Annals of Library and Information Studies
Vol. 68, December 2021, pp. 376-388

Scientometric study of global mucormycosis (black fungus) research

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Received: 02 June 2021; revised: 15 November 2021; accepted: 23 November 2021

Mucormycosis, a rare infection, caught the attention during the COVID-19 pandemic. Many COVID-19 and post-COVID-19 patients were infected by the black fungus. This study presents a scientometric review of 6661 research articles related to mucormycosis published from 1947 to 2021 indexed in Scopus and Web of Science. The study analyses the publications quantitatively in terms of growth, collaboration, countries, institutions, journals, keywords, and impact (citation) using the Bib-Excel and visualized in the VOSviewer tool. The highest number of publications on mucormycosis research is from the USA, followed by India, China, Germany, France, and Japan. Most of the research collaborations are among institutions in Europe and the USA. The University of Texas-USA is the most productive institute followed by PGIMER-India. However, the papers from Indian institutes have a significantly lower citation impact than those from the other leading countries. Since most international research is restricted among a few institutes, the international collaboration in mucormycosis research needs to be enhanced for high-quality research. The analysis of author-assigned keywords showed that the studies on the drug isavuconazole to treat mucormycosis are lesser than other major drugs. The research on surgical management of mucormycosis can be improved. Research on the diagnosis methods for mucormycosis and the genetic studies on the causative fungi of the order *Mucorales* are to be promoted. There are a few studies on *Rhizomucor*, *Lichtheimia*, *Cunninghamella*, *Saksenaea*, and *Apophysomyces*, among the several fungi genera that cause mucormycosis. Since mucormycosis is becoming more prevalent and severely affecting a larger population as a post-COVID syndrome, research in this area should be strengthened and new drugs should be explored.

Keywords: Black Fungus; Mucormycosis; Scientometric; Research Trends

Introduction

Mucormycosis (sometimes called black fungus) is a fungal infection caused by fungi in the order *Mucorales*. The major predisposing conditions are uncontrolled diabetes, neutropenia, malignancies, receipt of a transplant, and traumatic injury; and the use of systemic glucocorticoids for the treatment of COVID-19 may also lead to secondary bacterial or fungal infections, including mucormycosis[1-4]. A total of 11 genera and ~27 species under the order *Mucorales* cause mucormycosis. *Rhizopus, Lichtheimia*, and *Mucor* represent the most common fungi genera associated with human disease[5]. Types of mucormycosis in the human body include rhino-orbital-cerebral, pulmonary, gastrointestinal, cutaneous, renal, disseminated, and central nervous system mucormycosis[6]. The prognosis of mucormycosis is poor, with an approximate mortality rate of 54%; the mortality rate depends upon the underlying patient condition, type of fungus, and part of the body affected[7].

Though the exact burden of mucormycosis is unknown, studies suggest that the cases are rising globally. The rise is very high in India and China among patients with uncontrolled diabetes mellitus[8]. Blindness, clots in brain or lung blood vessels, and partial loss of neurological function are the major complications of mucormycosis[9]. Mucormycosis is usually rare, affecting fewer than 2 people per million in San Francisco each year. However, it is currently 80 times more common in India[10].

During the COVID-19 pandemic in India, the disease became a major public health concern. As of July 2021, approximately 45,374 cases of mucormycosis were reported from India, and more than 4,300 people have died[11]. Mucormycosis rates in India were predicted to be 70 times greater than the rest of the world even before the COVID-19 epidemic[12]. The cases of mucormycosis in India may be underreported due to the difficulties in diagnosis in rural areas, and a number of recovered patients after treatment appeared to be suffering from a relapse[11].

Mucormycosis has a higher morbidity rate than other invasive fungal infections like aspergillosis. More advances in understanding host defence, the invention of advanced early diagnostic systems, and the development of new superior therapeutic methods may help to improve the prognosis of the disease[13].

Scientometrics was first defined by Nalimov (1971) as developing "the quantitative methods of the research on the development of science as an informational process"[14]. Scientometrics helps to measure and analyse academic publications. The measuring of the influence of research papers and academic journals, as well as the comprehension of scientific citations and the application of such measurements in policy and management contexts, are the major applications of scientometrics[15].

This scientometric study on mucormycosis may aid researchers in exploring less focused subject areas, identify the researchers, institutes, or countries for research collaboration, and select journals for publishing the output. This study may also assist the policymakers and governments to understand the current research scenario and make better-informed decisions and benefits the funding agencies for better allocation of their funds to focus on the research gaps.

Review of literature

One scientometric study has been published on mucormycosis[16]. The study attempted to illustrate the mucormycosis research with bibliometric software "Biblioshiny" with the data retrieved from WoS. The results indicate that the research collaboration between institutes was fewer.

Kalra et al., studied 616 papers from WoS on COVID-19 related research on ophthalmology. India, USA, UK, and China had published most, and they classified Ranibizumab and keratitis as emerging or declining research areas[17]. A scientometric evaluation of coronavirus research published during 1900-2020 was conducted. More than 89 percent of papers came from the top twenty nations, indicating a lack of international cooperation. The majority of networking was among wealthy countries, implying that low and middle-income countries require more collaboration[18]. Global COVID-19 research based on the Dimensions database was examined. China was found to be the highly cited country, and the majority of productive institutes were from China. The most collaborative studies were conducted by Fudan University[19]. The United States was leading international collaborative efforts, and the countries severely affected by COVID-19 accelerated their research on COVID-19[20].

Ramírez-Malule H et al.,[21] analysed 227 Scopus indexed papers on Candida auris published during 2009-2018. The leading publishing countries were the USA, India, and the UK. The authors also listed the possible drugs used by researchers for facing the emerging antifungal resistance to *Candida auris*. Yujieet al.,[22] examined 1906 records indexed in Web of Science (WoS) on fungal keratitis published during 1959-2019 and explained the current status, trends, and hotspots of the fungal keratitis research field. Singh P et al.,[23] analysed 5358 records on *Fusarium oxysporum* published during 2009-2018 using WoS. The most productive country was China, followed by India, and India topped the list when analysing citations received. They also observed that many of the *Fusarium oxysporum* fungi species were not getting sufficient research attention.

