Vol. 3, No. 1, 1-15. DOI: 10.47909/ijsmc.38

Pro-Metrics

ORIGINAL RESEARCH

Mucormycosis Research: A global outlook through bibliometric approaches

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ABSTRACT

Objective. Mucormycosis is a fungal infection in humans where the causative pathogens belong to the order of Mucorales. The fungal pathogens are also known as black fungi based on morphological characteristics. Mucormycosis is increasingly observed in patients suffering from the COVID-19 virus from different states of India, wherein steroids are being used as standard therapy. The prevalence of coronavirus disease and the infection by the black fungus (Mucormycosis) poses several challenges to its mitigation. The purpose of the study is to analyze the research trends of mucormycosis using bibliometric methods.

Design/Methodology/Approach. The study utilizes standard bibliometric methods to analyze bibliographic literature on Mucormycosis retrieved from the SCOPUS database. All keywords (MeSH terms) associated with Mucormycosis were used to frame a search query and retrieve bibliographic data from the database. The bibliometric indicators were used to assess research productivity in mucormycosis for publication growth; subject distribution; productive authors, institutes, and countries; journals, highly cited articles; and hot spots and research progress based on the keyword analysis. VOSviewer network visualization tools have been used for mapping research.

Results/Discussion. The analysis of 25,251 bibliographic records shows exponential growth in literature during seventy years. Though mucormycosis research is spread across the globe, the prevalence of the study is widespread in the South-East Asian region. Author keyword analysis shows that the research focuses on the medical subject and expands into multidisciplinary research areas.

Conclusions. Bibliometrics always provides insight into the research progress in any field or topic of study. This study provides insight into research progress in Mucormycosis. The researcher may use the results to analyze different areas of mucormycosis and utilize the key concepts for further research, especially researching better clinical practices and drug developments.

Received: 28-01-2023. **Accepted:** 15-04-2023

Editor: Carlos Luis González-Valiente

How to cite: Ram, S.; Sharma, H.; & Rai, A. K. (2023). Mucormycosis Research: A global outlook through bibliometric approaches. *Iberoamerican Journal of Science Measurement and Communication; 3*(1), 1-15. DOI: 10.47909/ijsmc.38

Originality/Value. Through this paper, it is quite clear that the appearance of research contribution on mucormycosis coupled with COVID-19 has opened a new direction of research that clinical researchers take up in future research.
Keywords: mucormycosis; black fungus; fungal infection; bibliometric analysis; research impact, citation analysis.

1. INTRODUCTION

Fungal infection in humans where the causative agents represent saprophytic fungi typically belonging to the class Zygomycetes and order Mucorales is known as Mucormycosis. It is commonly known as *'Black Fungus'* due to its morphological appearance. The possible origin of the Mucormycosis can be tracked from 1885, then further observation as rhino-orbital cerebral mucormycosis in 1943 (Baker, 1957). It usually infects weakened patients due to underlying diseases such as diabetes, pneumonia, and sinusoids. Based on the anatomical site clinical investigation, Mucormycosis has six categories: (i) rhinocerebral, (ii) pulmonary, (iii) cutaneous, (iv) gastrointestinal, (v) disseminated, and (iv) miscellaneous (Spellberg *et al.,* 2005). Rhinocerebral disease, a form of mucormycosis, is commonly observed in severely diabetic or dehydrated individuals (Pillsbury and Fischer, 1977), and Acute invasive fungal rhinosinusitis primarily infects immunosuppressed individuals (Mekonnen *et al.,* 2021).

Recently, severe COVID-19 infections have been managed using hormones such as glucocorticoids to improve the immune system (Singh *et al.,* 2020). Alongside, several cases of mucormycosis are being observed in patients suffering from diabetes mellitus, pulmonary infections, rhino-orbital-cerebral, eye infections, and sub-cutaneous disease, and the standard therapy involving glucocorticoids could increase the risk (Garg *et al.,* 2021; Sharma *et al.,* 2021). Apart from diabetes, hematological malignancy and transplants involving solid organs comprise the major risk factors associated with mucormycosis (Pasero *et al.,* 2020; Werthman-Ehrenreich, 2021). Other mucormycosis-related factors include pulmonary tuberculosis, pulmonary disease, and steroid therapy. Rhino-orbital-cerebral mucormycosis is the most common form reported in India. Cutaneous, pulmonary, renal, gastrointestinal, and disseminated infections are also observed in other forms of mucormycosis. Other peculiar infections reported from India include the breast, ears, spine, heart, and bones (Prakash and Chakrabarti, 2021).

Pathogenic Mucorales isolated from the air samples of community and hospital settings in India shows that the most common causes of mucormycosis were due to *Rhizopus* sp., *Rhizomucor* sp., *Mortierella* sp., *Absidia* sp., and less frequent species belonging to the genus of *Mucor, Cunninghamella, Mortierella, Saksenae* and *Apophysomyces* (Prakash *et al.,* 2020). The recent outbreak and limelight of Mucormycosis in India motivated undertaking this bibliometric analysis to understand the research progress.

2. LITERATURE REVIEW

The prevalence of mucormycosis and COVID-19 has posed another challenge for patients and doctors to handle Mucormycosis - declared an epidemic in India. Mucormycosis has undoubtedly become a grave concern in diabetic individuals with COVID-19 patients treated with steroids and immunosuppressants such as Remdesivir supplemented with a reduced immune response due to the decreased count of T Lymphocytes, CD8+ and CD4+ cells. In recent years, the fungal disease spread has been quite common worldwide due to the weak immune defence system (Pathakumari *et al.,* 2020). There is a necessary research progress analysis in demand to know the state of Mucormycosis disease (Suvvari *et al.,* 2021).

Bibliometric analysis provides a direction and status of the research progress across the period in a given subject through published literature. Bibliometrics has become an integral part of the evaluative method for research progress (Borgman and Furner, 2002). It also paves the path for future research through network analysis and visualization (van Eck and Waltman, 2014).

A journal *(Journal of the Association of Physicians of India)* bibliometric analysis of 'infectious diseases' revealed that more than 30% of research in India is being carried out on HIV and tuberculosis. However, the reported results are limited to infectious disease and not covering any involvement of mycology subjects (Kumar and Aravinda, 2012). Another study for *"Mycopathologica"* journal eighty years showed progress in fungal disease research in humans and animals. The study reported highly cited articles from the journal in various decades of their publication with no evidence of mucormycosis research (Chaturvedi *et al.,* 2018).

