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Scientometric analysis on mushrooms in Brazil: a case study of the family *Agaricaceae* (Kingdom *Fungi*)

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Abstract: Mushrooms of *Agaricaceae* are important in the maintenance of ecological balance, taxonomic issues, as well as in biotechnology interests. This work aimed to evaluate the publications about fungi of this family in Brazil, providing subsidies for projects that seek strategies on the conservation of the group and environment. Thus, a scientometric analysis utilizing the "Web of Science" database on *Agaricaceae* in Brazil revealed 38 documents published during 2002–2022, with the *Universidade Federal do Rio Grande do Norte*, *Universidade Federal do Rio Grande do Sul*, and *Jardim Botânico do Rio de Janeiro* as most productive institutions, and 22 publication sources with Mycotaxon having eight articles. V.G. Cortez, R.M.B. da Silveira, and M.A. Neves stood out as having more published articles, while the most used keywords were: '*Basidiomycota*', '*Agaricaceae*', 'forest', 'phylogeny', and 'state'. We concluded here that studies are still pioneers, serving as a background for future research, and more articles on *Agaricaceae* are expected, due new methods and young researchers trained in Brazilian institutions.

Key words: *Agaricales*, Atlantic Forest, bibliometrics, Neotropic, South America.

Análise cienciométrica sobre cogumelos no Brasil: um estudo de caso da família *Agaricaceae* (Reino Fungi)

Resumo: Os cogumelos da família *Agaricaceae* são importantes na manutenção do equilíbrio ecológico, em questões taxonômicas e informações ecológicas, bem como em interesses biotecnológicos. Também têm relevância nos interesses biotecnológicos entre a comunidade científica e também a população. Este trabalho teve como objetivo avaliar as publicações sobre fungos desta família no Brasil, fornecendo subsídios para projetos que busquem estratégias para a conservação deste grupo de organismos e do meio ambiente. Assim, a análise cienciométrica utilizando a base de dados *Web of Science* sobre *Agaricaceae* no Brasil revelou 38 documentos publicados durante 2002–2022, com a Universidade Federal do Rio Grande do Norte, Universidade Federal do Rio Grande do Sul, e Jardim Botânico do Rio de Janeiro como instituições mais produtivas, e 22 periódicos com Mycotaxon possuindo oito artigos.

V.G. Cortez, R.M.B. da Silveira e M.A. Neves se destacaram por terem mais artigos publicados, enquanto as palavras-chave mais utilizadas foram: '*Basidiomycota*', '*Agaricaceae*', 'floresta', 'filogenia' e 'estado'. Os estudos ainda são pioneiros, servindo de base para pesquisas futuras, sendo esperados mais artigos sobre *Agaricaceae*, devido a novos métodos e jovens pesquisadores formados em instituições brasileiras.

Palavras chave: *Agaricales*, América do Sul, bibliometria, biodiversidade, neotrópico.

Introduction

The Kingdom *Fungi* is one of the megadiverse groups of living organisms (Niskanen *et al.* 2023). They have an important role as bioindicators of ecosystem quality, mostly due to recycling processes in the ecosystems (Gadd *et al.* 2007). Among this kingdom, the order *Agaricales* correspond a group of macrofungi known as 'mushrooms' (Singer 1986), and have been used by humans since prehistoric period (Peintner *et al.* 1998), and used by many civilizations and cultures as religious purposes, and as main source of human's food (Ainsworth 1976). Into this order, the family *Agaricaceae* is a well-defined group characterized by mostly fleshy gilled basidiomes, by bearing a central stem (**Figure 1**) (Singer 1986, Vellinga 2004, Wartchow 2018), and a high scientific and biotechnological interest, as well as insights in gastronomic and medicinal issues (Wasser *et al.* 2003), comprising 51 genera and more than 900 species (He *et al.* 2024).

Ecologically, these organisms are found in substrates rich in organic matter (Gadd *et al.* 2007), with their nutrient uptake absorbed from them after enzymatic secretion, playing an important role in nutrient cycling (Deacon 2006). They also have an important role in the maintenance of ecological balance, as well as taxonomic issues and ecological information, which results in environmental and industrial benefits (Kavanagh 2005).

Bibliometry and scientometry seek to evaluate the impact of scientific research through analytical bibliometric tools in any database (e.g., Pereira & Mugnaini 2023). Among them, the Web of Science database (WoS) is the oldest (Garfield 1964) and most used for authoritative database as parameter by funding agencies, covering more than 34.000 scientific journals (Birkle *et al.* 2020). In this paper, we use scientometry for evaluate the scientific production on the fungi of the family *Agaricaceae* in Brazil, during the interval 2002–2022, based on the information available in this very important indexing database.