Joshi K et al.,[24] examined global scientific productivity on forest fungi. The data published during 1987-2008 were extracted from WoS. The results indicated that the worldwide research on forest fungi is improving. The USA published most, and China had the highest growth rate in publications. A bibliometric study on oncolytic virus research for cancer therapy was conducted[25]. The researchers from the USA published most followed by China, and the most prominent institute was Mayo clinic-USA. The selected studies indicated that adenovirus, herpes simplex virus, reovirus, and Newcastle disease virus had shown potent anti-cancer activity.

As the number of cases of mucormycosis rises during the COVID-19 period, this study will assist in understanding the research gaps to be addressed.

Objective of the study

- To examine and analyse research output on mucormycosis using various scientometric indicators, examine the citation pattern, identify the journals that publish mucormycosis research, review international and institutional collaboration, and analyse the keywords used by researchers to explore the focal areas of research as well as to identify less explored areas of mucormycosis research.

Methodology

Two major citation databases, Web of Science (WoS) and Scopus, were selected to download the research papers to ensure broad coverage of global

research output on mucormycosis. Some disputes were there over the terminology used to refer to infections caused by *Mucorales*. Initially, the term 'mucormycosis' was used, and then it was replaced by 'zygomycosis'. As per molecular studies, the term 'mucormycosis' is currently in use[26-29]. The term 'black fungus' was not included in the search string as the black fungus is another fungi family, and the term is linked to mucormycosis due to the appearance of black dots in the culture of white fungal colonies[30-31]. Since the term 'phycomycosis'is mostly associated with animal diseases, the authors excluded the term 'phycomycosis' in the search[32].

The search was conducted in June 2021. The papers published between 1945 and 2021 (as of 28th June 2021) were selected for the analysis. Since a surge in the cases of mucormycosis being reported to be associated with COVID-19 during the period of study, the authors decided to include the research output published up to the date of the search. The following search string provided 4763 publications from WoS.

TI=(mucormyco OR zygomyco*) OR AB=(mucormyco* OR zygomyco*) OR AK=(mucormyco* OR zygomyco*)*

With the search string "*TITLE-ABS (mucormycosis OR zygomycosis) OR AUTHKEY (mucormycosis OR zygomycosis)"*, Scopus retrieved 6367 publications. Less scholarly materials like notes, corrections, letters etc., from both databases, were removed and selected 4333 publications from WoS and 5845 from Scopus. The records included in both databases were filtered out using Microsoft excel and finally selected 6661 papers for the study. Among the selected papers, 1613 had no abstract, 314 had no address, and the author details of 10 papers were not included in the databases. Citation data from WoS has been taken for papers included in both WoS and Scopus, while citation data from Scopus has been chosen for papers included only in Scopus. The papers were analysed using Microsoft Excel and BibExcel and visualised in VOSviewer.

Results and discussion

The final dataset considered six types of items; research articles (5183 papers, received 88994 citations), review articles (647, 21576), meeting abstracts (480, 191), editorial materials (195, 1634), proceeding papers (153, 5547) and book chapters (3, 62).

Growth of research

The first impression of mucormycosis research was published in 1876[33]. The first record in selected databases is a paper (1947) from WoS published in the *American Journal of Pathology*[34]. The initial research on mucormycosis was mainly published in clinical pathology-related journals. The research increased slowly and reached an average of eight publications per year by 1970. There were around 22 publications per year during the 1970s, fifty-five during the 1980s, ninety-one during the 1990s, and an average of 230 publications per year during the last decade. In the current year, 213 publications were indexed till June 2021. As seen in Figure 1 and Table 1, the number of publications has progressively increased more than threefold over the previous 20 years. As of now, the citations per publication on the topic are 17.72. Since any publication takes time to receive citations and the publications of early years are still getting cited in the current decade. The citations per publication for a period are calculated as the average number of citations of the publications till that period (cumulative citations/cumulative publication).

Geographical distribution of research output

The number of publications by the top twenty countries and their impact is detailed in Table 2. The United States has the most number of publications (1823), followed by India (748) and China (401). India and China are the countries with the highest burden of mucormycosis[8], and there is a rapid growth in research from these countries. Since a spike in mucormycosis cases has been linked to COVID-19 during the research period, the research performance of countries on mucormycosis during 2021 (till June 2021) has been analysed. The USA (48) published the highest number of papers during the first six months of 2021, followed by India (47) and China (34). India

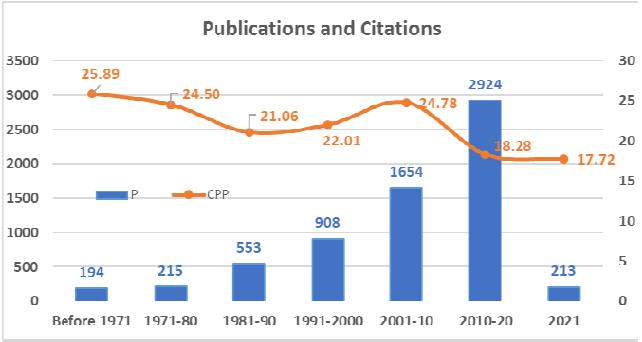

Fig. 1 — Pattern of research output

Table 1 — Growth of research over the years

Period	Publications (P)	Citations (C)	Cum. P	Cum. C	CPP = Cum. C/ Cum. P	Avg. Papers/Year	Growth Rate
Before 1971	194	5023	194	5023	25.89	8	
1971-80	215	4997	409	10020	24.50	22	10.825
1981-90	553	10240	962	20260	21.06	55	157.209
1991-2000	908	20902	1870	41162	22.01	91	64.195
2001-10	1654	46167	3524	87329	24.78	165	82.159
2010-20	2924	30562	6448	117891	18.28	292	76.784
2021 (As of July)	213	113	6661	118004	17.72	213	