Evidence of bibliometric analysis related to disease resistance for antifungal triazole used for the treatment of fungal diseases has been found (Sweileh *et al.,* 2017). A bibliometric study associated with Mycorrhizal fungi *'ectomycorrhizae'* showed a high increase in publication since 2003. The hot spot in ectomycorrhizae is concentrated over the keywords related to fungi, but no evidence of mucormycosis research was reported in the study (Jiang and Yanbin, 2018). During the COVID-19 pandemic, the pathogenesis shows that mucormycosis also impacted the central nervous system and ocular system (Polo Martínez *et al.,* 2022). So, a study involving another disease, *"fungal keratis"* reveals that most of co-citation research is concentrated on the disease's epidemiology in and around keratomycosis. However, no evidence and correlation of mucormycosis can be established through this research (Cen *et al.,* 2020).

Bibliometric research evidence on mucormycosis can be found in two recent publications. Dubey and Sharma (2021) presented a post-covid mucormycosis research status by analyzing only forty-one documents. The limitation of the study can be observed in less publications, and the study is limited to mucormycosis associated with COVID-19. Another study on cluster analysis of mucormycosis research for ten years from 2011 to 2021, analyzes 1896 publications contributed by 9423 authors. Again, the data reported in this study is limited to ten years only, whereas mucormycosis research publications ended up appearing in the 1940s. The longer the period, the larger the bibliography helps assess the research progression and impact (Balstad and Berg, 2020). Another study reported by Gupta et al. (2021) on murcomycosis analyses bibliographic data ranging from 1998-2021 (5658 documents), which is having fewer articles reported when mucormycosis research had been a long history. Therefore, to fill these gaps, a comprehensive bibliometric survey has been proposed for a longer duration which shows the progression of research over time. The progression of research needs to be analyzed in terms of publication growth; subject distribution; productive authors, institutes, and countries; journals, highly cited articles; and hot spot and research progress based on the keyword analysis.

3. METHODOLOGY

The study is based on bibliographic data retrieved from the SCOPUS database. SCOPUS is a multidisciplinary abstracting and citation database covering over twenty-five thousand journals, more than fifteen thousand academic conferences, seventy-five million articles, over ten million author profiles. SCOPUS covers about 95% of MEDLINE titles, efficiently covering suitable data sources for any bibliometric analysis. The search strategy was based on using keywords (MeSH Terms) related to Mucormycosis available in the Author, Title and Abstract fields of the SCOPUS database. The search string used to retrieve data was:

> TITLE-ABS-KEY ("Mucormycosis" OR "Mucormycoses" OR "Mucormycose" OR "mucormycetes" OR "Mucorales Infection" OR "Mucorales Infections" OR "Infection, Mucorales" OR "Rhizopus" OR "Rhizomucor" OR "Mucor" OR "Syncephalastrum" OR "Cunninghamella bertholletiae" OR "Cunninghamella" OR "Apophysomyces" OR "Mortierella" OR "Absidia" OR "Saksenaea" OR "Black Fungus" OR "Black Fungi") AND PUBYEAR > 1950 AND PUBYEAR < 2021

The study was conducted over seventy years (1951-2020) and subjected to data analysis. The longer the period, the better is the comprehensive understanding of the research trends (Balstad and Berg, 2020; Weaver and McCleary, 1989). The published data were carefully analyzed with the key objectives to know the considerable volume of academic literature

published and the growth trends; subject distribution; most productive authors, institutions, countries; journals; highly cited articles and research proliferation typically based on author keyword analysis. The network visualization was done using the VOSviewer software. The research impact was analyzed based on a considerable number of citations scored by the articles since their publication, including *h*-Index and Impact Factor for the year 2021 (IF_{2021}).

4. RESULTS

4.1. Research productivity

The SCOPUS database resulted in 25,251 documents on Mucormycosis within seventy years (1950-2020). These published literatures were distributed in fourteen different document types, where the majority of the publications were published as an article (86.92%) with distantly published reviews (5.96%), conferences (2.50%), letters (1.78%) and notes (1.05%). Other document types collectively comprise 1.79%. Most of the research was published in the English language (90.91%), followed distantly by Spanish (1.62%), French (1.46%), Chinese (1 45%), German (1.38%), and Russian (1.03%) along with twenty-eight other languages (2.91%).

The literature growth associated with mucormycosis disease has increased exponentially up to 2014, after that short decline and again increasing trends. Figure 1 shows the publication trends throughout the study period. It is observed that the correlation coefficient *(r)* of 0.9455, indicates 94.55% of positive growth in future. Also, a linear adjustment to the measured values provides *(r)* of 0.8572; therefore, a percentage of unexplained variability of 14.28%. It can be concluded that publication trends in Mucormycosis are more fitted to exponential adjustment than a linear adjustment. Its compliance with Price's Law of exponential growth (Price, 1963). Similar results have been reported to the bibliometric analysis for attention-deficit hyperactivity disorder (López-Muñoz *et al.,* 2008) and Anti-psychotic drugs (López-Muñoz *et al.,* 2018).