Methods

The present study was partially adapted from Carvalho *et al.* (2022) conducted during the year of 2023, with the selection of articles indexed in the WoS during the interval 2002–2022 using the keyword: '*Agaricaceae* Brazil'. We used *Bibliometrix data package* in the R environment for data analysis (Aria & Cuccurullo 2017). The systematic review was conducted according the following methodological steps: (1) establish the time interval for the research and database, (2) definition of the evaluation criteria, (3) analysis of the obtained data, and (4) discussion of these data (Carvalho *et al.* 2022).

In this first moment, the following criteria were here evaluated: (1) the number of publications in Brazil in this time interval and the chronological distribution of the studies; (2) how publications are distributed according to institutions, journals and authors; (3) and the keywords used in the documents. The top twenty positions for each criterion were evaluated in the results of this research. Finally, we perform a discussion and final considerations of the obtained results.

Results

A total of 38 documents published during 2002–2022 on the family *Agaricaceae* in Brazil were retrieved from WoS database (**Table 1**), with two major peaks in 2009 (with five publications) and 2017 (with six) (**Figure 2**).

Figure 1. Basidiomes of two member of *Agaricaceae* showing the general aspect of members of this family. A. *Lepiota* sp. B. *Agaricus* sp. Photo by: F. Wartchow. Scale bar: 10 mm.

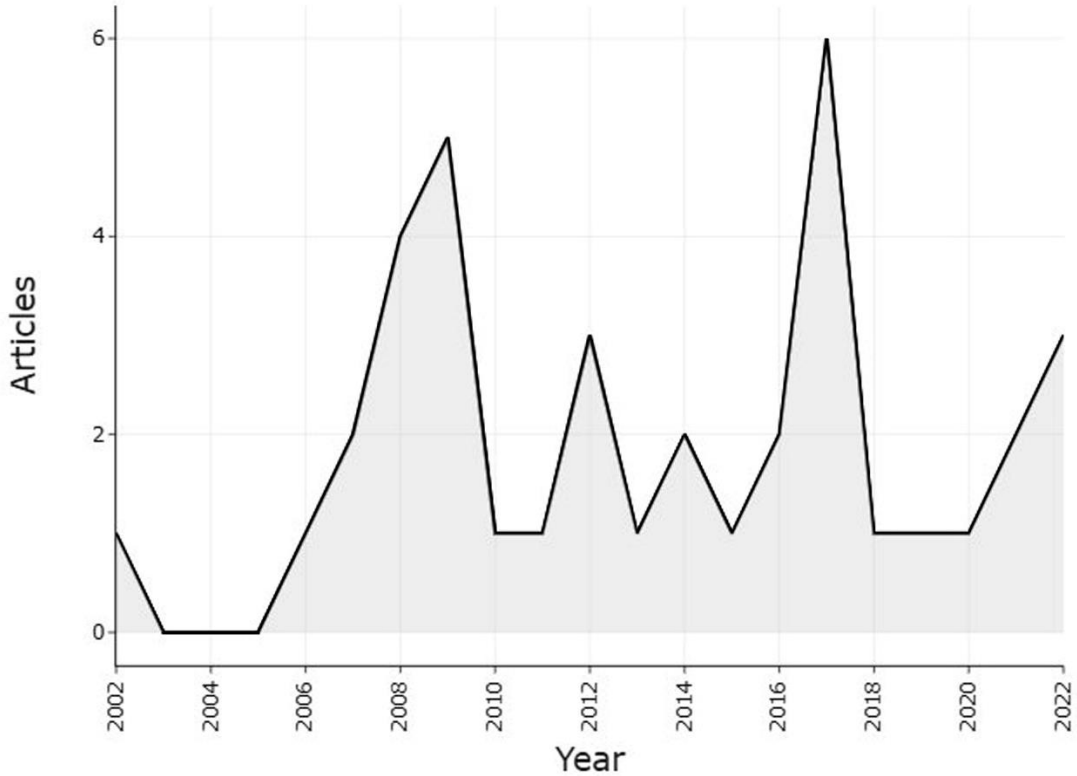

Figure 2. Chronological distribution of scientific publications about *Agaricaceae* from Brazil between 2002–2022, with the peaks in the years of 2009 and 2017.

Table 1. List of documents relating the family *Agaricaceae* in Brazil from January 2002 to December 2022 in WoS database.

