Review

Microbial Biosystems 8(2) (2023) 2023. 328318
10.21608/mb.2023.328318

Contents lists available at Egyptian Knowledge Bank
Microbial Biosystems
Journal homepage: http://mb.journals.ekb.eg/

Fungi in Egypt: A bibliometric analysis of current research and future prospects

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ARTICLE INFO

Article history
Received 25 July 2023
Received revised 25 October 2023
Accepted 25 November 2023
Available online 7 December 2023

Corresponding Editors:
Abdel-Azeem M. A.
Mohamed A. H.

Keywords
Abstract,
article title,
endophytic fungi,
H-index,
keywords,
mycology.

ABSTRACT

Fungi constitute one of the most pivotal components of our planet's ecosystems, playing multifaceted roles crucial to the environment, industries, agriculture, and beyond. Despite their profound significance, mycological research in Egypt has, to some extent, been overlooked. Over an extended period, crucial information concerning scientific activity and publication rates has been lacking. It is imperative to integrate advancements in statistical analysis with scientific research to discern future research directions and potential limitations. This review undertakes a comprehensive bibliometric analysis of mycological research trends in Egypt. Our study employs innovative bibliometric tools, such as bibliometrix and VOSviewer, to analyze data extracted from three databases (Scopus, Web of Science, & CABI). The study highlights the peak publishing periods, with the highest rates observed between 2012-2022 for Web of Science and 2013-2021 for Scopus & CABI. Consequently, the review enables the identification of knowledge gaps and monitoring the dynamics of research activity, fostering the growth of mycological research, and contributing to the conservation of fungi in Egypt.

Published by Arab Society for Fungal Conservation

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Introduction

Fungi are largely invisible ecosystem engineers. Most live as branching, fusing networks of tubular cells known as hyphae and mycelium. Globally, the total length of fungal mycelium in the top 10 cm of soil is more than 450 quadrillion km, id est about half the width of our galaxy (Kiers and Sheldrake 2022; Abo Nahas et al. 2023).

Where plants produce, animals consume, and fungi recycle as a great player in the ecosystem. The potential and significance of fungi in ecosystem services, such as bioremediation, pollution reduction, and as a source for manufacturing of medications to treat various human diseases, have been demonstrated through practical studies. Additionally, fungi are considered one of the most excellent sources of nutrients, cosmetics, proteins, vitamins, lipids, and minerals (Niego et al. 2023). In other words, fungi are incredibly important for both the environment and human health. It is mandatory to identify, and conserve fungal diversity to protect fungal resources, understand and predict how ecosystems function, and learn about the evolution and dissemination of fungal diseases (Lofgren and Stajich 2021).

Documentation of fungi and mycological work in Egypt is overlooked, till Abdel-Azeem (2010) published his pioneer comprehensive review of Egyptian mycology, which included a checklist of 2281 fungal species and an assessment of future perspectives for mycology research in Egypt. Abdel-Azeem et al. (2020 a) studied the mapping fungal ignorance: Checklists of fungi and fungal-like organisms known for Egypt in two centuries. They mentioned that the documentation of fungal diversity in Egypt is urgently needed because natural habitats worldwide are being lost on a large scale through climate change and to promote proper exploration as a tool to facilitate fungal identification and to aid conceptualization and justification of future research projects.

Bibliometrics (scientometric) is a quantitative statistical method for assessing the power and significance of scientific publications. Bibliometric analysis can be vital in tracking evolution in a particular field, identify gaps between research, and spot novel patterns in article and journal performance (dos Santos 2022; Alegre and Pastore 2023). It is important to point out that the development of scientific databases including Scopus and Web of Science (WOS) has made it relatively simple to create large volumes of bibliometric data, and bibliometric software like Gephi, Leximancer, and VOSviewer. This facilitated the analysis of such data in a very practical and convenient way (Donthu et al. 2021). Therefore, increased academic interest in using bibliometric analysis was shown as it made it easier for researchers to access a wide range of scientific data.

The approaches used in bibliometric analysis can be categorized into two main types: performance analysis and science mapping. Performance analysis involves assessing the contributions of various research components. Reviews often report on the progress of different research elements like authors, institutions, countries, and journals, making performance analysis a common feature in most reviews, including those without science mapping. In contrast, science mapping focuses specifically on exploring the connections between different research components (Donthu et al. 2021). Both performance analysis and science mapping are presented in figure (1).

Our study utilized bibliometrics to analyze data from three significant databases namely: Web of Science, Scopus, and Centre for Agriculture and Bioscience International (CABI). Scopus and Web of Science stand out as the two most extensively used citation databases globally. Scopus, being a comprehensive multifunctional database, incorporates references and abstracts from peer-reviewed journal articles, business publications, books, records, and conference proceedings. On the other hand, Web of Science encompasses nearly 11,400 journals in over 45 languages. CABI, recognized for its coverage of Egyptian publications, comprises multiple bibliographic databases with a total of 8.8 million bibliographic records ("CAB Direct," n.d.). So, to cover the performance of mycological research in Egypt, those 3 databases were selected for their relevance in scientific community.

The databases were initially searched to gather all information related to fungi in Egypt. Subsequently, the results were refined to ensure greater accuracy regarding either the fungi or the nationality of authors (i.e., whether the research was conducted in Egypt or elsewhere). Following this, the data were exported in BibTeX format and document texts. Data analysis was primarily carried out using Excel, along with two software tools: Bibliometrix and VOSviewer. The outcomes encompassed the highest publication rates in Egyptian universities, the most prolific authors and their h-index, leading journals, the annual number of research papers on fungi in Egypt, and more.

This review seeks to bridge the gap in fungal research in Egypt, track citations, and promote the use of bibliometric analysis in future studies, aiding scientists in enhancing their scientific reproducibility and activity

Materials and Methods

From the publications available on the platforms Web of Science, Scopus, and CABI, a study has been performed. For Web of Science data base, a combination of keywords was made using "AND" and "OR" as following: ("fungi" OR "fungus" OR "Endophytic" OR "Endophytes" OR "Blastomycosis" OR "Coprophilous" OR "Candidiasis"

OR "Aspergillosis" OR "Cryptococcosis" OR "Coccidioidomycosis" OR "fimicola" OR "plant pathogens" OR "powdery mildew" OR "Basidiomycota" OR "Ascomycota" OR "Hyphomycetes" OR "Dueteromycetes" OR "ascomycetes" OR "Chytridiomycota" OR "Zygomycota" OR "micromycete" OR "macromycete" OR "antifungal" OR "mold" OR "yeast" OR "fungal") AND ("Egypt"). The used search terms were "Topics", "Titles", "Abstracts" and "keywords". For Scopus database, the search term was "Article title, Abstract, Keywords" with the same keywords combination. As for CABI database search keywords were "fungi in Egypt" with no limitation options applied. All search results were individually evaluated based on compliance with the core topic of the research.