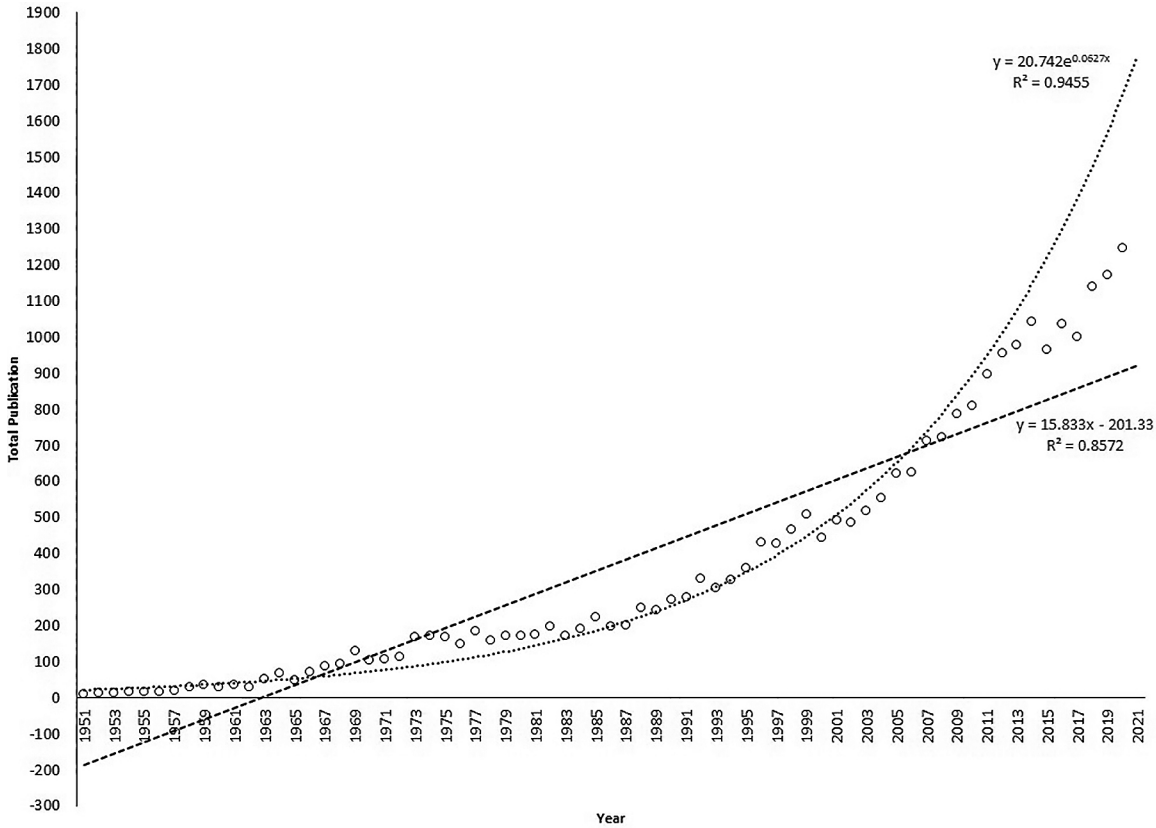

Figure 1. Trends of literature growth on Mucormycosis, 1951-2020.

The publication growth of Mucormycosis research witnessed an exponentially from 10 publications in 1951 to 1245 publications in 2020, with slight fluctuations in 1971, 1979 and 2015. The exponential growth indicates that Mucormycosis research is taking place increasingly globally: The most commonly used parameter for research impact assessment is the citations or average citations per paper counts (Aksnes *et al.,* 2019; Finch, 2012; Simko, 2015). The average number of citations per paper (ACPP) was observed between 2.50 to 40.30 citations from 1951 to 2020, with a peak of 40.30 in 2005 with an overall mean of 18.18 citations per paper. The articles published between 1984 to 2012 were highly cited with ACPP over the mean citation value (Fig. 2).

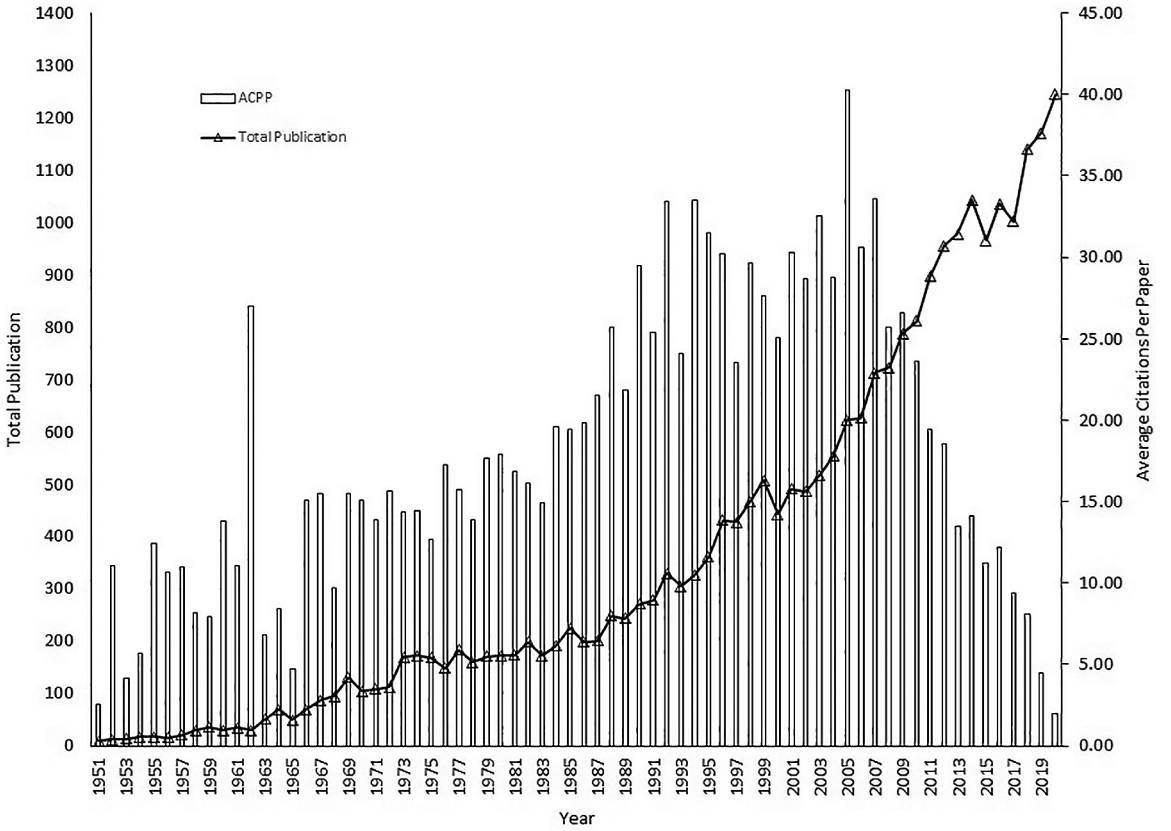

Figure 2. Citation trends published literature on Mucormycosis, 1951-2020.