Manuscript title	Authors (year)	Journal	DOI / URI
Agaricaceae Fr. (Agaricales, Basidiomycota) from areas of Atlantic Forest in Pernambuco, Brazil	Wartchow F., Putzke J. & Cavalcanti M.A.C. (2008)	Acta Botanica Brasilica	10.1590/S0102-33062008000100026
New records of *Agaricaceae* (Basidiomycota, Agaricales) from Araripe National Forest, Ceará State, Brazil	Nascimento C.C. & Alves M.H. (2014)	Mycosphere	10.5943/mycosphere/5/2/6
Leuocagaricus taniae sp. nov. (Agaricaceae), a sand-dwelling mushroom from Brazil	Heisecke C., Lima D.F., Mueller G.M. & Neves M.A. (2022)	Brittonia	10.1007/s12228-021-09693-6
Leucocoprinus Pat. (Agaricaceae ,Basidiomycota) species in Itapuã State Park, Viamão, Rio Grande do Sul	Rother M.S. & da Silveira R.M.B. (2009a)	Acta Botanica Brasilica	10.1590/S0102-33062009000300011
Leucoagaricus lilaceus (Agaricaceae), a poorly known Neotropical agaric	Rother M.S. & da Silveira R.M.B. (2009b)	Mycotaxon	10.5248/107.473
Taxonomic and nomenclatural novelties in *Leucoagaricus* (Agaricaceae) from Brazil	Heisecke C., Barbosa J.A.D., Neves M.A. & Carvalho Jr. A.A. (2021)	Phytotaxa	10.11646/phytotaxa.494.1.2
Lepiotoid *Agaricaceae* (Basidiomycota) from São Camilo State Park, Parana State, Brazil	Ferreira A.J. & Cortez V.G. (2012)	Mycosphere	10.5943/mycosphere/3/6/11
Calvatia guzmanii sp. nov. (Agaricaceae, Basidiomycota) from Parana State, Brazil	Alves C.R. & Cortez V.G. (2013)	Phytotaxa	10.11646/phytotaxa.85.2.1
Volvate *Macrolepiota* from Brazil: *M. dunensis* sp. nov., *M. sabulosa* var. *velistellaris* var. nov., and observation on *M. pulchella*	Freitas D.S. & Menolli N. (2019)	Mycotaxon	10.5248/134.223
A new species of *Cyathus* (Agaricaceae) from India	Das K., Hembrom M.E., Parihar A. & Zhao R.L. (2016)	Turkish Journal of Botany	10.3906/bot-1311-38
Agaricus globocystidiatus: a new neotropical species with pleurocystidia in *Agaricus* subg. *Minoriopsis*	Drewinski M.D., Menolli N. & Neves M.A. (2017)	Phytotaxa	10.11646/phytotaxa.314.1.4
New records of *Agaricales* from Atlantic Forest fragments of Pernambuco, Northeast Brazil	Wartchow F., Maia L.C. & Cavalcanti M.A.Q. (2011)	Mycotaxon	10.5248/118.137
Taxonomy and phylogeny of *Macrolepiota*: two new species from Brazil	Perez E.F., Blandon S.C.S., Alves-Silva G., Lechner B.E., … (2018)	Mycologia	10.1080/00275514.2018.1500848
Leucocoprinus rhodolepis (Agaricaceae: Basidiomycota), a new species from Brazilian semi-arid region	Ferretti-Cisneros N.U., Silva-Filho A.G.S. & Wartchow F. (2022)	Rev. Mex. Biodivers.	10.22201/ib.20078706e.2022.93.3821
Incidences of poisonings due to *Chlorophyllum molybdites* in the state of Parana, Brazil	Meijer A.A.R., Amazonas M.A.L.D., Rubio G.B.G., … (2007)	Braz. Arch. Biol. Technol.	10.1590/S1516-89132007000300014
Nutritional value of *Agaricus sylvaticus*: mushroom grown in Brazil	Orsine J.V.C., Novaes M.R.C.G. & Asquieri E.R. (2012)	Nutrición Hospitalaria	10.1590/s0212-16112012000200015
A família Agaricaceae Chevall. em trechos de Mata Atlântica da Reserva Biológica do Tinguá, Nova Iguaçu, Rio de Janeiro, Brasil: Gêneros *Agaricus*, *Cystolepiota* e *Lepiota*	Albuquerque M.P., Pereira A.B. & Carvalho Júnior A.A. (2010)	Acta Botanica Brasilica	10.1590/S0102-33062010000200020
Medicinal fungi used by rural communities in Northeastern Brazil	Andrade L.H.C., Barros R.F.M., Lopes J.B. & Sousa S.B. (2021)	Indian J. Tradit. Knowl.	10.56042/ijtk.v20i4.27775
Mushrooms of the genus *Agaricus* as functional foods	Orsine J.V.C., Costa R.V. & Novaes M.R.C.G. (2012)	Nutrición Hospitalaria	10.3305/nh.2012.27.4.5841
Description and affinities of *Agaricus martineziensis*, a rare species	Capelari M., Rosa L.H. & Lachance M.A. (2006)	Fungal Diversity	www.fungaldiversity.org/fdp/sfdp/21-2.pdf