For every article retrieved from Web of Science and Scopus databases, the following data was registered: Year of publication, average citation of article per year, the journal in which the article was published, H-index for each journal, area of concentration, keywords and co-occurrence between them, authors and co-authors, H-index for each author, national affiliation of authors and co-authors, most cited articles, collaboration between affiliations and journals. The study was performed using the package "bibliometrix R core team 2020" (Aria and Cuccurullo, 2017). Visualization and bibliographic maps were made using the software "VOSviewer 1.6.19" and the line graph maker tool in "RabidTables" website.

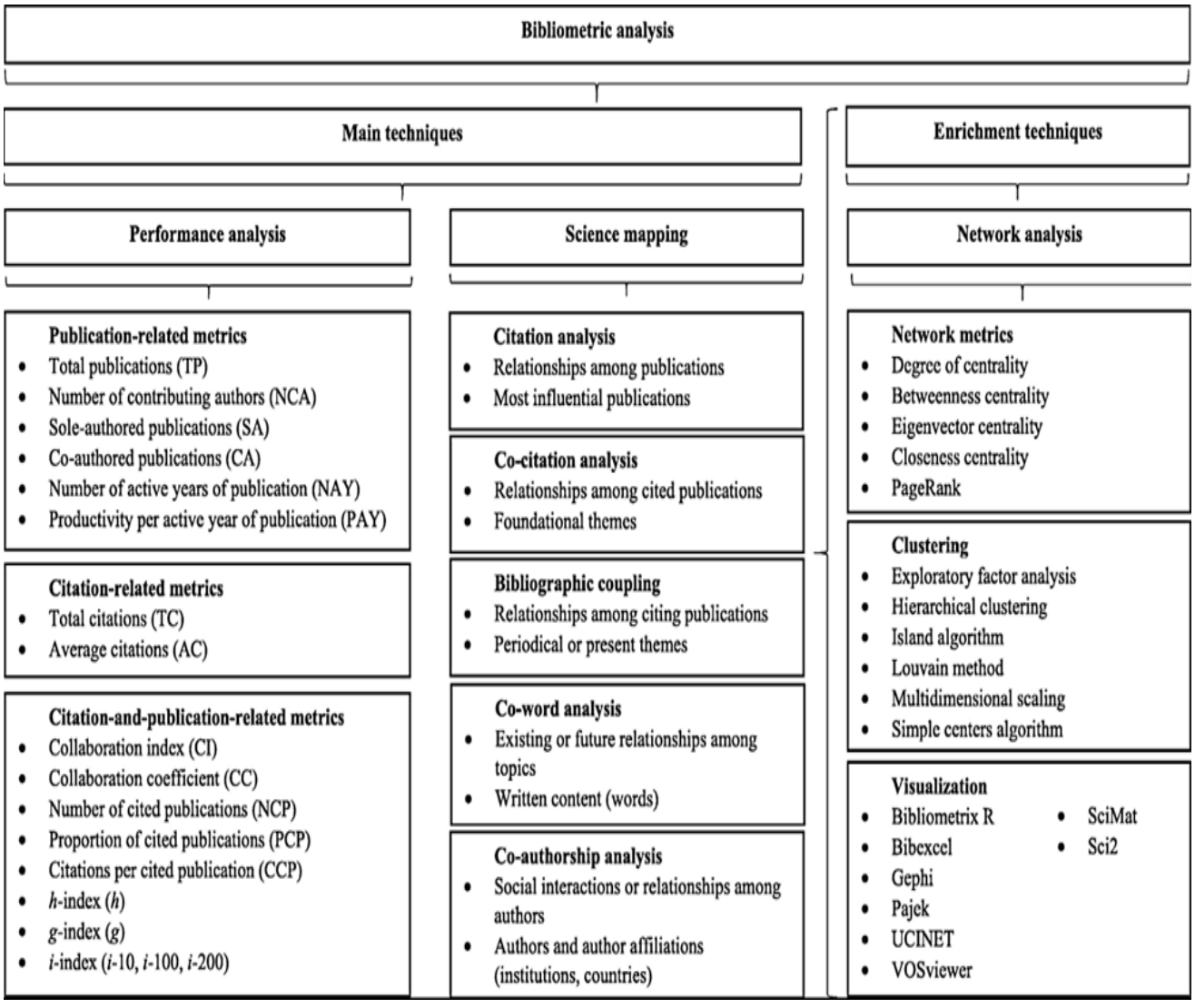

Fig 1. The bibliometric analysis toolbox after Donthu et al. (2021).

For the publications retrieved from CABI database only the following information could be recorded: publication year, publication type, authors and co-authors of each publication, institution of each author, publisher of each article, the journal in which the article was published and the language of each article.

All statistical analyses were made with Excel Office 365 (Version 16) for windows 10. All figures were created using R studio software Ver. 2023.06.2+561 for Mac OS.

Results

Initial search in the 3 databases resulted in 1335, 2089 and 11548 scientific articles in Web of Science, Scopus and CABI, respectively. Out of which 788, 1228 and 3565 articles were filtered from Web of Science, Scopus and CABI, respectively. Table (1) shows a comparison of the general information of the articles analyzed from the Web of Science and Scopus database.

Table 1 General information about publications from Web of Science and Scopus databases

Point of Comparison	Web of Science	Scopus
Time span	1956 - 2023	1934 - 2023
Annual growth rate	4.86%	2.36%
Average citation/article	11.35	12.3
No. of keywords	2324	3136
Total No. of authors	2159	3167
Average No. of co-authors per article	4	4
No. of single authored articles	95	168
No. of sources	345	538

Web of Science (WOS) and Scopus

The first document available on the Web of Science database was a single-authored essay published in 1956 under the title "A CONTRIBUTION TO THE FUNGI OF EGYPT," while the first document available on Scopus was published in 1934 under the subject "Entomogenous fungi of Egypt."