Table 2 — Country-wise distribution of publications

Sl No.	Country	Publications (P)	Citations (C)	CPP = C/P	Publications (P) during 1981 to 2000	Publications (P) during 2001 to 2020	TAI = {(Ci/Co)/(Wi/Wo)} x 100 1981-2000	TAI = {(Ci/Co)/(Wi/Wo)} x 100 2001-20	Change in TAI	i10 Index
1	USA	1823	59540	32.66	466	1206	116.54	96.26	-20	964
2	India	748	7167	9.58	75	622	45.71	120.99	75	176
3	P R China	401	6964	17.37	5	362	5.68	131.35	126	128
4	Germany	366	11912	32.55	39	305	48.58	121.25	73	166
5	France	325	9437	29.04	57	257	79.96	115.06	35	136
6	Japan	303	6202	20.47	90	199	135.42	95.56	-40	93
7	Spain	299	6736	22.53	81	209	123.51	101.70	-22	119
8	U K	212	8116	38.28	55	143	118.28	98.14	-20	108
9	Italy	178	4974	27.94	28	142	71.72	116.07	44	69
10	Australia	159	4070	25.60	42	113	120.43	103.41	-17	96
11	Brazil	152	3762	24.75	28	117	83.99	112.00	28	76
12	Iran	135	1500	11.11	2	125	6.75	134.72	128	29
13	Canada	128	6858	53.58	26	96	92.61	109.13	17	65
14	Turkey	128	1852	14.47	12	113	42.74	128.45	86	36
15	Greece	126	4373	34.71	6	117	21.71	135.11	113	70
16	S. Korea	120	1672	13.93	13	103	49.39	124.89	75	37
17	Switzerland	107	3150	29.44	14	81	59.65	110.15	50	48
18	Austria	106	4247	40.07	7	93	30.11	127.66	98	50
19	Mexico	101	1322	13.09	8	84	36.11	121.01	85	27
20	Netherlands	100	4671	46.71	10	82	45.59	119.31	74	53

had a significant research performance in the first half of 2021, which might be attributed to the impact of a higher number of mucormycosis patients in India linked to COVID-19.

Figure 2 depicts the progress of mucormycosis research in the top countries over the decades. More than 110 countries have been contributed to mucormycosis research. The top twenty countries have been published for 78.4% of the total publications and received 86.2% citations. The data depicts that the research on mucormycosis is active only in a few countries, so involvement of other countries in research on mucormycosis is needed for tackling this fatal infection.

The impact of the research is counted in citations received; amongst the top twenty countries, publications from Canada (53.58) have obtained the highest CPP, followed by the Netherlands (46.71) and Austria (40.07). All the Asian countries in the top twenty list had a comparatively lower CPP. Except for Spain (22.53), all European countries, Australia, and the USA received a CPP of more than twenty-five. Among the top ten countries, the highest CPP was for papers from the UK (38.28), followed by the USA (32.66) and Germany (32.55).

Impact of research output of prolific countries

The i10 index measures the number of publications with at least ten citations. For seven countries (Australia, Greece, USA, Netherlands, UK, Canada, and Brazil,) more than 50% of their publications received ten or more citations. The USA, India,

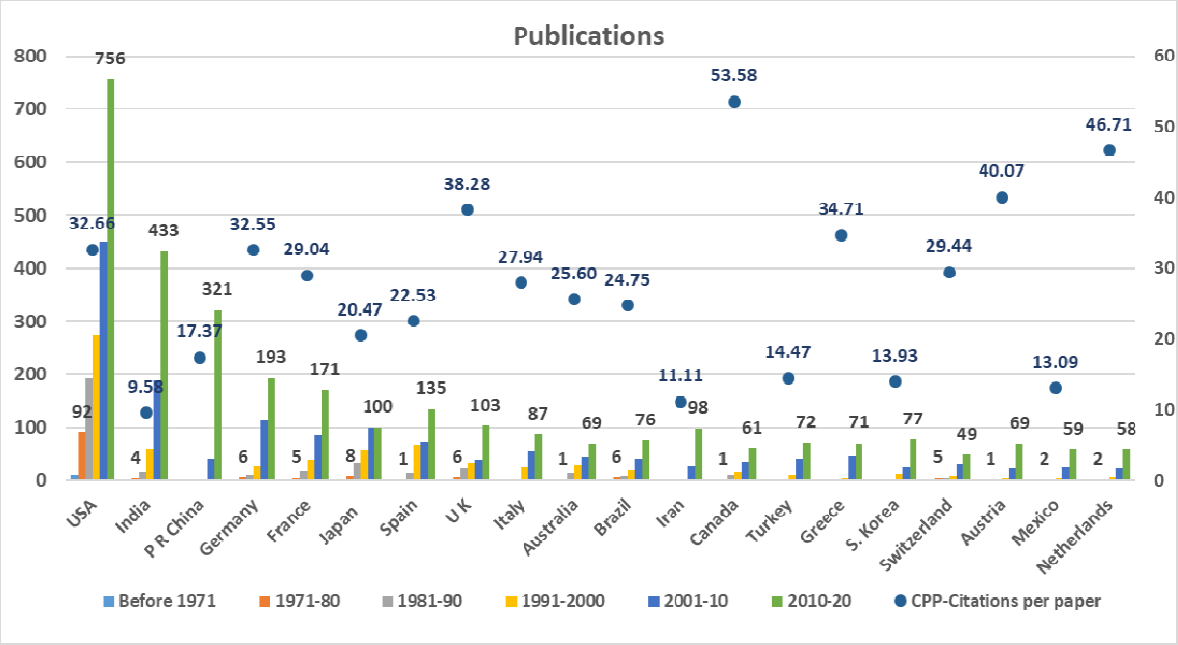

Fig. 2 — Research growth in top twenty countries

China, Germany, France, Spain, and the UK have obtained an i10 index value of more than hundred.