Morganella nuda, a new puffball (Agaricaceae, Basidiomycota) in the upland forests of the Brazilian semi-arid	Alfredo D.S. & Baseia I.G. (2014)	Nova Hedwigia	10.1127/0029-5035/2014/0164
Clarifying the typification of *Tulostoma dumeticola* (Agaricaceae, Basidiomycota)	Trierveiler-Pereira L., Baltazar J.M. & da Silveira R.M.B. (2017)	Phytotaxa	10.11646/phytotaxa.296.3.9
A new species of *Leucoagaricus* (Agaricaceae) from Colombia	Ortiz A., Franco-Molano A.E. & Bacci M. (2008)	Mycotaxon	www.researchgate.net/publication/238523429_A_new
Revision of species previously reported from Brazil under *Morganella*	Alfredo D.S., Baseia I.G., Accioly T., Silva B.D.B., … (2017)	Mycological Progress	10.1007/s11557-017-1332-y
Revision of the Herbarium URM I. Agaricomycetes from the semi-arid region of Brazil	Drechsler-Santos E.R., Wartchow F., Baseia I.G., … (2008)	Mycotaxon	www.researchgate.net/publication/232240417_Revisi
Record of the rare greenhouse fungus *Lepiota elaiophylla* (Agaricales, Agaricaceae) in Prague, Czech Republic…	Holec J. & Halek V. (2008)	Mycotaxon	www.researchgate.net/publication/289137748_Recor
The symbiotic fungus *Leucoagaricus gongylophorus* (Möller) Singer (Agaricales, Agaricaceae) as a target organism to control leaf-cutting ants	Araújo S., Seibert J., Ruani A., Cruz R.A., … (2022)	Insects	10.3390/insects13040359
Two new records of puffballs in Thailand	Kumla J., Suwannarach N. & Lumyong S. (2017)	Mycotaxon	10.5248/132.99
Medicinal mushroom *Agaricus subrufescens* from Iran shares genetic markers with specimens from China and Thailand	Mahdizadeh V., Safaie N., Goltapeh E.M., Asef M.R. … (2017)	Botany	10.1139/cjb-2016-0198
Synergistic effect of aromatic plant essential oils on the ant *Acromyrmex balzani* (Hymenoptera: Formicidae) and antifungal activity on its symbiotic fungus *Leucoagaricus gongylophorus* (Agaricales: Agaricaceae)	Melo C.R., Oliveira B.M.S., Santos A.C.C., Silva J.E., Ribeiro G.T., Blank A.F., Araújo A.P.A. & Bacci L. (2020)	Environmental Science and Pollution Research	10.1007/s11356-020-08170-z
In vitro pharmacological screening of macrofungi extracts from the Brazilian northeastern region	Silva F.S., de Sa M.S., Costa J.F.O., Pinto F.P., … (2009)	Pharmaceutical Biology	10.1080/13880200902755226
Serum hepatic biochemistry and electrophoretic protein profile of healthy and Ehrlich tumor-bearing mice treated with extracts of *Agaricus blazei* Murrill	Verçosa Junior D., Oliveira N.J.F., Duarte E.R., Bastos G.A., Soares A.C.M., Cassali G.D., Soto-Blanco B. & Melo M.M. (2016)	Semina: Ciências Agrária	10.5433/1679-0359.2016v37n2p763
Morganella austromontana sp. nov. from the South Brazilian Plateau	Alves C.R., Cortez V.G. & da Silveira R.M.B. (2017)	Mycotaxon	10.5248/132.281
Antioxidant activity of edible blushing wood mushroom, *Agaricus sylvaticus* Schaeff. (Agaricomycetideae) *in vitro*	Percario S., Naufal A.S., Gennari M.S. & Gennari J.L. (2009)	Int J Med Mushrooms	10.1615/IntJMedMushr.v11.i2.30
Antimicrobial activity of ethanol extracts of *Agaricus brasiliensis* against mutans streptococci	Lund R.G., Del Pino F.A.B.., Serpa R., Nascimento J.S., … (2009)	Pharmaceutical Biology	10.1080/13880200902950801
Biotechnological applications of *Lentinus edodes*	Silva E.S., Cavallazzi J.R.P., Muller G. & Souza J.V.B. (2007)	J. Food Agric. Environ.	www.researchgate.net/publication/264534014_Biotec
Influence of aqueous extract of *Agaricus blazei* on rat liver toxicity induced by different doses of diethylnitrosamine	Barbisan L.F., Miyamoto M., Scolastici C., … (2002)	J. Ethnopharmacol.	10.1016/s0378-8741(02)00171-x
Fungal diversity notes 111-252 – taxonomic and phylogenetic contributions to fungal taxa	Ariyawansa H.A., Hyde K.D., Jayasiri S.C., Buyck B. … (2015)	Fungal Diversity	10.1007/s13225-015-0346-5