Out of the 1228 documents retrieved from Scopus, 1171 were research articles and only 17 were categorized as review articles. For the Web of Science database, 726 out of 788 documents were research articles and only 9 were review articles.

Scopus and WOS databases show a very low number of publications per year until the 1990s period (Figs 2, 3). The highest peak in the number of articles per year for the Scopus database was in 2021 with 103 publications, on the other hand WOS database's highest peak was in 2022 with 69 publications. The highest rate of increase in number of publications per year was between 2012 and 2022 for the WOS database, and between 2013 and 2021 for the Scopus database.

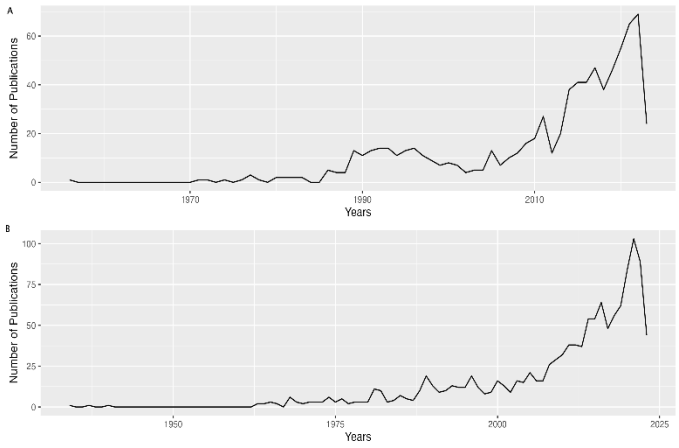

Fig 2. The number of publications per year: A- WOS, and B- Scopus.

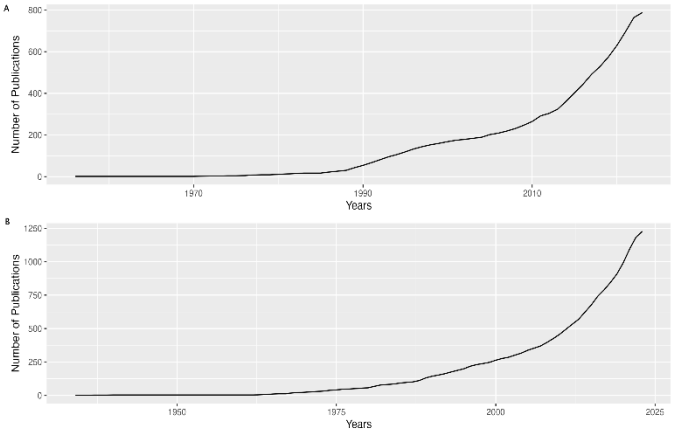

Fig 3. The cumulative number of publications each year: A- WOS, and B- Scopus.

With a mean citation per year score of 2.73 for the WOS database, 2006 had the greatest average citations per year (Fig. 4A). The papers "Antifungal efficacy of chitosan and its thiourea derivatives upon the growth of some sugar-beet pathogens" (Eweis et al. 2006) and "Evaluation of pan-fungal PCR assay and Aspergillus antigen detection in the diagnosis of invasive fungal infections in high-risk pediatric cancer patients" (El-

Mahallawy et al., 2006) have a peak impact for this particular year and are attributed to them. These papers were published in the journals "International Journal of Biological Macromolecules" and "Medical Mycology," respectively, and have 184 and 62 citations.

As for the Scopus database, the highest average citation per year was in 2018 with a mean citation per year score of 2.51 (Fig. 4B). The most cited article in that year is “Eco-friendly cellulose nano fibers via first reported Egyptian *Humicola fuscoatra* Egyptia X4: Isolation and characterization.” (Hasanin et al., 2018) published in: “Environmental Nanotechnology, Monitoring and Management” with a citation score of 80 followed by “Effect of *Thermomyces* fungal endophyte isolated from extreme hot desert-adapted plant on heat stress tolerance of cucumber” (Ali et al., 2018) published in: “Applied Soil Ecology” with citation score of 58.

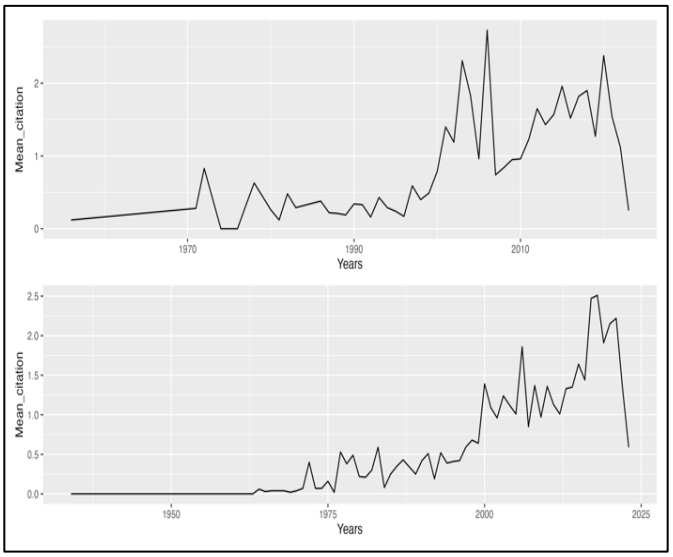

Fig4. The mean citation per year. A- WOS database, and B- Scopus database.

In both databases, the journals “Egyptian Journal of Biological Pest Control” and “Mycopathologia” had the highest number of published articles. “Egyptian Journal of Biological Pest Control” placed first with a total number of articles of 55 and 64 in Scopus and WOS, respectively, followed by “Mycopathologia” with 47 and 27 articles in Scopus and WOS, respectively. Figures 5A and 5B demonstrate the top 10 journals in both databases.

As for the H-index of journals, “Mycopathologia” placed first in both Scopus and WOS with H-index of 20 in Scopus and 14 in WOS. Followed by “Egyptian Journal of Biological Pest Control” with H-index of 11 in both databases. Figures 6A and 6B show the top 10 journals regarding H-index.

Overall journal production over time in WOS explained in figure (6C) and in Scopus explained in figure (6D).