Despite the fact that India has one of the highest mucormycosis prevalence and a considerable number of papers published from India, the citations received for Indian papers were significantly lower, with a CPP of 9.58, and just 24% of its publications received an i10 index. This data emphasizes the need to enhance the quality of Indian publications.

We employed the Transformative Activity Index (TAI) proposed by Guan and Ma to examine the relative change in the output of the most productive nations. TAI can be defined mathematically, TAI = [(Ci /Co)/(Wi /Wo)] x100, Where Ci denotes the number of publications of the specific country in the ith block, Co indicates the total number of publications of the specific country during the study period, Wi represents the total number of publications of all countries in the ith block, and Wo signifies the total number of publications of all countries during the study period[35].

The TAI values portraits that the research output on mucormycosis is showing positive growth. Fifteen out of the top twenty countries reported a positive change in TAI value in the second block. The maximum increase in TAI was observed for Iran, and the maximum decrease was for Japan. The research activity has increased significantly in Iran, China, Greece, Austria, Turkey, Mexico, South Korea, India, Netherlands, and Germany. The research growth has been declined in Japan, Spain, the UK, the USA, and Australia.

Most preferred journals with their Impact factor and Citescore

The 6661 publications selected for this study were published across over 1800 journals; however, the papers were mainly concentrated in a few prominent journals. Nearly 20% of the papers were published in the top twenty journals. Only thirty-eight journals have been published more than twenty research publications on mucormycosis. Table 3 lists the fifteen journals ranked by the number of publications on mucormycosis.

The journal *Mycoses* (273) has published the highest number of papers, and 36% of them had cited more than ten times (i10=100); however, 33% of the publications in *Mycoses* were not cited.

The two major citation level metrics that are utilized for evaluating the impact of a scientific journal are journal impact factor (IF) by Clarivate and Citescore by Elsevier. Despite the fact that these two measures are based on similar principles for calculating the impact of citations, they have some differences. Some of these differences include the number of years considered to compute the metric, access to computing data, and the number of journals covered[36].

The analysis of the CPP of top journals vs. their IF and Citescore (Figure 3 & 4) depicts a relation

Table 3 —Top fifteen journals

	SO	Publications (P)	Citations (C)	i10 index	Non-Cited Publications (NCP)	i10 as % P	NCP as % P	CPP = C/P	IF-C (2020)	Citescore (2020)
1	*Mycoses*	273	2880	100	91	36.63	33.33	10.55	3.575	6.1
2	*Medical Mycology*	97	1499	47	17	48.45	17.53	15.45	2.822	5.7
3	*Mycopathologia*	96	1010	29	6	30.21	6.25	10.52	2.452	5.0
4	*Clinical Infectious Diseases*	96	12110	83	6	86.46	6.25	126.15	8.313	13.2
5	*Medical Mycology Case Reports*	59	190	5	12	8.47	20.34	3.22	-	1.8
6	*Journal De Mycologie Medicale*	59	238	6	12	10.17	20.34	4.03	1.56	4.0
7	*Journal of Clinical Microbiology*	57	2264	50	3	87.72	5.26	39.72	5.897	9.4
8	*Mycologia*	54	2217	38	0	70.37	0.00	41.06	2.149	3.9
9	*Clinical Microbiology And Infection*	54	3104	51	1	94.44	1.85	57.48	7.117	11.7
10	*Journal of Fungi*	47	334	11	11	23.40	23.40	7.11	4.621	5.5
11	*Chest*	47	582	18	24	38.30	51.06	12.38	8.308	10.3
12	*Antimicrobial Agents And Chemotherapy*	47	2517	35	1	74.47	2.13	53.55	4.904	9.1
13	*Transplant Infectious Disease*	44	878	18	6	40.91	13.64	19.95	2.071	3.1
14	*Indian Journal of Otolaryngology And Head & Neck Surgery*	41	121	1	10	2.44	24.39	2.95	-	0.6
15	*Current Fungal Infection Reports*	41	348	6	12	14.63	29.27	8.49	-	1.9

between the citations received by the publications on mucormycosis and the IF and Citescore of the journals that published them. However, in the case of some journals such as *Clinical Infectious Diseases, Clinical Microbiology and Infection,* and *Antimicrobial Agents and Chemotherapy*, the papers published on mucormycosis have received more citations than the average citations received for the papers on other subject areas. It can also be observed from the figures that the publications on mucormycosis in the journals, *Journal of Fungi, Chest, Medical Mycology Case Reports* and *Journal De Mycologie Medicale* have received citations that is significantly lower than the average citations received for papers in the same journals on other subject areas, while considering the IF and Citescore of journals.

Impact of research output of prolific institutions

More than 4000 institutions were published on mucormycosis research; however, the research is concentrated in a few institutions. Only twenty-eight institutions in the world have published more than thirty papers on mucormycosis. Table 4 lists the institutes that published more than forty papers on mucormycosis. The top nineteen institutes contributed 20% of the global publications and acquired 63% of the total citations. This data suggests that a few institutes published the top-cited publications. Hence more institutes need to collaborate with prominent institutes for conducting and publishing high-quality research. The University of Texas-USA has published the most number of papers and secured 11.65% of the global citations with a CPP of 62.22. It was the only institute that had an i10 index of more than hundred (143). The second top institute was PGIMER-India, which published 134 papers with a relatively lower CPP of 21.12.