The institutions with most published articles were *Universidade Federal do Rio Grande do Norte* (UFRN) with nine publications, *Universidade Federaldo Rio Grande do Sul* (UFRGS) with eight, and *Jardim Botânico do Rio de Janeiro* (JBRJ) with seven (**Figure 3**).

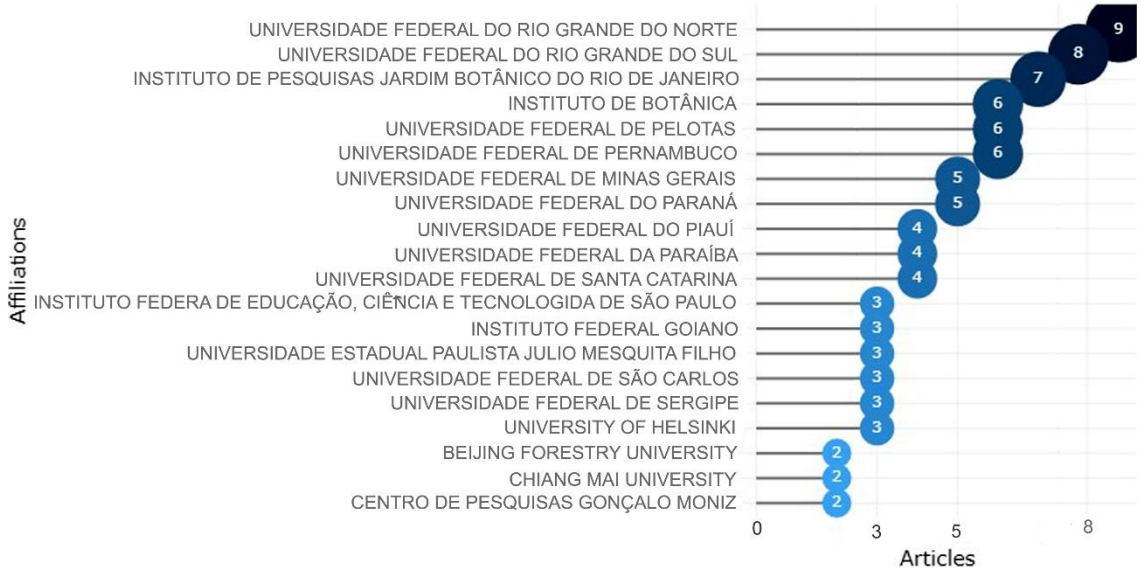

Figure 3. Institutions with more articles published on *Agaricacece* during the interval of 2002–2022 in Brazil based on the adopted methodology.

We found 22 publication sources, with "Mycotaxon" having eight published articles, followed by "Phytotaxa" and "Acta Botanica Brasilica" both having four and three, respectively (**Figure 4**). From the 243 authors who published about this family (**Table 1**), three stood out, authoring equally three publications each: "Cortez V.G." – *Universidade Federal do Paraná* (UFPR), "Da Silveira R.M.B." – UFRGS, and "Neves M.A." – *Universidade Federal de Santa Catarina* (UFSC) (**Figure 5**). Following such authors, we also observed eleven researchers with two articles each (**Figure 5**). Regarding the keywords, a total of 130 were mostly used, with "Basidiomycota" being reproduced eight, "Agaricaceae" five times and "forest", "phylogeny", and "state" used four times each (**Figure 6**).