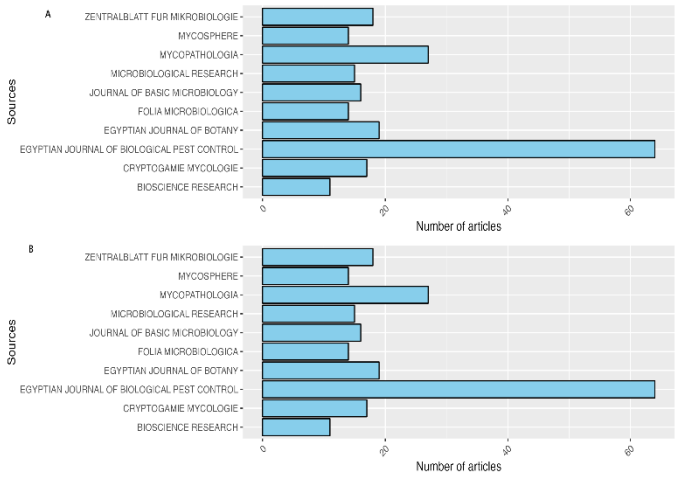

Fig 5. The top 10 journals, A- Scopus database, and B- WOS database.

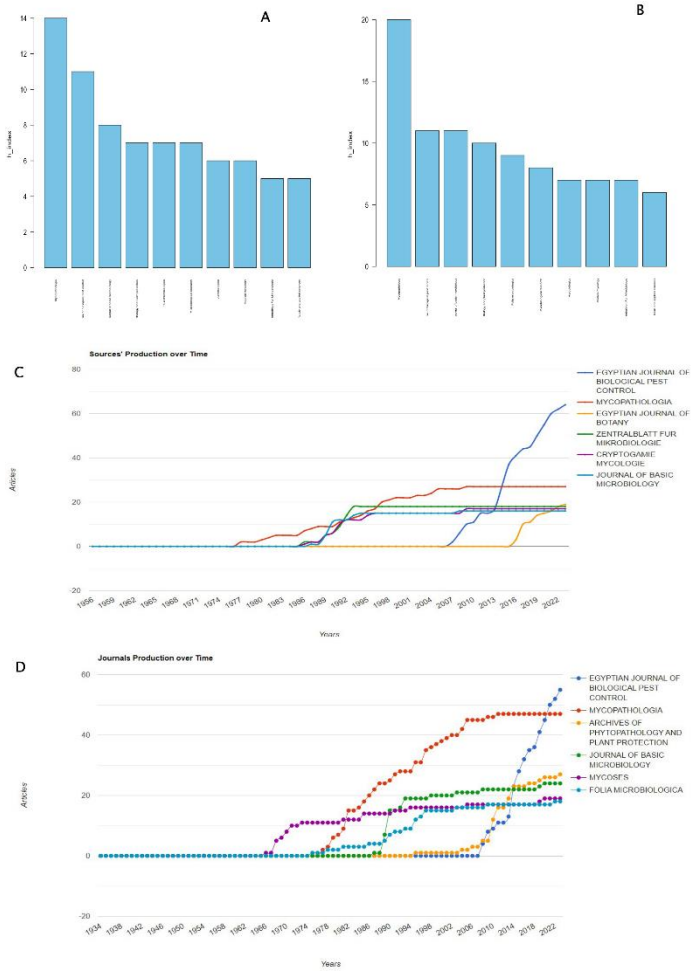

Fig 6. The top 10 journals regarding H-index, A- WOS, B- Scopus, C- Journals’ production over time in WOS, and D- Journals’ production over time in Scopus.

As for authors' activity and production, Scopus demonstrated a higher number of authors than Web of Science. The most productive author on Web of Science was **Bagy** MMK with 18 articles followed by **Abdel-Azeem AM** with 14 articles. On the other hand, the most productive author on Scopus was **Moubasher** AH with 22 articles, followed by **Abdel-Hafez** SII with 20 articles. Figure 7 (A and B) shows the 10 most productive authors in both databases.

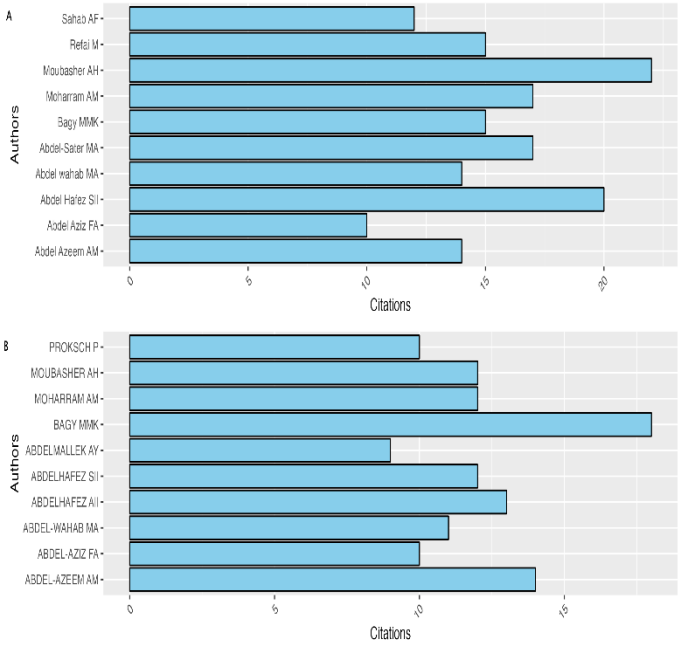

Fig 7. The most productive authors, A- Scopus, and B- WOS.

The author with the highest H-index in Scopus records was the late professor **Moubasher** AH with H-index of 13 followed by late professor **Abdel-Hafez** SII with H-index of 11. Authors with the highest H-index in Web of Science were **Moubasher** AH and **Proksch**. P with H-index of 9 and 8, respectively (Fig. 8 A and B**)**.

The most locally cited author in Scopus was **Esmail** SM with 15 local citations followed by **Abdel-Kader** MM with 14 local citations. On the other hand, the most locally cited author in Web of Science was **Abdel-Wahab** MA with 31 local citations followed by **Abdel-Aziz** FA with 23 local citations. Figure 9 (A and B) represents authors with the highest local citations.

The search for the most used keywords revealed that "Egypt", "Fungi", and "Biological control" were the most used keywords in both databases. On the other hand, the most used bi-words in titles were "Biological control", "Upper Egypt" and "Fungi isolated" in both databases. The most used keywords in both databases while, were represented in figure 10, while figure 11 shows the most used bi-words in titles in both databases.