Apart from the four institutes each from the USA and Europe, only two institutes from other continents were involved in the top ten most productive institutes. They were PGIMER and AIIMS, both from India. However, the publications from these institutes cited significantly less than that of the other top institutes. The publications from AIIMS-India had received the lowest CPP of 8.26, and only 29% of the publications from AIIMS-India were received more than ten citations. The University of Pennsylvania-USA has obtained the highest CPP (142.31) among the top institutions, followed by Duke University-USA (103.56). Almost one-third of the publications

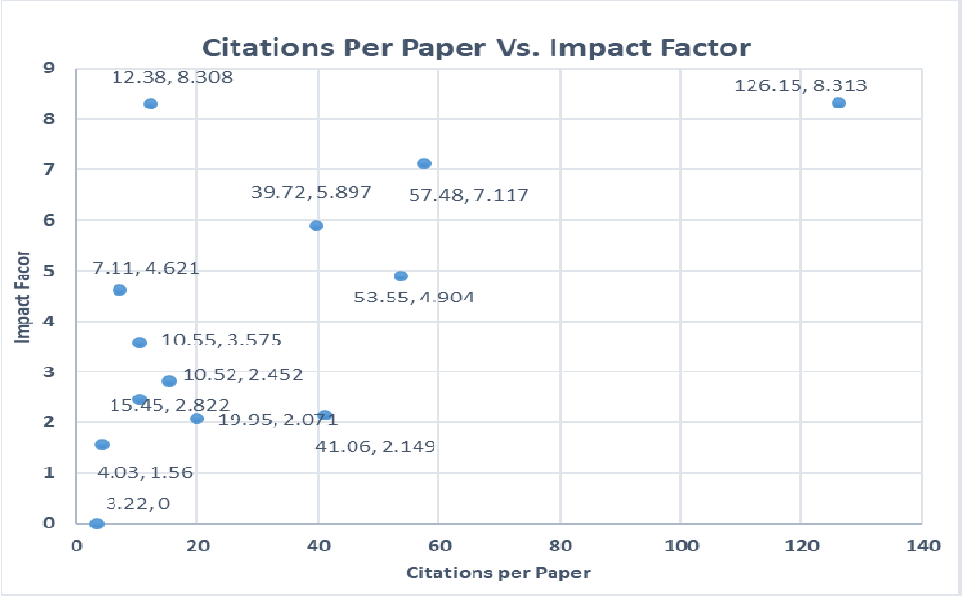

Figure 3— CPP of top journals vs. its IF (2020)

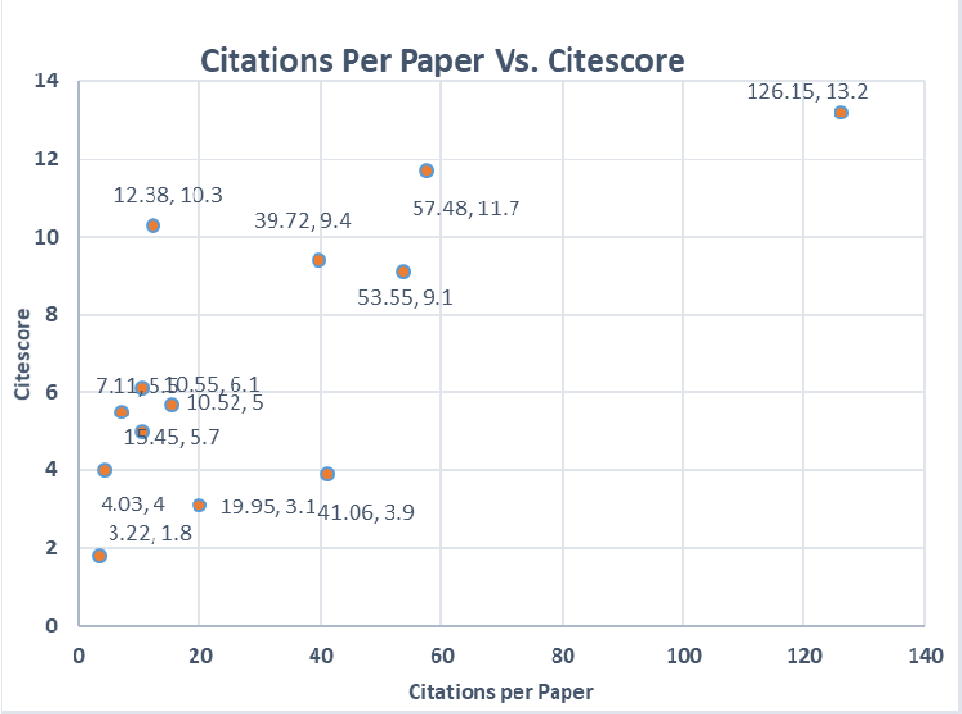

Fig. 4 — CPP of top journals vs. its Citescore (2020)

from the University of Cologne-Germany was not cited, and only 5% of the papers from Cornell University were not cited. While considering the performance of institutes in the COVID-19 period (first half of 2021), the University of Texas-USA and University of California-USA have been published seven papers each, followed by three papers each from AIIMS-India, PGIMER-India, Baylor College of Medicine-USA, and University of Medical Science-Iran. The improved performance of Asian institutes may be noted in the COVID-19 period.

International collaboration

Collaboration between different institutes enhances both the impact and quality of papers[37]. Only 10% of the total research papers on mucormycosis were

Table 4 — Most prolific institutes

	Institutions	Publications (P)	Citations (C)	CPP = C/P	i10	i10 as % of P	Not cited Publications (NCP)	NCP as % of P
1	Univ. Texas-USA	221	13750	62.22	143	64.71	31	14.03
2	Postgrad. Inst. Med. Educ. & Res. PGIMER-India	134	2830	21.12	57	42.54	17	12.69
3	Duke Univ.-USA	94	9735	103.56	69	73.40	10	10.64
4	Univ. Calif. Los Angeles UCLA-USA	89	5128	57.62	68	76.40	4	4.49
5	CNRS, Inst. Pasteur-France	77	3233	41.99	51	66.23	7	9.09
6	Med. Univ. Innsbruck-Austria	69	2789	40.42	34	49.28	21	30.43
7	All India Inst. of Med. Sciences-India	69	570	8.26	20	28.99	16	23.19
8	Univ. Cologne-Germany	64	1520	23.75	26	40.63	20	31.25
9	Hop Necker Enfants Malad-France	58	2853	49.19	34	58.62	8	13.79
10	Cornell Univ.-USA	57	3252	57.05	33	57.89	3	5.26
11	Mayo Clinic-USA	55	3536	64.29	32	58.18	10	18.18
12	Univ. Athens-Greece	53	3097	58.43	38	71.70	9	16.98
13	Aristotle Univ. Thessaloniki-Greece	47	2320	49.36	27	57.45	8	17.02
14	CDCP, Natl. Ctr. Infect. Dis.-USA	46	3565	77.50	37	80.43	3	6.52
15	Univ. Pittsburgh-USA	44	2219	50.43	26	59.09	10	22.73
16	Univ. Manchester-United Kingdom	44	1875	42.61	27	61.36	6	13.64
17	Univ. Penn.-USA	42	5977	142.31	27	64.29	5	11.90
18	Chinese Acad. Sci.-Peoples R China	42	2895	68.93	26	61.90	1	2.38
19	Univ. Calif. Los Angeles-USA	41	2992	72.98	35	85.37	3	7.32