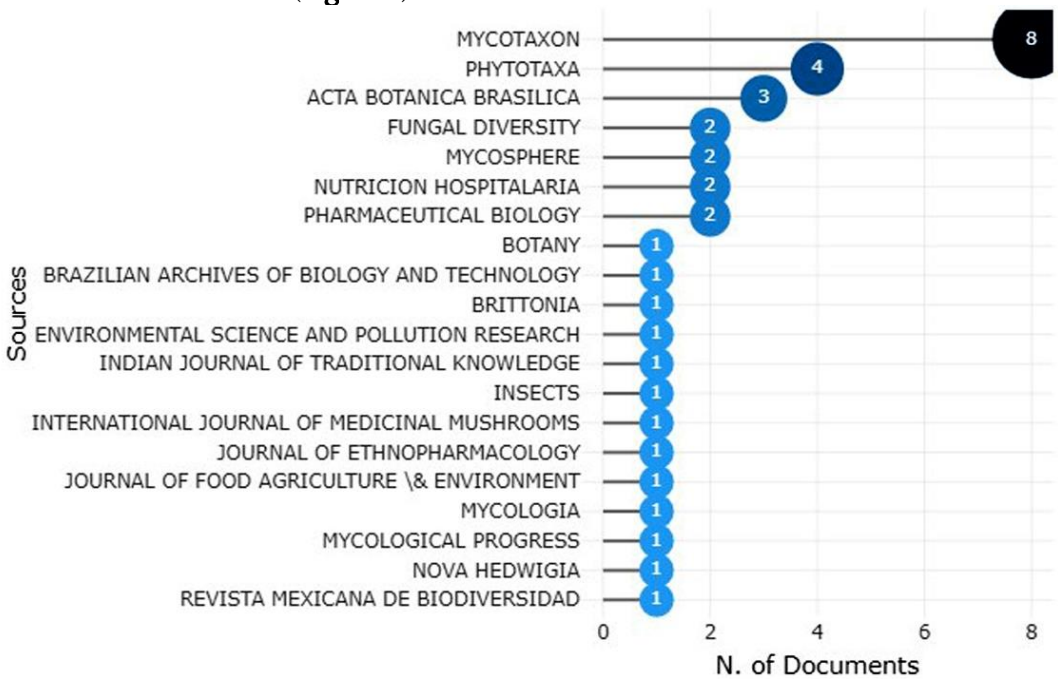

Figure 4. Twenty (20) journals with more articles on the family *Agaricaceae* published between 2002–2022 in Brazil based on the adopted methodology.

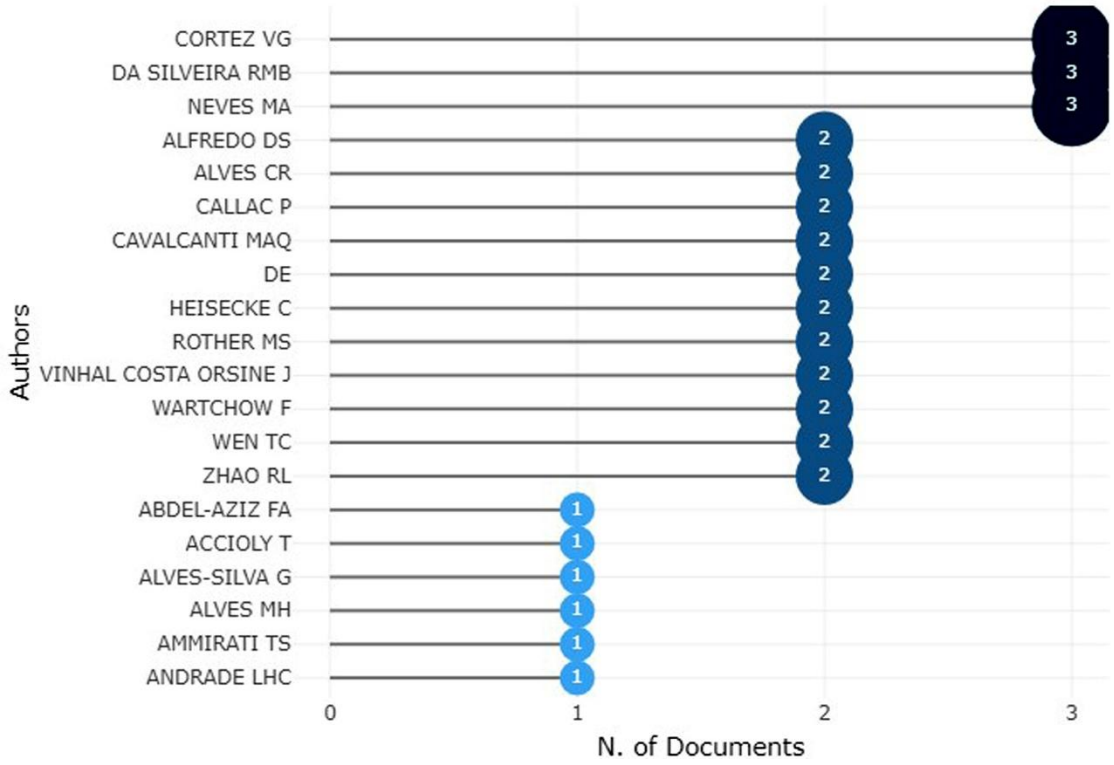

Figure 5. List of authors with more articled published about the family *Agaricaceae* between 2002–2022 in Brazil.