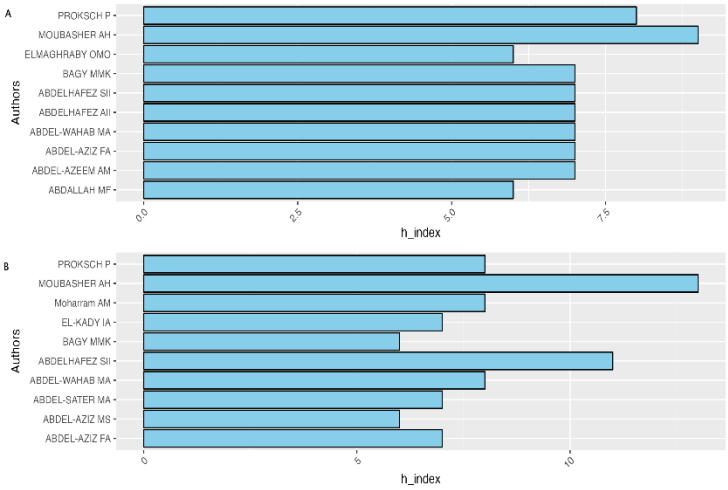

Fig 8. The most productive authors, A- Scopus, and B- WOS.

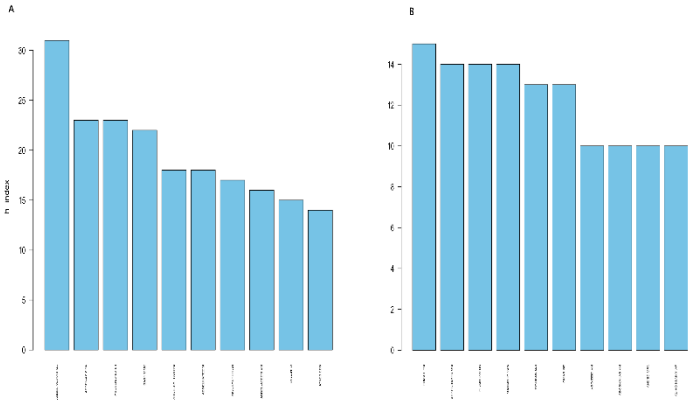

Fig 9. Authors with high local citation, A- WOS, and B- Scopus.

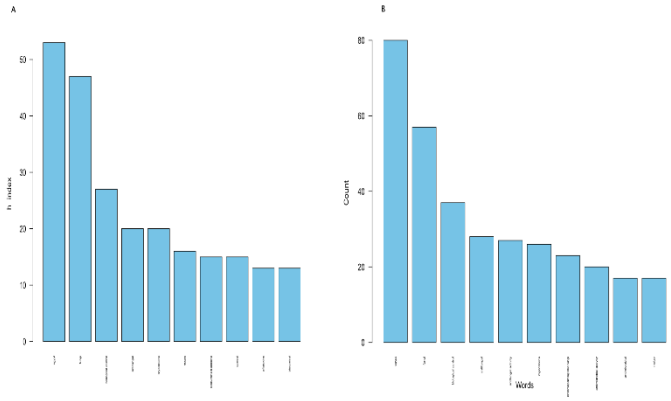

Fig 10. The most used keywords, A- WOS, and B- Scopus.

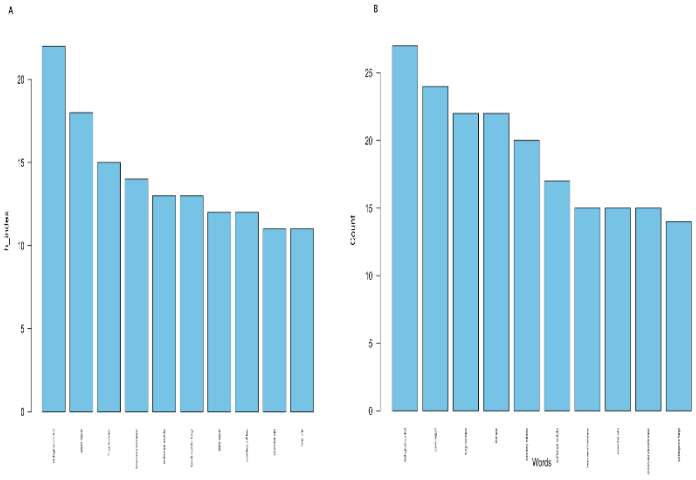

Fig 11. The most used bi-words in titles, A- WOS, and B- Scopus.

When the most productive affiliations in both databases were compared, it was discovered that The National Research Center was the most productive institution in Web of Science with 212 published articles, followed by Assiut University with 203 published articles. In the Scopus database, Assiut University had the most active affiliation with 204 publications, followed by Cairo University with 200 articles (Fig. 12).

Table (2) compares the top funding agencies in both databases. The National Research Center ranked first in both databases, with 20 articles in WOS and 29 in Scopus. Science and technology development financing (STDF) ranked second, with 20 articles in WOS and 9 in Scopus.

The study of scientific research categories of the available articles in Scopus database shows that 30% of publications are categorized as agricultural and biological sciences, 14% are under the category of Immunology and microbiology and 12% are categorized as medicine articles.

Figure 13 depicts the whole category distribution of articles in the Scopus database. Figure 14 depicts a bibliographic coupling map based on the number of references shared by affiliations, journals, or authors. It demonstrates that Cairo University shares the most resources with the National Research Center, the Agriculture Research Center, and Al-Azhar University. Figure 15 is a co-authorship map that illustrates the number of articles shared by affiliations, journals, and authors. It has been discovered that the National Research Center shares the most papers with Cairo University, the Agriculture Research Center, and Al-Azhar University. To keep things simple, only associations with 20 or more articles are displayed.