4.2. Subject Categories

The SCOPUS categorizes its database into *Health Sciences, Life Sciences, Multidisciplinary, Physical Sciences, Social Sciences & Humanities* with 334 sub-areas. The analysis was conducted to determine distribution trends under different subject categories. The document on Mucormycosis was distributed across twenty-seven subject categories. The results provide an understanding of the literature on Mucormycosis published. Mucormycosis is an area of medical science, especially Mycology, so most of the articles are related to Medicine (40.01%). Mucormycosis also covers the category of Biochemistry, Genetics and Molecular Biology (30.01%), followed by Agriculture and Biological Science (22.03%), Immunology and Microbiology, Immunology and Microbiology (19.94%), Chemical Engineering (12.13%), Chemistry (11.98%), Pharmacology, Toxicology and Pharmaceutics (7.84%) and Environmental Science (7.28%).

The gradual progression of an article published in these most productive subject categories is appropriately presented in Figure 3. It can be carefully observed that Medicine continuously remains the prime subject area.

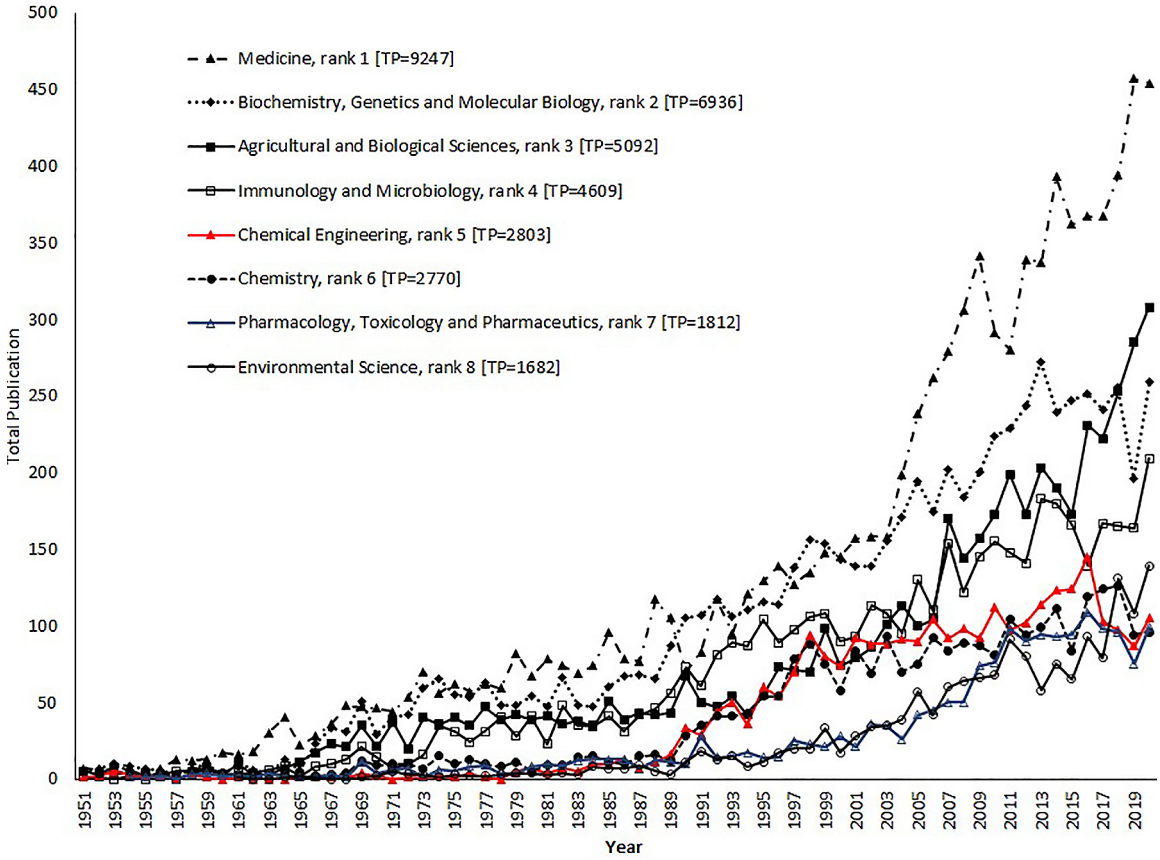

Figure 3. Distribution of the subject categories in Mucormycosis research, 1951-2020.

However, Biochemistry, Genetics and Molecular Biology related research progressed in a few years, surpassing medicine. In recent years, Agriculture and Biological Science, though ranked third, occupies the second position in terms of the number of scholarly publications. Almost all subject categories typically exhibited an increasing trend, with a slight decline in the publication in Chemical Engineering. Further categorization of the Mucormycosis falls under the subject, and interdisciplinary categories in engineering, energy, materials science, etc., are gaining momentum. Many of the documents fall under multidisciplinary subject categories, so it can be observed that the percentage contribution might be higher.

4.3. Research Active Authors

Table 1 shows the top authors with more than fifty publications on Mucormycosis research from 1950 till 2020. The authors' contribution has been assessed based on total publication, total citations and rank; average citation per paper and rank; and *h*-index and rank. The author D. P. Kontoyiannis from the University of Texas MD Anderson Cancer Center, Houston, USA, ranked first with overall publications (N=130), total citations (TC=11449) and *h*-Index of 47. The papers were cited on an average of 88.07 citations (2nd rank). T. J. Walsh from Weill Cornell Medicine, New York, USA, was ranked second in overall publication (N=99), total citation (TC=9459) and *h*-Index of 43. However, it is ranked first with the highest average citation per paper, 95.55 citations. Whereas, A. S. Ibrahim from Harbor-UCLA Medical Center, USA ranked 8th in terms of total publication (N=62) but ranked 3rd in total citations (TC=3849), ranked 5th in ACPP (ACPP=62.08) and ranked 3rd in *h*-index of 33. The cooperation network of authors is shown in Figure 4. Based on the author's collaboration networks for average papers per year published, it gives eleven clusters. The size and thickness of the node represent the average articles and collaboration strength

between the authors per year. Thicker the network, the higher the frequency of collaboration. The colours of the network are the activeness of the author. Most of these authors have been quite active in recent years and represented by a yellow colour, whereas the green to blue colour illustrates the activeness of the authors in the nineties.

