et al.[24] |
| Dacrymycetales 0.44% | *Dacryopinax spathularia* (Schwein.) GW Martin | Cavalcante et al.[19] Nascimento et al.[24] |
| Cantharellales 0.44% | *Cantharellus amazonenses* Wartchow | Wartchow et al.[27] |

**TABLE 3:** Biological activities of Agaricomycetes from the Brazilian Amazon

| Biological activity | Microorganism | Agaricomycetes Species | Ref. |
|---|---|---|---|
| Antibacterial | *Escherichia coli* 46.42% | *Cyclomyces iodinus* | Santos et al.[40] |
| | | *Gloeoporus thelephoroides* | |
| | | *Gloeophyllum* sp. | Oliveira et al.[41] |
| | | *Hydnopolyporus fimbriatus* | Santos et al.[40] |
| | | *Lentinus citrinus* | Castillo et al.[42] |
| | | *Lentinus citrinus* | Bertéli et al.[43] |
| | | *Marasmius* sp. | Santos et al.[40] |
| | | *Neolentinus lepideus* | Castillo et al.[42] |
| | | *Oudemansiella canarii* | Oliveira et al.[41] |
| | | *Phellinus gilvus* | Santos et al.[40] |
| | | *Pleurotus cornucopiae* | Castillo et al.[44] |
| | | *Pleurotus* sp. | Oliveira et al.[41] |
| | | *Trametes* sp. | |
| | *Staphylococcus aureus* 25% | *Cymatoderma* sp. | Santos et al.[40] |
| | | *Favolus tenuiculus* | |
| | | *Ganoderma* cf. *amazonense* | |
| | | *Gloeophyllum* sp. | Oliveira et al.[41] |
| | | *Lentinus citrinus* | Bertéli et al.[43] |
| | | *Oudemansiella cubensis* | Costa et al. [20] |
| | | *Pleurotus* sp. | Oliveira et al.[41] |
| | *Klebsiella pneumoniae* 17.85% | *Cerrena caperata* | Santos et al.[40] |
| | | *Cymatoderma* sp. | |
| | | *Ganoderma* cf. *amazonense* | |
| | | *Hydnopolyporus fimbriatus* | |
| | | *Polyporus grammocephalus* | |
| | *Streptococcus pneumoniae* 10.71% | *Cymatoderma* sp. | Santos et al.[40] |
| | | *Pycnoporus sanguineus* | |
| | | *Tyromyces* cf. *polyporoides* | |
| Antifungal | *Candida albicans* 77.77% | *Earliella scabrosa* | Oliveira et al.[41] |
| | | *Gloeophyllum* sp. | |

**TABLE 3:** (*continued*)

| Biological activity | Microorganism | Agaricomycetes Species | Ref. |
|---|---|---|---|
| | | *Lentinus citrinus* | Castillo et al.[42] |
| | | *Neolentinus lepideus* | |
| | | *Pleurotus cornucopiae* | Castillo et al.[44] |
| | | *Pleurotus* sp. | Oliveira et al.[41] |
| | | *Pleurotus eryngii* | Andrade et al.[45] |
| | *Candida parapsilosis* 11.11% | *Pleurotus eryngii* | Andrade et al.[45] |
| | *Candida tropicalis* 11.11% | *Pleurotus eryngii* | |
| Antioxidant | β-tocoferol<br>Oxalic acid<br>Malic acid<br>*p*-hydroxybenzoic acid | *Lentinus citrinus* | Bertéli et al.[43] |

**TABLE 4:** Enzymatic activity of Agaricomycetes from the Brazilian Amazon

| Enzyme | Species | Ref. |
|---|---|---|
| Xilanase 27.27% | *Fomitopsis subtropical*<br>*Marasmius cladophyllus*<br>*Neonothopanus nambi*<br>*Phanerochaete australis*<br>*Perenniporia tephropora* | De Araújo et al.[46] |
| | *Trametes* sp. | Pereira et al.[47] |
| Pectinase 22.72% | *Fomitopsis subtropical*<br>*Marasmius cladophyllus*<br>*Neonothopanus nambi*<br>*Phanerochaete australis*<br>*Perenniporia tephropora* | De Araújo et al.[46] |
| Cellulase 18.18% | *Fomitopsis subtropical*<br>*Marasmius cladophyllus*<br>*Neonothopanus nambi* | De Araújo et al. [46] |
| | *Trametes* sp. | Pereira et al.[47] |
| Protease | *Lentinus citrinus* | Ana et al.[48] |
| 13.63% | *Pleurotus albidus* | Martim et al.[49] |
| | *Pleurotus cornucopiae* | Ana et al.[48]<br>Fonseca[80] |
| Amylase 13.63% | *Fomitopsis subtropical*<br>*Neonothopanus nambi*<br>*Perenniporia tephropora* | De Araújo et al.[46] |
| Laccase 4.54% | *Panus lecomtei* | De Araújo et al.[46] |

## IV. DISCUSSION

The most common orders of Agaricomycetes in the Brazilian Amazon were Polyporales, Agaricales, and Hymenochaetales.