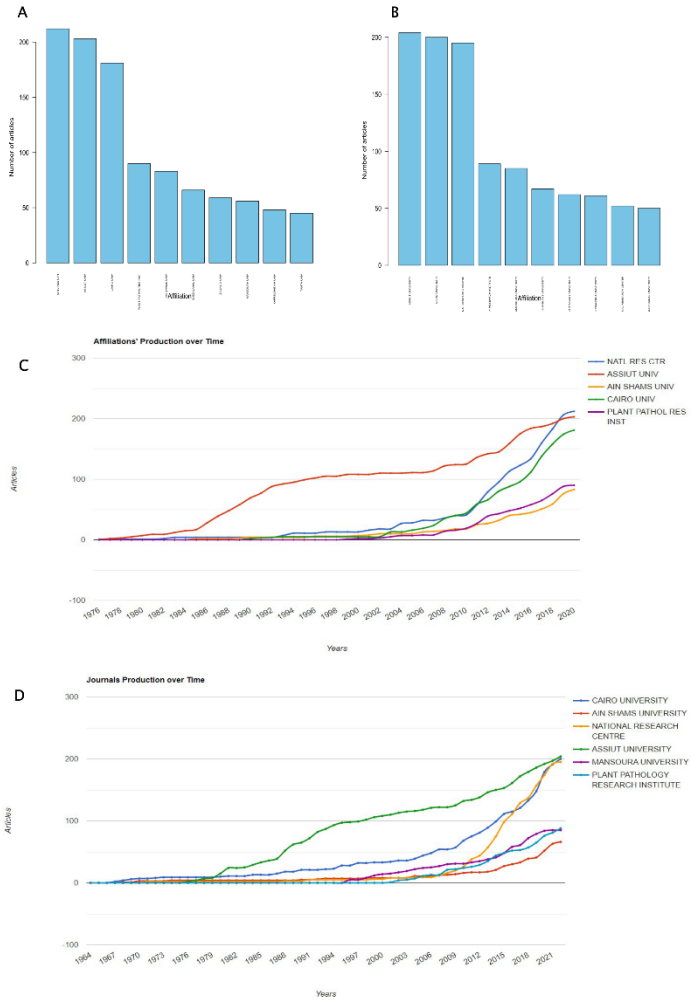

Fig 12. The most productive affiliations, A- Scopus, B- WOS, C- Affiliations' production over time in WOS, and D- Affiliations' production over time in Scopus.

CABI

The number of publications per year, publishing type, number of articles per publisher, number of articles per author, number of articles per institution, and number of articles per source were the only parameters for which data could be extracted from the CABI database. Figure 16A shows the annual number of articles pertaining to the CABI database, and Figure 16B shows the total annual number of articles.

1969 saw the publication of the first paper in the CABI database, along with three further articles in that same year. In contrast to the databases of Scopus and WOS, CABI had a respectable annual volume of papers during the 1960s and 1980s. The yearly scientific production curve also showed two peaks: the first occurred in 2013 with 139 articles, and the second in 2020 with 144

articles. In 2021, the number of publications decreased to 143. Nevertheless, at this time, we are unable to obtain the entire number of publications in 2023.

Table 2 Top funding agencies in Scopus and Web of Science database

Agencies	Databases	
	Scopus	WOS
National research center	29	20
STDF	9	20
Cairo University	8	-
Taif University	8	-
Bundesministerium für Bildung und Forschung	7	-
Assiut University	6	6
Deanship of Scientific Research, King Saud University	6	-
Academy of Scientific Research and Technology	5	-
Alexandria University	5	-
Deutscher Akademischer Austauschdienst	5	6
Federal Ministry of Education Research Bmbf	-	9
King Saud University	-	9
Ministry Of Higher Education Scientific Research Mhesr	-	9
Sohag University	-	9
Egyptian Government	-	5
Egyptian Knowledge Bank	-	5

Table 3 The distribution of publication type in CABI database

Publication type.	Number of publications.
Journal article	3320
Conference paper/Journal article	102
Conference paper	82
Miscellaneous	26
Book chapter/Conference paper	13
Conference proceedings	4
Abstract only	3
Correspondence	3
Journal issue	3
Issues/Conference proceedings	3
Abstract/Conference paper	2
Book	1
Book chapter	1
Thesis/Abstract only	1

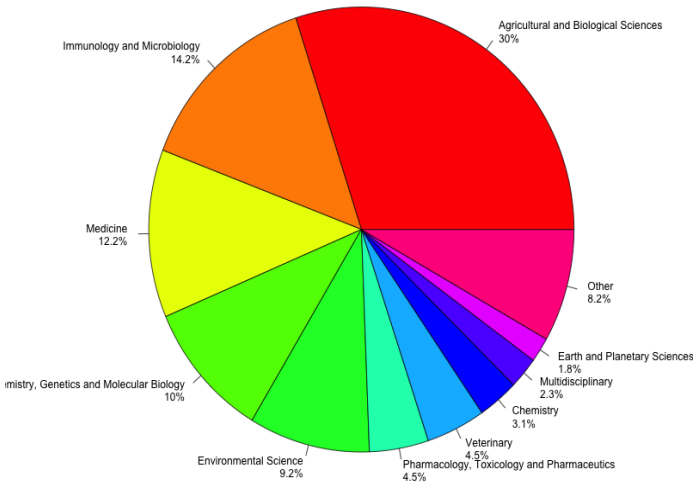

Fig 13. The Scientific categories of articles in Scopus database.

Journal articles made up about 93.1% of all publications on the CABI database; the remaining 6.9% was split among the various publication types, as shown in Table 3.

With 148 publications, Springer ranked first among other publishers; National Center of Information and Documentation (NIDOC) came in second with 107 publications. The total number of publications for each publisher is summarized in Table 4. To simplicity, publishers with fewer than 20 publications are disregarded.

Moubasher, A. H., with 47 articles, and Abdel-Hafez, S. I. I., with 36 publications, were the most productive authors on the CABI database. The top 10 productive authors in CABI are displayed in figure 17.

Figure 18, Similar to the Scopus and WOS databases, the National Research Center had 425 publications, making it the most productive affiliation in CABI. Next in line were the Agriculture Research Center and the Assiut University, with 399 and 355 articles, respectively.

With 176 articles, Agricultural Research Review had the most publications in the CABI database (Fig. 19). Egyptian Journal of Phytopathology and Egyptian Journal of Biological Pest Control came in second and third, with 119 and 110 publications, respectively.