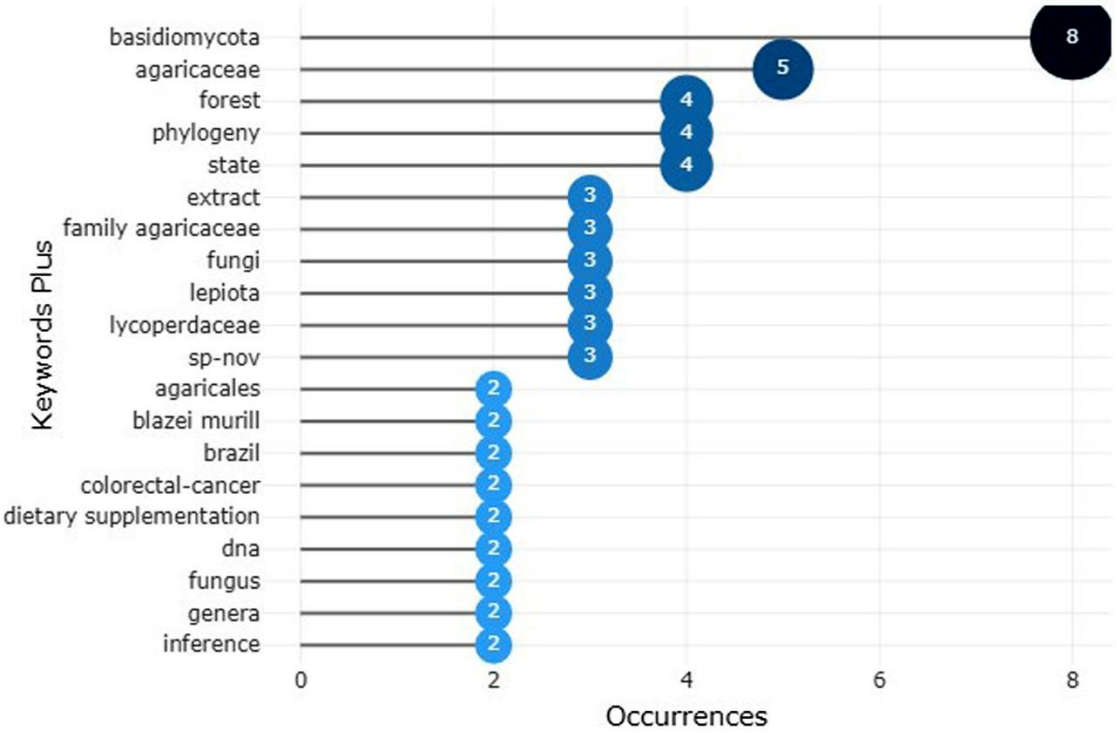

Figure 6. Most cited keywords in publications about *Agaricaceae* obtained between 2002–2022, with *Basidiomycota* being the most used.

Discussion

Brazil is recognized as a megadiverse country with an estimated fungal richness about seven times greater than what is described (Lewinsohn & Prado 2005). However, there is still an

underestimated number of scientific studies mainly on mushrooms of the family *Agaricaceae*, which does not reflect the fungal diversity in the country, where many species are still unknown to science (Niskanen *et al.* 2023). The periodic descriptions of new species of fungi for the northeastern and southern Brazil, mainly of *Agaricaceae* (e.g., *Chlorophyllum tenue* E. Falcão, Ferretti-Cisn., Silva-Filho, Koroiva & Wartchow, *Leucoagaricus nzumbae* C. Heisecke, A.A. Carvalho & M.A. Neves, *La. taniae* C. Heisecke & M.A. Neves, *Leucocoprinus attinorum* S. Urrea-Valencia, A. Rodrigues & R.J. Bizarria, *Lc. dunensis* S. Urrea-Valencia, A. Rodrigues & R.J. Bizarria, *Lc. rhodolepis* Ferretti-Cisn. & Wartchow, *Macrolepiota capelariae* A.D. Souza, C.C. Nascimento & Menolli, and *M. capelariae* var. *sororivulpina* E. Falcão & Wartchow) demonstrate the underestimated knowledge of the group in the country (Heisecke *et al.* 2021-2022, Ferretti-Cisneros *et al.* 2022, Souza *et al.* 2023, Urrea-Valencia *et al.* 2023, Falcão & Wartchow 2024, Falcão *et al.* 2025).