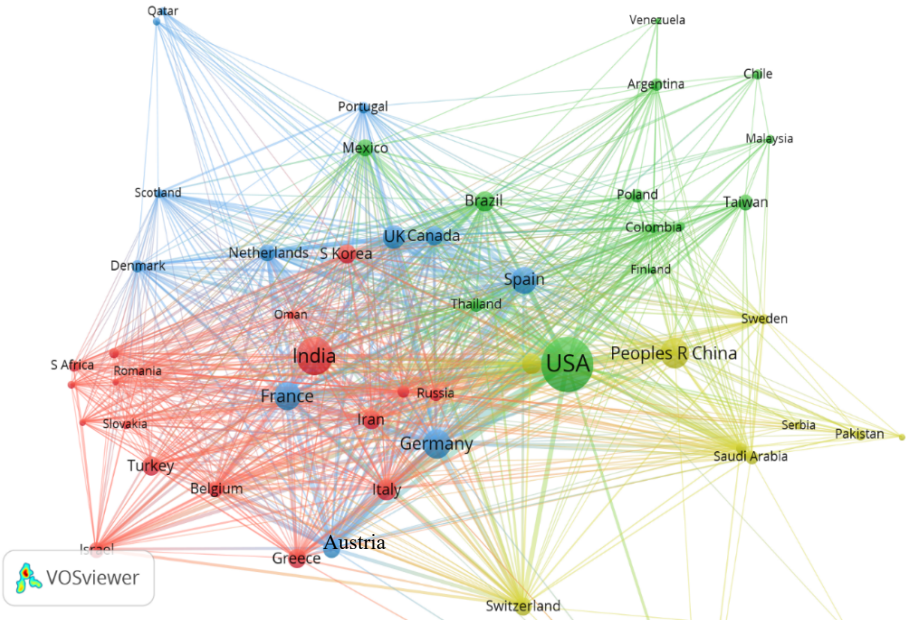

Fig. 5 — International collaboration

conducted with international cooperation. Those papers had received two-fold more CPP (38.29) than the papers with authors from single countries. Figure 5 shows a collaborative diagram with countries as nodes and links as the number of collaborative publications between countries. The size of the nodes is proportional to the publications from the country. The thickness of the connecting diagram is proportional to the collaborative publications between the countries.

The highest number of collaborative publications is from the USA with Germany (61), followed by Austria with Germany (45). As visible in the green cluster, authors from the USA collaborated with a

number of countries from all continents except Africa. Authors from the USA had published more than thirty papers with Germany (61), Canada (41), France (39), Spain (38), China (36), and Greece (34).

The blue cluster is the collaboration between European countries; Germany had co-operative research with the USA (61), Austria (45), France (37), Switzerland (31), Netherlands (29), and the UK (25). The Asian countries that were involved in publishing a minimum of fifteen papers with collaboration were China (36 papers with the USA), India (27 papers with the USA), and Israel (16 papers with the USA). The only country involved from South America was Brazil (22 papers with the USA). Australia published twenty-two papers with the USA and fifteen with Germany. Researchers from the USA were found to be more connected with researchers from developing countries like China, India, and Brazil.

Only four countries, China, India, Israel, and Brazil, published at least fifteen publications with international collaboration, aside from the European countries, the United States, Canada, and Australia. Only 10% of the publications on mucormycosis were published with international collaboration, and the countries involved were also limited. Asian and African countries need to involve in more research with international cooperation.

Institutional collaboration

Figure 6 represents the institutional collaboration links. While analysing the institutional collaboration, the strongest link was between the French institutes, CNRS Institut Pasteur, and Necker–Enfants Malades Hospital (39), followed by the US institutes, University of California, and University of Texas (32). The University of Cologne-Germany has published more than ten papers in partnership with three international institutes. The strongest links were between institutes from the USA, Germany, France, Austria, and Greece. PGIMER is the Indian institute that was actively collaborated with other institutes. PGIMER-India collaboratively published six papers each with the Medical University of Innsbruck-Austria and Canisius Wilhelmina Hospital-Netherlands, as well as five papers each with AIIMS-India, University of Pittsburgh-USA and Enfants Malades Hospital-France.