Author	Organization	TP	R(TC)	R(ACPP)	R(*h*-Index)
Kontoyiannis, D.P.	University of Texas MD Anderson Cancer Center, Houston, USA	130	1(11449)	2(88.07)	1(47)
Walsh, T.J.	Weill Cornell Medicine, New York, USA	99	2(9459)	1(95.55)	2(43)
Shimizu, S.	Kyoto University, Kyoto, Japan	86	7(2964)	9(34.47)	15(19)
Cerniglia, C.E.	National Center for Toxicological Research, Jeffersonville, USA	69	10(2171)	10(31.46)	18(18)
Chakrabarti, A.	Postgraduate Institute of Medical Education & Research, Chandigarh, India	64	8(2639)	8(41.23)	4(31)
Papp, T.	Szegedi Tudományegyetem, Szeged, Hungary	64	16(939)	17(14.67)	7(28)
Vágvölgyi, C.	Szegedi Tudományegyetem, Szeged, Hungary	64	14(1050)	14(16.41)	9(26)
Ibrahim, A.S.	Harbor-UCLA Medical Center, Torrance, USA	62	3(3849)	5(62.08)	3(33)
Chen, H.	Jiangnan University, Wuxi, China	61	15(941)	16(15.43)	13(20)
Chen, W.	Jiangnan University, Wuxi, China	60	19(820)	19(13.67)	8(28)
Cornely, O.A.	University of Cologne, Koln, Germany	60	9(2505)	7(41.75)	14(19)
Choudhary, M.I.	University of Karachi, Karachi, Pakistan	59	18(850)	18(14.41)	10(25)
Chen, Y.Q.	Jiangnan University, Wuxi, China	58	17(938)	15(16.17)	12(23)
Roilides, E.	Hippokration General University Hospital, Thessaloniki, Greece	58	6(3517)	6(60.64)	17(18)
Garre, V.	Universidad de Murcia, Murcia, Spain	57	13(1395)	13(24.47)	16(19)
Lortholary, O.	AP-HP Assistance Publique - Hopitaux de Paris, France	56	4(3784)	4(67.57)	5(29)
Sakuradani, E.	Tokushima University, Tokushima, Japan	56	12(1444)	12(25.79)	19(18)
Valero, F.	Universitat Autònoma de Barcelona, Barcelona, Spain	54	11(1648)	11(30.52)	11(24)
Lewis, R.E.	Alma Mater Studiorum Università di Bologna, Bologna, Italy	51	5(3562)	3(69.84)	6(28)

Table 1. Most productive authors in Mucormycosis research.

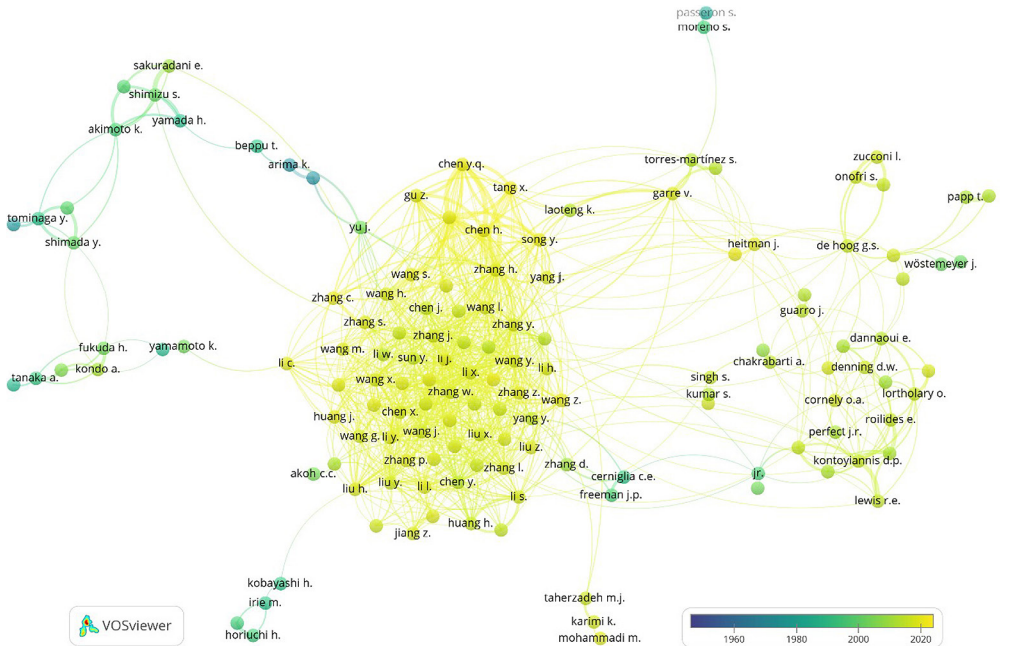

Figure 4. Most productive authors in mucormycosis and active period.

4.4. Research Active Institutes

The most productive institutes with more than 150 scholarly publications engaged in Mucormycosis research during the study period based on the number of publications; global share; total citations, average citation per paper and rank; and *h*-index is provided in Table 2. Of these most productive institutes, six are from the USA; three from China and France; two from Japan, India, and Spain; and one from Brazil, Russia, Germany, Saudi Arabia, the Netherlands, and Pakistan. All these institutes shared less than one per cent of global contribution except the Ministry of Education China, China with a 1.02% share (257 published articles).