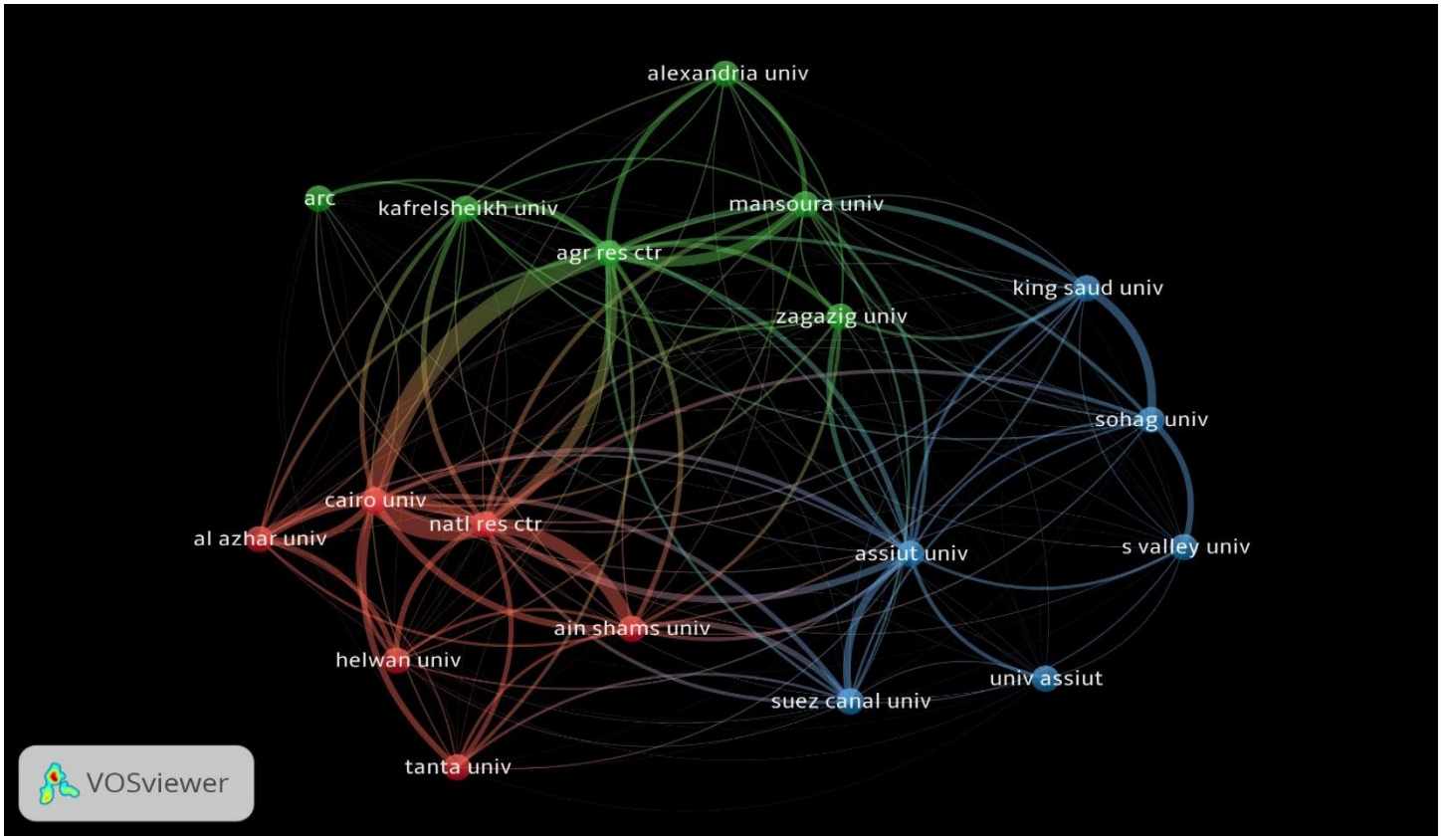

Fig 14. Bibliographic coupling map of affiliations.

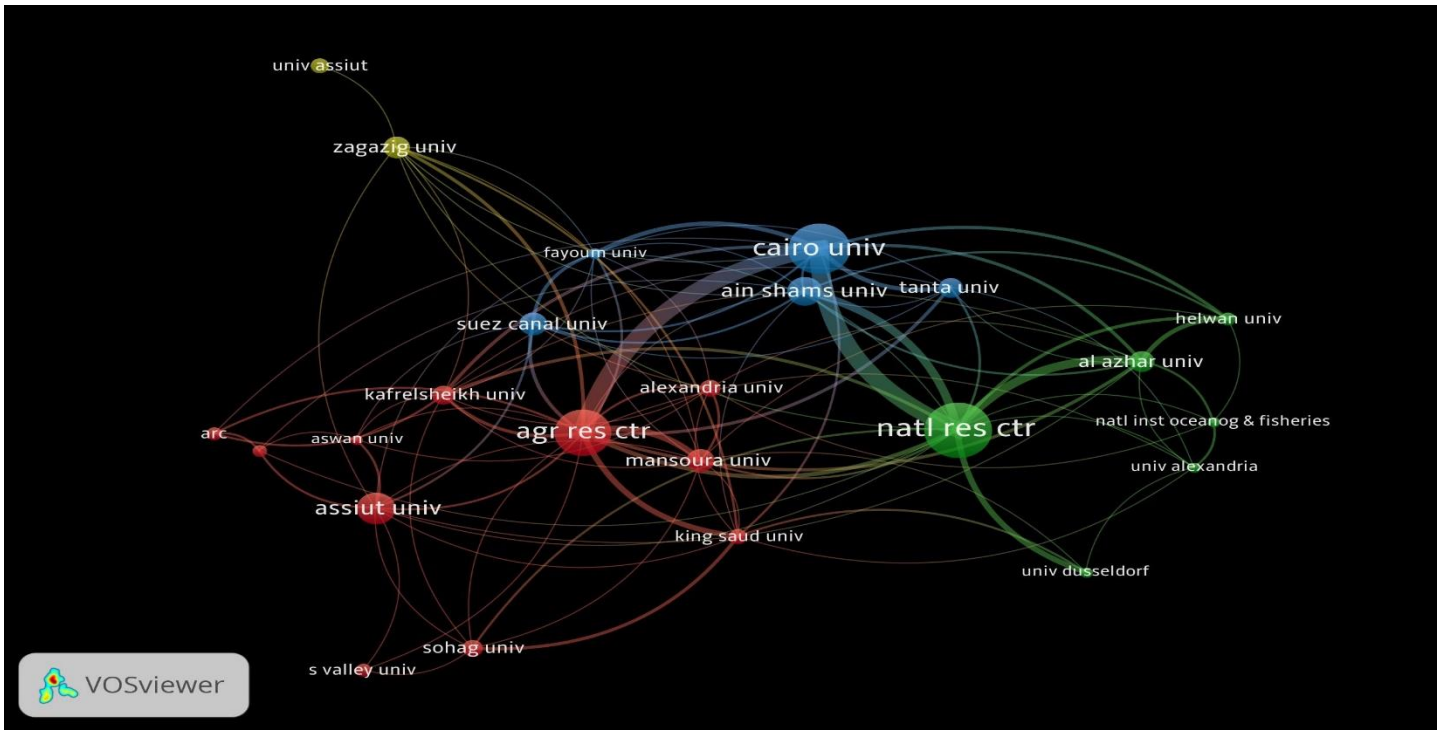

Fig 15. Co-authorship map of affiliations.