A reason for the somewhat low number of publications is due to the fact that the studies are restricted to regions with more active groups of mycologists (Maia *et al.* 2015) and that also work on other families (Carvalho *et al.* 2022). Another reason is mostly due they correspond to unpublished works (i.e., master dissertation and doctoral thesis), or the journals that are not indexed in the database analyzed here as well as other relevant databases such as Scopus (Carvalho *et al.* 2022).

Studies by Vetrone *et al.* (2023) considered a period of 2003-2021 for medicinal fungi. Different from our study, such researchers noted an exponent increase of published documents, with more than hundred publications indexed in WoS during this period. It probably occurred because these studies are focused on health science instead taxonomy, a neglected area of knowledge (e.g., Ely *et al.* 2017).

UFRN (northeastern Brazil), JBRJ (southeastern Brazil) and UFRGS (southern Brazil) are Brazilian institutions that stand out in terms of scientific production on the fungi of the family *Agaricaceae*, mainly because of infrastructure and human resources (experts) (Velloso *et al.* 2004, Vans *et al.* 2018). Three authors with more published studies on the family *Agaricaceae* and order *Agaricales* belong to institutions localized in southern Brazil (**Figure 5**) (Carvalho *et al.* 2022). A recent decrease in funding for biodiversity and environmental studies carried out by young researchers has negatively influenced the expansion of scientific production (Guedes *et al.* 2023).

Among the journals with more published articles on *Agaricaceae* (**Figure 4**), 'Mycotaxon' had a focus and scope restricted to taxonomy and nomenclature of fungi (https://www.mycotaxon.com/index.html), while 'Phytotaxa' (https://phytotaxa.mapress.com/pt/about), and 'Acta Botanica Brasilica' (https://www.scielo.br/j/abb/) share similar scope on nomenclature and taxonomy in plants and also fungi, both areas of knowledge with the largest number of published articles in *Agaricaceae* from Brazil.

For a long time, keywords are considered important for research indexing (e.g., Harter 1975) in a number of online databases, including the WoS (Roth 2005). During the target period (2002–2022), "basidiomycota", "agaricaceae", "forest", "phylogeny", and "state" were the most used keywords (**Figure 6**). The first keyword is due systematic classification of the family into the phylum *Basidiomycota* (He *et al.* 2024). On the other hand, the keyword "agaricales", representing the order *Agaricales* where *Agaricaceae* is nested (Singer 1986), did not appear in the first twenty listed keywords of the analyzed contents, differently when searching the indexed articles on this order (Carvalho *et al.* 2022). As an important tool for systematic (Hyde *et al.* 2013), the keyword "phylogeny", is also frequently used (**Figure 6**). Words regarding the habitat such as "Atlantic Forest" (a biome found in many Brazilian States) are also well used (**Figure 6**) (IBGE 2004, 2012). Such a biome is an ecosystem where most of the studies on Agaricaceae were performed (Wartchow 2018) mainly due the localization of the research institutions with more human resources in comparison to other biomes (Carvalho *et al.* 2022).

Even so, although a satisfactory number of published articles on *Agaricaceae* in Brazil between 2002–2022, these studies might be yet considered pioneers serving as a starting point for future research through modern methods in identifying and describing fungi, as for

example, phylogenetic analysis (e.g., Kooij *et al.* 2024). However, this factor is directly proportional to financial investment in research offered by the Brazilian funding agencies (McManus & Baeta Neves 2021, Carvalho *et al.* 2022), and presence of mycologists in the institutions (Carvalho *et al.* 2022). There is a greater participation of Brazilian researchers in studies on the family *Agaricaceae* (see **Figure 6**) and order *Agaricales* (Carvalho *et al.* 2022). This condition is also important in training human resources in taxonomy and systematics through scholarships and grants (McManus *et al.* 2021, Ribeiro 2024), contributing to the knowledge of the richness and biodiversity of the group in Brazil.

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Conflicts of interest

The authors declare no relevant conflicts of interest.

Data availability statements

The dataset of the analyses can be requested to the corresponding author.

Author contributions

Hugo Leite Santos Campos: Conceptualization (Lead), Data curation (Lead), Formal analysis (Lead), Software (Lead), Visualization (supporting), Writing – original draft (supporting). Felipe Wartchow: Funding acquisition (Lead), Methodology (Supporting), Project administration (Lead), Validation (Lead), Writing – review & editing (Lead).

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