Name of the Institute	TP	%share	TC	R(ACPP)	*h*-Index
Ministry of Education China, China	257	1.02	4960	20(19.30)	16(32)
Kyoto University, Japan	248	0.98	8226	13(33.17)	24(18)
Chinese Academy of Sciences, China	186	0.74	4603	15(24.75)	23(20)
Universidade de Sao Paulo - USP, Brazil	183	0.72	2918	22(15.95)	8(38)
Jiangnan University, China	180	0.71	3003	21(16.68)	18(29)
University of Texas MD Anderson Cancer Center, USA	173	0.69	13028	36(75.31)	10(36)
The University of Tokyo, Japan	170	0.67	3753	25(22.08)	20(25)
Postgraduate Institute of Medical Education & Research, Chandigarh, India	168	0.67	3868	24(23.02)	21(24)
United States Department of Agriculture, USA	163	0.65	6015	8(36.90)	12(35)
CNRS Centre National de la Recherche Scientifique, France	152	0.60	5602	9(36.86)	1(54)
USDA Agricultural Research Service, USA	148	0.59	5570	7(37.64)	11(35)
Consejo Superior de Investigaciones Científicas, Spain	141	0.56	5085	11(36.06)	4(42)
Russian Academy of Sciences, Russia	140	0.55	1202	24(8.59)	22(24)
Friedrich Schiller Universität Jena, Germany	117	0.46	4082	12(34.89)	5(41)
King Saud University, Saudi Arabia	110	0.44	2402	18(21.84)	6(40)
Université de Paris, France	110	0.44	4695	5(42.68)	17(30)
Central Food Technological Research Institute India, India	109	0.43	2163	19(19.84)	14(34)
Duke University Medical Center, USA	109	0.43	5871	3(53.86)	15(33)
Wageningen University & Research, Netherlands	107	0.42	3872	10(36.19)	7(39)
Institut Pasteur, Paris, France	103	0.41	4106	6(39.86)	2(51)
University of California, Los Angeles, USA	101	0.40	5858	2(58.00)	3(49)
University of Karachi, Pakistan	101	0.40	1378	23(13.64)	9(38)
Universidad de Murcia, Spain	101	0.40	2776	14(27.49)	13(35)
University of Texas Health Science Center at San Antonio, USA	101	0.40	5033	4(49.83)	19(28)

Table 2. Productive institutions engaged in Mucormycosis research, 1951-2020.

In terms of Citation count, the University of Texas MD Anderson Cancer Center, USA has accumulated the highest number of citations of 13028 citations with an average of 75.31 citations per academic paper, followed by Kyoto University Japan (8226 citations) and United States Department of Agriculture, USA (6015 citations). The academic institutes whose articles were most frequently cited as per the parameter of Average Citation Per Paper (ACPP) include the University of Texas MD Anderson Cancer Center, USA (ACPP=75.31 citations), University of California, Los Angeles, USA (ACPP=58.00 citations) and Duke University Medical Center, USA (ACPP=53.86 citations).

Articles from the institutes in the USA were top ranked and most frequently cited, followed by institutesin the USA were top-ranked and most frequently cited, followed by institutes in France. All these most productive institutes comply with the most productive countries. The bibliometric parameter *h*-Index has always remained a key parameter for ranking individual research and extended to evaluate the institute (Hirsch, 2005; Meyers and Quan, 2017; Molinari and Molinari, 2008). Among these productive institutions, the top three institutes ranked based on *h*-Index include Centre National de la Recherche Scientifique (CNRS), France (*h*-Index=54),

Institut Pasteur, Paris, France (*h*-Index=51) and University of California, Los Angeles, USA (*h*-Index=49). Productive institutions, the top three institutes ranked based on *h*-Index include Centre National de la Recherche Scientifique (CNRS), France (*h*-Index=54), Institut Pasteur, Paris, France (*h*-Index=51) and University of California, Los Angeles, USA (*h*-Index=49).

4.5. Productive Countries

The scholarly Mucormycosis publications were distributed among 158 countries, naturally making it global research. Precisely, 104 countries (65.82%) published 1 to 50 articles; 13 countries (6.96%) published 50 to 100 articles; 30 countries (18.99%) published 100 to 500 articles, and 11 countries (6.96%) published more than 500 articles. Of these most productive countries, the USA has undoubtedly contributed the most considerable number of scholarly articles on Mucormycosis, which is 18% (4546 articles) of the combined contribution, followed by India at 10.36% (2617 articles), China at 8.68% (2192 articles), and Japan 8.05% (2032 articles). The most productive counties over two or more than two per cent of valuable contribution in Mucormycosis are indicated in Table 3.

Country	TP	R (% Share)	TC	ACPP
United States	4546	1(18.00)	145443	2(31.99)
India	2617	2(10.36)	41148	10(15.72)
China	2192	3(8.68)	33048	11(15.08)
Japan	2032	4(8.05)	43576	8(21.44)
Germany	1226	5(4.86)	33649	6(27.45)
United Kingdom	1057	6(4.19)	32853	3(31.08)
Spain	1043	7(4.13)	25614	7(24.56)
France	901	8(3.57)	27502	4(30.52)
Brazil	892	9(3.53)	17783	9(19.94)
Canada	645	10(2.55)	24893	1(38.59)
Italy	640	11(2.53)	18953	5(29.61)

Table 3. Most productive countries in Mucormycosis research, 1951-2020.
Note: TP: Total Publication; R: Rank; TC: Total Citations; ACPP: Average Citations Per Paper.

The studies on epidemiology suggest that Mucormycosis is quite prevalent in Asian regions where diabetes, tuberculosis, and renal infection add more risk to it. This study shows that three Asian countries, India, China, and Japan, are the most productive. The research impact on the Average Citation Per Paper (ACPP) parameter, Canadian papers are most frequently cited and ranked first with 38.59 citations per paper, followed by USA ranked second with ACPP=31.99 citations, and the UK ranked third with 31.08 citations per paper. Regarding total publications, second-ranked India and third-ranked China have ACPP of 15.72 and 15.08 citations per paper and are ranked 10th and 11th, respectively.

4.6. Productive Journals

Table 4 gives the most productive journals with more than one hundred publications on Mucormycosis. The journals were ranked by total publications, percentage share, and Impact Factor 2021 (IF_{2021}) released by Journal Citation Report in 2021. The articles on mucormycosis published in the journals (excluding books, book chapters, and conferences) were distributed in 4777 journals. The analysis of scattering of the Mucormycosis literature across the discipline shows that it does not stand with the law scattering 1:n:n^2 (105:593:3979) (Bradford, 1953). Most of the journals have less than one per cent of total publications, except *Mycoses*

(1.10%; IF2021=4.931) and *Agricultural and Biological Chemistry* (1.08%). Except one, the top most productive journals have registered their impact factor (IF2021). Clinical Infectious Diseases was the highest impact factor factor-bearing journal (IF2021= 20.999).