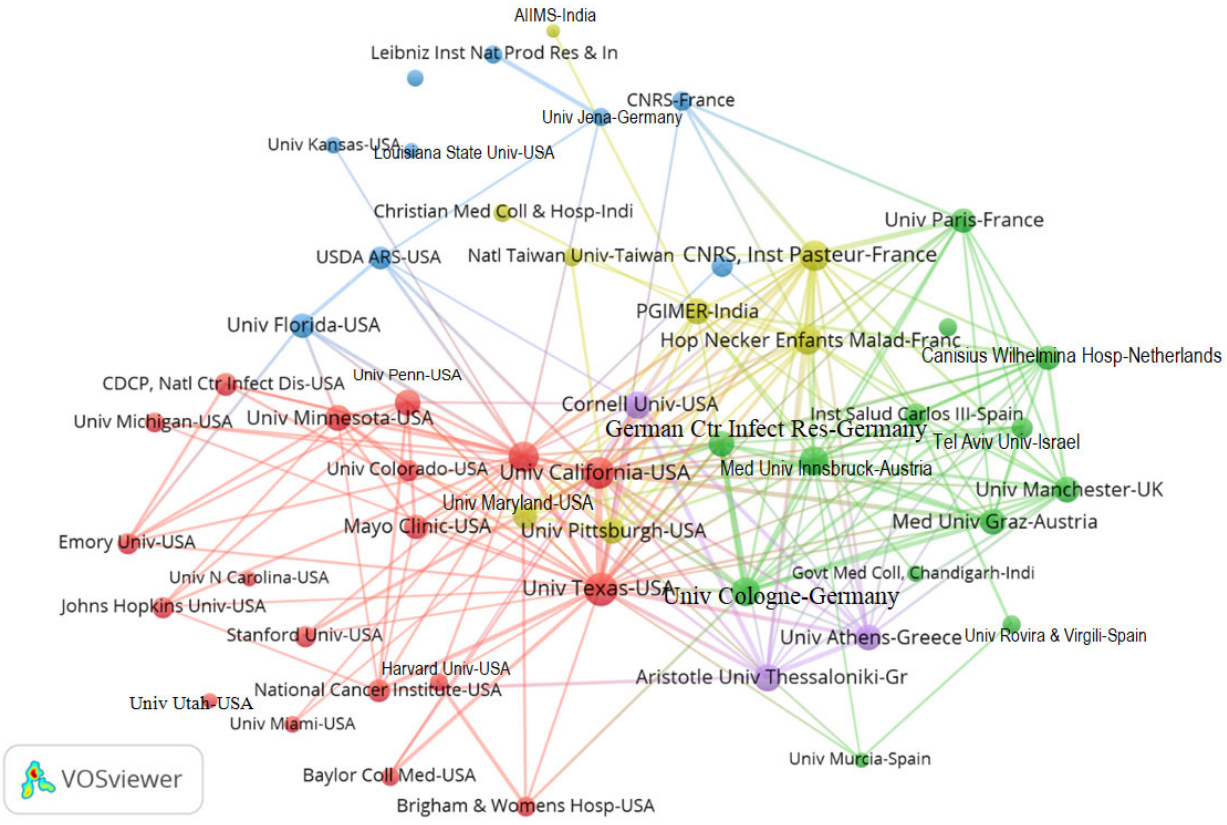

Fig. 6 — Institutional collaboration

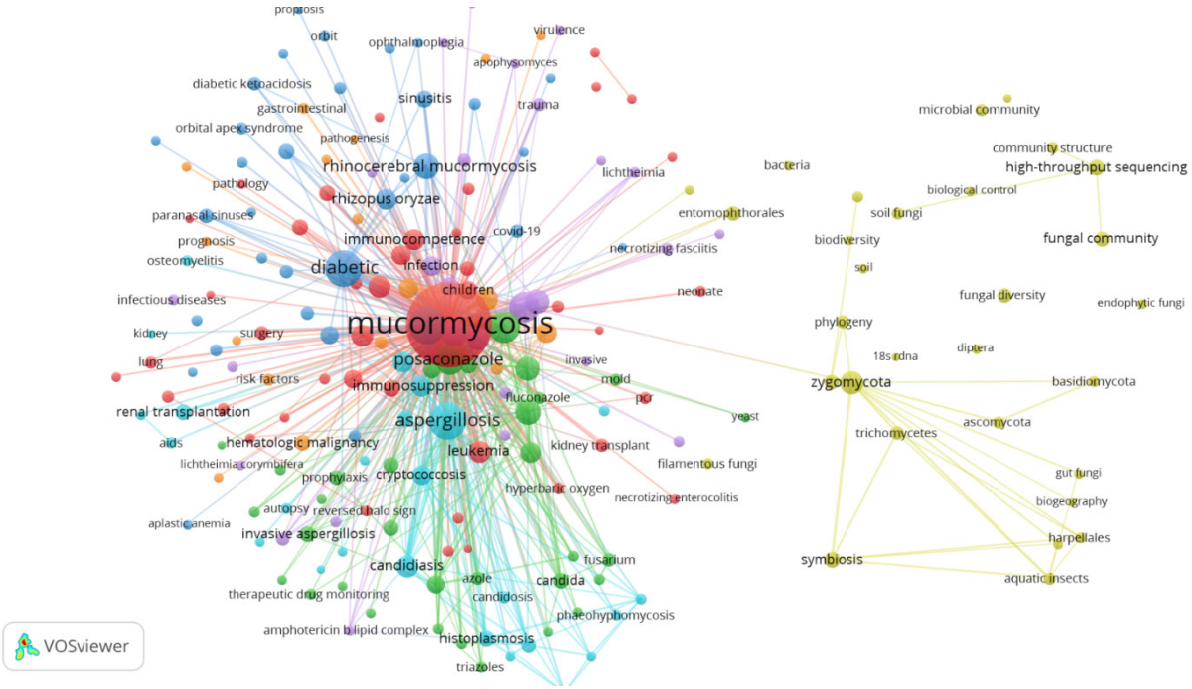

Fig. 7 — Distribution of author keywords

Keyword analysis

Keywords in research publications represent the main content, and the analysis predicts the focal areas of a research field and can be used for finding the research gap. Figure 7 represents the keywords given by the authors. Keywords with at least ten occurrences were selected for analysis. Keywords are classified and grouped as follows,

Drugs & Surgery

Amphotericin B (370) was the most discussed drug, of that ninety-three keywords were on Liposomal amphotericin B, followed by posaconazole (159), isavuconazole (74), and voriconazole (56). Other antifungal medicines, such as itraconazole (21), fluconazole (19), echinocandins (18), caspofungin (18), and micafungin (11), had discussed in a fewer number of studies.