Table 4 The number of publication for each publisher

Publisher	Number of publications
Springer	148
National Center for Information & Documentation (NIDOC)	107
Taylor & Francis	91
Elsevier	86
Egyptian Society for Biological Control of Pests	78
Faculty of Agriculture, Zagazig University	65
Faculty of Agriculture, Ain Shams University	63
Academic Journals Inc.	61
Agricultural Research Centre, Ministry of Agriculture and Land Reclamation	59
INSInet Publications	56
Wiley	56
MDPI Publishing	51
American-Eurasian Network for Scientific Information	49
IDOSI Publications	46
Faculty of Veterinary Medicine, Assiut University	41
Academy of Scientific Research and Technology, National Center for Information and Documentation (NIDOC)	39
Asian Network for Scientific Information	34
Assiut University, Mycological Centre	28
Faculty of Agriculture, Alexandria University	27
Association of Agricultural Technology in Southeast Asia (AATSEA)	26
ANSInet, Asian Network for Scientific Information	25
Regional Center for Mycology and Biotechnology	22
Faculty of Agriculture, Assiut University	21

Discussion

The guardians of our ecosystem are fungi. They offer limitless services to industry and the environment. It is generally accepted that just 7% of all fungi have been identified, with the remaining 93% still unknown. Like animals and plants, fungi are underappreciated and poorly protected species, but human activity puts them at risk (Abdel-Azeem 2010). In Egypt, research on fungi is far less advanced than in other nations. They receive little study attention, and little is known about the scientific work being done on them. It was crucial to emphasize the use of bibliometric analysis for this reason (Abdel-Azeem et al. 2020).

In addition to covering scientific activity in a particular field, bibliometrics analyzes productivity and citations across databases, enables writers to assess their influence within the scientific community and publications, and more.

Using bibliometrics, our review examined three significant databases used in Egyptian fungus-related scientific research. They are CABI, Scopus, and Web of Science (WOS). While only "fungi in Egypt" is used in CABI, other keywords combining the terms "AND" and "OR" are used in WOS and Scopus to cover all publications about fungi in Egypt. Excel, Bibliometrix, and VOSviewer were the primary tools used to evaluate, filter, and export the data that were retrieved. Web of Science covered the years 1956–2023, Scopus the years 1934–2023, and CABI the years 1969–2023.

Accordingly, research on fungi was mostly done in Egypt in the domains of biological science and agriculture, next immunology and microbiology, and finally medicine. "EGYPTIAN JOURNAL FOR BIOLOGICAL PEST CONTROL" and "AGRICULTURE RESEARCH REVIEW" were the top journals with the highest journal production over time in WOS & Scopus, respectively. "MYCOPATHOLOGIA" was identified as the top journal with the greatest H-index in Scopus and WOS.

Furthermore, the largest number of publications in WOS was recorded in 2022 with 69 publications, while the highest number in Scopus was reported in 2021 with 103 publications. The highest number in CABI was recorded in two different years, 2020 with 144 publications and 2013 with 139 publications.

The most used keywords in publications regarding WOS and Scopus were ‘Egypt’, ‘fungi’, and ‘biocontrol’. While bi-words were ‘biological control’, ‘upper Egypt’, and ‘fungi isolated’. Thus, biological control is top used in mycological research in Egypt. Arthropods, nematodes, and gastropod mollusks are just a few of the many agricultural pests that can be controlled using biological control. Additionally, invading plants and harmful microbes can be controlled with it due to its efficacy and reduced environmental pollution (Freitas Soares et al. 2023).

Moreover, Moubasher AH was one of the most productive authors throughout the 3 databases. Moubasher had the highest H-index and recorded the most productive author in both Scopus and CABI. One of the most cited articles published by Moubasher is ‘Studies on the fungus flora of three grains in Egypt’ with 42 citations (Moubasher et al. 1972). While Bagy

MMK is the most publisher with 18 publications in WOS followed by Abdelazeem AM with 14 publications. Bagy also published 'Two stage biodiesel and hydrogen production from molasses by oleaginous fungi and *Clostridium acetobutylicum* ATCC 824' that cited by 52 (Bagy et al. 2014). While Abdelazeem AM published 'Mycogenic Silver Nanoparticles from Endophytic *Trichoderma atroviride* with Antimicrobial Activity' with 38 citations (Abdel-Azeem et al. 2020b).

In WOS and CABI, the National Research Center was the most productive affiliate, although Assiut University dominated the Scopus database. Science, Technology, and Innovation financing authority (STDF) was ranked as the top funding agency by both WOS and Scopus, behind the National Research Center.

Our study evaluates the overall contributions made by authors, organizations, and journals to the field of fungi in Egypt, concentrating on the quantitative aspects of publications such as co-authorship, citation frequency, and publication counts.

Conclusion and future prospects

Without a doubt, the performance and activity of scientific research is a gateway to improved future research and enhanced innovation. To improve the level of research and its impact on societal growth, an environment of support for scientific production must be created (Yousef and Dashash 2023). Fungal research in Egypt is critical in order to safeguard, conserve, and retain the ultimate benefit from the fungal resources available in Egypt. Ongoing research in this field is expected to yield more information about fungal strains, their ecology, secondary metabolites, and biomedical research services. Bibliometrics assists in covering all areas of scientific activity in a certain field. It aided in detecting author activity, funding sources, and productive associations, as well as comparing the best journals in that discipline. Finally, it is obvious that fungi had the highest rate of publication in Egypt between 2012 and 2022 in the WOS, Scopus, and CABI databases. Furthermore, Assiut University has consistently been the most productive affiliation. Agriculture and biological sciences were the most common scientific research categories, with 'biological control' being the most frequently used bi-word in most databases. This demonstrates how fungi can be quite influential and give long-term pest management solutions.

Our study contributed to the reduction of gaps in scientific research and encouraged researchers and affiliations to fund mycological research. This is, to the best of our knowledge, Egypt's first bibliometric statistical examination of fungi.

Declaration of competing interests

There are no conflicts of interest to declare.

Data availability

Data will be made available on request.

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