The highest occurrence of Polyporales is unusual, as the order Agaricales is the one that represents the greatest diversity of species in the phylum Basidiomycota, which presents about 31,515 species, within the estimate of 1.5 million fungal species.[50]

The order Agaricales has 38 families, 508 genera and about 17,291 known species.[51] In Brazil, all families of Agaricales occur, naturally or introduced, distributed in 170 genera and 1038 species, and of these, 143 species occur in the Amazon.[52] The order Hymenochaetales is composed of 36 genera and 180 species, and 51 species occur in the Amazon.[53]

The Brazilian Amazon has a wide biodiversity and is characterized by a considerable species richness and high levels of endemism. The occurrence of these orders is more frequent in forest biomes, as they find in these places the conditions that guarantee their physiological needs, acting as decomposers of organic matter, mainly cellulose and lignin, and maintaining the environments.[54]

In the record of macroscopic fungi done in the Brazilian Cerrado[55] 95 species of the phylum Agaricomycota, 23 families and 11 orders were identified, with the order Polyporales also being more frequent. *Cyathus* Haller, *Geastrum* Pers., *Phallus* Junius ex L. and *Scleroderma* Pers. were genera described in the state of São Paulo,[56] and *Pycnoporus sanguineus* (L.) Murrill, *Cerrena caperata* (Berk.) Zmitr., *Amauroderma praetervisum* (Pat.) Torrend species reported in the Cerrado.[57]

In a survey of macroscopic fungi, the genera *Phallus* and *Mutinus* Fr. were described for the Pampa and Atlantic Forest biomes.[58] Species of the genus *Lactifluus* (Pers.) Roussel, of the Russulaceae family, have also been reported for the Caatinga biome.[59] *Inonotus rickii* (Pat.) Reid, of the order Hymenochaetales, has records in the Caatinga,[60,61] Cerrado,[62] Atlantic Forest and Pampa.[63,61] Twenty-seven species of the order Geastrales were identified during a survey in the Pampa, among them the genera *Cyathus*, *Geastrum*, *Lycoperdon* Pers. and *Morganella* Zeller,[64] also reported in this work, evidencing the wide distribution in Brazil.

Regarding antimicrobial activity, the most frequently inhibited microorganism was the bacteria *Escherichia coli*, a Gram-negative bacterium. Studies report better results of Agaricomycetes studied against Gram-positive bacteria[65,66] unlike what was found in this work, where 64.27% of fungi were effective against Gram-negative bacteria.

The literature reports that *Pleurotus cornucopiae* (Paulet) Quél. and *Lentinus* Fr. from different biomes also showed positive results against *E. coli*.[67–69] *Lentinus* it also showed positive results against the fungus *Candida albicans*.[69]

Compounds present in *Ganoderma australe* (Fr.) Pat. were able to inhibit the bacteria *E. coli* and *S. aureus* and the fungus *Candida albicans*.[70] This may be because Agaricomycetes species of this genus share these compounds, with similar results being found.

A study with ethanolic extracts of the fungus *Oudemansiella mucida* (Schrad.) Höhn. showed positive activity against the bacteria *Staphylococcus aureus* and *Klebsiella pneumoniae*.[71]

No studies were found with the species *Cerrena caperata*, *Cyclomyces iodinus* (Mont.) Pat., *Cymatoderma* sp., *Trullella polyporoides* (Ryvarden & Iturr.) Zmitr. and *Neolentinus lepideus* (Fr.) Redhead & Ginns, leading to the observation that these were the first works to address the antimicrobial potential for these species.

Regarding antioxidant activity, the only Amazonian Agaricomycete described was *Lentinus crinitus*. Currently the excessive amount of free radical species, which cause oxidative stress, is mainly associated with the pathology of many diseases.[65] Thus, the investigation into natural antioxidants without side effect for safe consumption by people has increased.

The vast majority of mushrooms are reported as a source of bioactive compounds with important pharmacological properties and are considered functional foods.[72] These compounds are mainly phenolic compounds, tocopherols, carotenoids, and phenolic acids,[73] these natural antioxidant compounds being for their anti-inflammatory and anticancer properties.[74,75]

The literature reports that *Pleurotus cornucopiae* (Paulet) Quél. and *Agaricus subrufescens* Peck showed high concentrations of phenolic compounds with antioxidant activities and may be considered functional foods.[76]

For enzymatic activity, the most reported enzymes in this study were xylanase (27.27%), pectinase (22.72%), and cellulase (18.18%). Most of the fungi that showed enzymatic activity for xylanase and cellulase belong to the Polyporales order, possibly due to their role as decomposers of wood and plant residues.[77]

In a study done with textile industrial effluents, the fungus *Fomitopsis pinicola* (Sw.) P. Karst. showed significant levels of biodegradation through the production of ligninolytic enzymes, such as lignin peroxidase and laccase.[78]

The fungus *Marasmius scorodonius* (Fr.) Fr. produced the enzyme laccase when cultivated in dextrose potato broth, this enzyme being capable of degrading dyes such as Congo red and crystal violet.[79]

The fungus *Pleurotus ostreatoroseus* Singer, when cultivated in a culture medium under controlled conditions, was able to produce the enzyme protease.[80] Agaricomycetes have a large enzymatic apparatus used in several industrial branches.[81] The fungus *P. ostreatoroseus* was able to produce the protease enzyme, at a temperature of 40°C and pH 5.0, and also to produce amylase and cellulase.[82] Species of *Trametes* Fr. were also producers of cellulase and laccase enzymes.[83,84]

Other cited species were not found in the literature with records of enzymatic activity, these being pioneering works. No studies were found reporting the production of the lipase enzyme for Amazonian Agaricomycetes.

## V. CONCLUSION

The most common orders of fungi of the Class Agaricomycetes in the Brazilian Amazon are Polyporales, Agaricales and Hymenochaetales, and studies with biological activities, such as antimicrobial, antitumor, antioxidant, anti-inflammatory, immunomodulatory and enzymatic are still scarce. This review shows the need to develop research with fungi of the Phylum Basidiomycota in the Brazilian Amazon.

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