Name of the Journal	TP	% Share	IF_{2021}
Mycoses	278	1.10	4.931
Agricultural and Biological Chemistry	272	1.08	0
Mycopathologia	233	0.92	3.785
Applied Microbiology and Biotechnology	232	0.92	5.560
Journal of the American Oil Chemists' Society	197	0.78	1.952
Bioresource Technology	187	0.74	11.889
Medical Mycology	172	0.68	3.747
Enzyme and Microbial Technology	171	0.68	3.705
Biotechnology Letters	167	0.66	2.716
Journal of Molecular Catalysis B: Enzymatic	155	0.61	2.269
Journal of Agricultural and Food Chemistry	151	0.60	5.895
Process Biochemistry	148	0.59	4.885
Journal of Clinical Microbiology	144	0.57	11.677
Clinical Infectious Diseases	138	0.55	20.999
Applied and Environmental Microbiology	131	0.52	5.005
Biotechnology and Bioengineering	117	0.46	4.395
Applied Biochemistry and Biotechnology	116	0.46	3.094
Antimicrobial Agents and Chemotherapy	114	0.45	5.938
Canadian Journal of Microbiology	106	0.42	3.226

Table 4. Most productive journals publishing Mucormycosis articles, 1951-2020.
Note: TP: Total Publication; IF: Impact Factor.

4.7. Highly Cited Articles

The top highly cited article is given in Table 5. 85.72% of the articles were cited with at least one citation since their publication, accumulating 5,08,648 citations by 25,251 documents. The highly cited articles are ranked according to the total and average citations per paper till 2020 (TC2020). The article entitled *"Biosorption of Heavy Metals"* was the most cited article, with 1795 citations (ACPY=69.04 citations) (Volesky and Holan, 1995). This article is related to the role of fungi as biosorbents of heavy metals. The article *"Epidemiology and outcome of zygomycosis: A review of 929 reported cases"* (an open access article) published in 2005 was most impactful in terms of the highest average citation per year of 94.38 citations (TC=1510 citations). The study was related to the impact of *Zycomycosis* in the development of life-threatening sinus, pulmonary, and cutaneous infections (Roden *et al.,* 2005).

"Industrial applications of microbial lipases" was the second most cited article with a high average citation per year (ACPY=89.53 citations; TC=1343 citations). Lipase is an enzyme with an industrial application in food, flavour and biocatalytic activities. *Rhizomucor miehei* is a fungi used to isolate Lipase enzymes (Hasan *et al.,* 2006; Herrgård *et al.,* 2000). Three of these highly cited articles were related to lipase enzyme (Brady *et al.,* 1990; Brzozowski *et al.,* 1991; Hasan *et al.,* 2006; Herrgård *et al.,* 2000), and two are related to the removal of heavy metals using fungus (Ahluwalia and Goyal, 2007; Volesky and Holan, 1995). Two articles related the infection impact of *Zygomycosis* and *Zygomycetes* (Ribes *et al.,* 2000; Roden *et al.,* 2005).

4.8. Hot Spot and Trend in Mucormycosis Research

The research hotspot and trends analysis are gaining popularity in assessing the relationship between various subject areas. Network analysis (a weightage network based on the node's thickness and color) provides

Authors	Document Title	Journal Title	PY	TC	ACPY
Volesky B. & Holan Z. R.	Biosorption of Heavy Metals	Biotechnology Progress, 11(3)	1995	1795	69.04
Roden M. M. *et. al.*	Epidemiology and outcome of zygomycosis: A review of 929 reported cases	Clinical Infectious Diseases, 41(5)	2005	1510	94.38
Hasan F. *et al.*	Industrial applications of microbial lipases	Enzyme and Microbial Technology, 39(2)	2006	1343	89.53
Stevens D. L. et al.	Practice guidelines for the diagnosis and management of skin and soft-tissue infections	Clinical Infectious Diseases, 41(10)	2005	1161	72.56
Ahluwalia S. S. & Goyal D.	Microbial and plant derived biomass for removal of heavy metals from wastewater	Bioresource Technology, 98(12)	2007	1056	70.40
Ribes J. A. *et al.*	Zygomycetes in human disease	Clinical Microbiology Reviews, 13(2)	2000	1028	48.95
Brady L. *et al.*	A serine protease triad forms the catalytic centre of a triacylglycerol lipase	Nature, 343(6260)	1990	1025	33.06
Brzozowski A. M. *et al.*	A model for interfacial activation in lipases from the structure of a fungal lipase-inhibitor complex	Nature, 351(6326)	1991	1006	33.53

Table 5. Highly Cited Articles on Mucormycosis research.
Note: PY: Publication Year; TC: Total Citations; ACPY: Average Citations Per Year.

a relationship between two or more concepts (van Eck and Waltman, 2014). In this study, the author's keywords were analyzed to assess the research hotspot and trends in Mucormycosis. It was found that there were eleven clusters formed generated through VoSviewer for author keywords. The keywords in the centre of these cluster were *Mucormycosis* (network link=32480) followed by *Lipase* (network link=1666), *Fungi* (network link=1470), *zygomycosis* (network link=1233), *aspergillosis* (network link=1144), *Rhizopus oryzae* (network link=1096), *aspergillus* (network link=1017), *amphotericin* (network link=845), *Rhizopus* (network link=832), *mucor* (network link=758), *posaconazole* (network link=699), and *Biotransformation* (network link=603). These keywords make Mucormycosis a research hotspot. In recent years, the keywords started appearing and showing the research trends in transesterification (1182 articles), solid-state fermentations (1150 articles), biodiesel (885 articles), Neutropenia (612 articles), pichia pastoris (421 articles), peritonitis (277 articles), otomycosis (71 articles) opening new dimensions for research.