Besides amphotericin, the only two other drugs that may be used to treat mucormycosis are posaconazole and isavuconazole; both are patented and expensive[12,38]. Though the publications on isavuconazole have been less, the average publication year of papers with the drug isavuconazole was 2018, which suggests that the isavuconazole may be one of the core areas of current drug research on mucormycosis. Surgical treatment was discussed only in sixty papers. Thus the studies on surgical management of mucormycosis must be improved.

Types of Mucormycosis

Rhino-cerebral-mucormycosis (151) was discussed most, followed by cutaneous (112), pulmonary (97), rhino-orbital-cerebral mucormycosis (43), and gastrointestinal mucormycosis (31). Disseminated mucormycosis and renal mucormycosis were found only in less than fifteen publications.

Diagnosis

Mucormycosis needs to diagnose early as a short delay in treatment with amphotericin B increases mortality rate[39]. Polymerase chain reaction (30) was the most discussed, followed by computed tomography (21), magnetic resonance imaging (11). Immuno–histochemistry was mentioned in 13 publications, pathology and histopathology were discussed in 27 studies. Since the studies related to diagnosis are lower than other topics, the researchers should be focused on diagnostic tools for early and precise diagnosis.

Associated fungal diseases

Aspergillosis (312) was the most discussed fungal disease other than mucormycosis, followed by candidiasis (117), cryptococcosis (60), histoplasmosis (39), fusariosis (32), coccidioidomycosis (17), and phaeohyphomycosis (16).

Types of fungi

The genus *Rhizopus* was a keyword in 248 publications, followed by *Mucor* (118), *Aspergillus*

(100), and the fungi class, Zygomyctetes (154). Other fungi genera discussed were *Absidia* (48), *Cunninghamella* (44), *Candida* (39), *Rhizomucor* (38), *Lichthemia* (29), *Apophysomyces* (27), *Saksenaea* (27), and *Fusarium* (27). The genera most commonly implicated in human mucormycosis infections are *Rhizopus*, *Mucor*, *Rhizomucor*, *Lichtheimia*, *Cunninghamella*, *Saksenaea*, and *Apophysomyces*[40]. The studies on the genera *Rhizomucor*, *Lichtheimia*, *Cunninghamella*, *Saksenaea*, and *Apophysomyces* need to be enhanced.

Since the genus, *Cunninghamella* is associated with higher mortality rates[1], more research on *Cunninghamella* is expected.

Risk factors

Uncontrolled diabetes mellitus, corticosteroid therapy, organ or bone marrow transplantation, neutropenia, trauma and burns, malignant hematologic conditions, and deferoxamine therapy in hemodialysis patients are some of the important risk factors for mucormycosis[41-43].

Diabetes (299) was the most discussed risk factor related to mucormycosis; of that, 38 papers were on diabetic ketoacidosis. There were 263 publications related to the immune system. The immuno–compromised host was discussed in 102, immuno–competent in 85, immunosuppression in 66, and immunodeficiency in 10 publications. Kidney transplantation was a topic in 61 publications, followed by stem cell transplantation (52) and liver transplantation (13).

Hematologic malignancies (including leukemia and lymphoma) were discussed in 141 publications and chemotherapy in 10. Neutropenia was studied in 49, and trauma was in 28 papers. Research related to iron was seen only in 24 publications, including 11 on deferoxamine. The human immunodeficiency virus was a keyword in 28 publications.

COVID-19 was a keyword in 25 publications.

Other keywords

Epidemiology was involved in 68, prophylaxis in 40, mortality in 28, and prognosis in 14 publications. Fungal sinusitis was a keyword in 98 papers, orbital apex syndrome in 22, necrotizing fasciitis in 19, and brain abscess in 15 papers. There were only 15 studies related to pharmacokinetics.

Conclusion

This study provides a scientometric review of the present body of literature focusing on mucormycosis research which is slowly increasing. The highest number of research output is from the USA, followed by India and China. Though India is the second most productive country in publishing papers on mucormycosis, it has not been adequate while considering the higher prevalence of mucormycosis in India. However, a spike in the research growth on mucormycosis in India was noticed in the first half of 2021, which might be due to the outbreak of mucormycosis associated with the COVID-19 in India. The impact of research from Asian countries was lower than the USA and European countries. The lowest CPP was for research from India.

The University of Texas was the most productive institute. The two Asian institutes in the top ten list were PGIMER and AIIMS from India; the rest were four each from the USA and Europe. Collaborative research has been actively conducted by institutions in the United States and Europe. Asian institutions, on the other hand, have produced fewer research papers with institutional collaboration. The number of research published by Asian countries with international cooperation was significantly lower; this may be the reason for less CPP of Asian publications. Institutions from countries other than Europe and the USA must involve in collaborative research for producing higher-quality output.

The keyword analysis revealed that the studies on isavuconazole, a drug used for mucormycosis, were lower than the other two drugs, amphotericin B and posaconazole; some studies suggested higher efficacy of isavuconazole over amphotericin B[44-45]. Since the average year of publications of isavuconazole is 2018, more research is expected to be conducted on isavuconazole. Improvement in research on the surgical management of mucormycsosis is also required.

The research on the diagnosis, diabetes associated with mucormycosis, and the mucormycosis caused by fatal *Cunninghamella* needs to be enhanced. More research of fungi genera *Saksenaea*, *Lichtheimia*, *Apophysomyces*, and *Rhizomucor* that cause infections in humans is required. The keywords related to Mucorale's genetic studies were also very few, indicating that genetic studies should be given sufficient attention.

Only two countries, the USA and India, have published more than five hundred publications on this topic. As mucormycosis, a disease with a higher mortality rate, started to spread as a post-COVID-19

syndrome and affected thousands of people within a short period[4], researchers need to provide more attention to this disease and funding agencies should allocate more funding to this research field.

Since no scientometric studies on mucormycosis have been published in the literature covering both WoS and Scopus, the findings of this study may be helpful to researchers in attaining a perspective of the current research scenario mucormycosis. Since the top twenty countries have published approximately 80% of the research output, more countries must engage in mucormycosis research in order to successfully tackle the fatal disease.

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