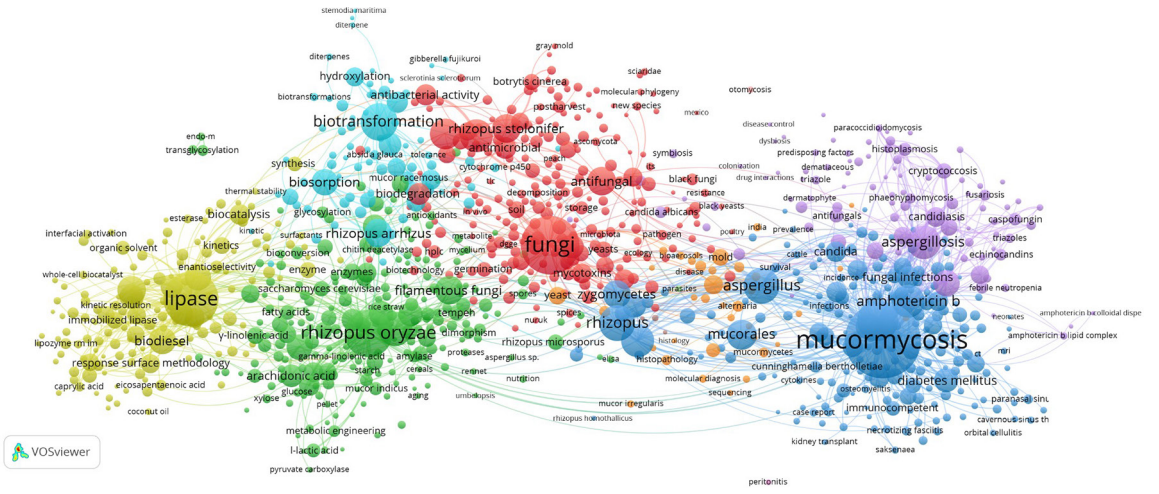

Figure 5. Research hotspot and network visualization (showing eleven clusters) of most frequently used author keywords in Mucormycosis research.

5. DISCUSSION

The bibliometric analysis constitutes an interesting tool for assessing research trends of a given discipline for assessing a discipline's research trends over a specific period. The bibliometric analysis was conducted for mucormycosis through the bibliographic data retrieved from SCOPUS. The keywords related to Mucormycosis recovered 25,251 documents within seventy years of the research period. The literature has grown exponentially (r=0.9455) and was more prominent than linear adjustment, which appears to comply with Price's Law of Exponential Growth. Many other studies in medical fields also complement exponential growth trends (López-Muñoz *et al.,* 2014, 2022). The research impact in the form of citations has been averaged at 18.18 citations per paper throughout the study period. It indicates that the Mucormycosis research is quite impactful in the medical field. Despite criticism of calculating average citations, the average citation parameter is often used to assess research impact (Waltman, 2016).

The articles published between 1984 to 2012 were highly cited with ACPP over the mean citation value. Mucormycosis is an area of medical science specially Mycology, so majority of the articles are related to Medicine (40.01%). Mucormycosis also covers the category of Biochemistry, Genetics and Molecular Biology followed by Agriculture and Biological Science, Immunology and Microbiology Immunology and Microbiology, Chemical Engineering, Chemistry, Pharmacology, Toxicology and Pharmaceutics and Environmental Science. However, Biochemistry, Genetics and Molecular Biology related research progressed in a few years, surpassing Medicine. In the recent years, Agriculture and Biological Science, though ranked third, occupies second position in terms of number of scholarly publications. Almost all subject categories typically exhibited an increasing trend, with slight decline in publication in Chemical Engineering. Over the periods the publication in these subject areas also shown continuous increasing trends.

Based on the author's collaboration networks for average papers per year published, it gives eleven clusters. The size and thickness of the node represent the average articles and collaboration strength between the authors per year. Thicker the network, the higher the frequency of collaboration. Most of the authors have been active in recent years, clearly visible through the network of highly productive authors. This study shows that three Asian countries, India, China, and Japan, are the most productive. Many highly cited articles were published in the 1990s as well last decades, which indicates that the articles on Mucormycosis do not reflect early citation characteristics (Aversa, 1985). Manifestations of mucormycosis with COVID-19, it can be observed that many articles in the year 2020 have been highly cited (Hanley *et al.,* 2020; Zhu *et al.,* 2020). The results also found thatThe results also found that most of the authors are active in most recent years, which is quite visible through authors network (Fig 4). Similarly, the most productive organization that has published the mostpapers belong to the Asian region. One of the reasons for the most publication from the Asian region is the prevalence of mucormycosis in the region (Prakash and Chakrabarti, 2019).

As for keyword distribution, the network diagram shows eleven clusters wherein the concentration dwells around keywords closely related to fungal diseases such as mucormycosis, fungi, and Rhizopus. The new subject areas which emerge from the subject include clinical trials etc. The network association of keywords like diabetes and COVID-19 shows the proliferation of the disease for future research direction (Tabarsi *et al.,* 2021).

6. CONCLUSION

Most of the publications that were observed during our study were articles. The exponential growth of the literature on Mucormycosis research was during seventy years. The literature published during the initial thirty years of research was not quite impactful. However, the articles were quite often cited during 1984-2012, showing the impactful research on Mucormycosis. It is apparent from this study that mucormycosis research is exponentially increasing with high publication growth in recent years. The most impactful was an article wherein the zycomycosis was found to be of

significance in developing infections in sinuses, pulmonary and cutaneous infections. Most authorshave been active in recent years, which is quite visible through the network diagram. The mucormycosis disease is quite prevalent in the Asian region, to the research. There are three Asian countries which include India, China and Japan, among the most productive countries in terms of research. However, the USA has the highest number of publications. The research in mucormycosis is being published in journals related to mycology bearing the impact factor IF 2019 ranging from zero to 8.313.

In contrast, *Mycoses* journal was the most productive and published the most significant number of articles. Among the most effective authors, those from the USA are highly productive and impactful. The research hotspot and trends analysis are gaining popularity in assessing the relationship between various subject areas. The significant number of clusters were observed for author keywords showing research hotspots and research trends in Mucormycosis. The author's keywords and research hotspots are centred on Mucormycosis, *Rhizopus, Rhisopus orizae, Rhizopus stolonifera,* lipase, aspergillosis, and biotransformation. The biotransformation using mucormycosis helps in various medical activities. The bibliometric method used to analyze the research publication in mucormycosis can help to understand the development of research in this field in more structured ways. The results could be helpful for the stakeholders in identifying the research areas and collaborating with the institutions and authors engaged in mucormycosis research.

Contribution statement

Conceptualization of the Topic, Data Analysis, Writing, Reference Management: Dr Shri Ram.

Theoretical background, literature Review and Editing: Dr Arun Rai.

Theory, Reference Management, Introduction: Hemant Sharma

Conflict of Interest

The authors declare that there is no conflict of interest.

Statement of data consent

The data generated during the development of this study has been included in the manuscript.

Funding

This research received no specific grants from funding agencies in the public, commercial, or not-for-profit sectors. ●

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