Global Mucormycosis Research: A Bibliometric Assessment Based on Scopus Database (1998-2021)

Brij Mohan Gupta[1], Ghouse Modin Mamdapur[2], Saniya Gupta[3], Latika Rohilla[3], Devi Dayal[3,*]

[1]Formerly with CSIR-National Institute of Science, Technology and Development Studies, New Delhi, INDIA.
[2]Information AND Documentation Division, Synthite Industries (Pvt.) Ltd., Kolenchery, Kerala, INDIA.
[3]Department of Pediatrics, Postgraduate Institute of Medical Education and Research, Chandigarh, INDIA.

ABSTRACT

Background: Mucormycosis is an invasive filamentous fungal infection that usually occurs in immunocompromised individuals. Although the disease is well-researched, the assessment of global research on mucormycosis is scarcely reported. **Materials and Methods:** We used Elsevier's Scopus database to retrieve mucormycosis publications from 1998 to 2021. Using various bibliometric tools, the publication data were analyzed with regard to the growth in the number of publications, their citations, top-yielding organizations and authors, collaborations, and productive journals. **Results:** One hundred twenty countries contributed 5658 publications to research on mucormycosis. The USA leads with a 30.6% share, followed by India (14.1%), France, Germany, and Spain (5.4% to 5.8%). The annual and absolute growth was 3.9% and 82.6%; only 11.2% of publications were funded. The average citations per paper decreased from 28.4 to 11.4 during the two 12-yr periods. The research involved 931 organizations and 1123 authors. The leading organizations were the University of Texas, Anderson Cancer Center, USA, PGIMER-Chandigarh, India, and the University of Paris, France, with 154, 150, and 89 publications. Kontoyiannis, Walsh,

and Cornely were the most prolific authors contributing 119, 76, and 58 publications. Mycoses, Clinical Infectious Diseases, and Medical Mycology were the most active journals. **Conclusion:** The quantity of mucormycosis research increased while the quality decreased during 1998-2021. Fostering collaboration between high- and low-income countries may improve the impact of global mucormycosis research.

Key words: Mucormycosis, Invasive fungal infection, Diabetes, Research output, Scientometrics.

Correspondence

Devi Dayal,

Endocrinology and Diabetes Unit, Department of Pediatrics, Advanced Pediatrics Center, Postgraduate Institute of Medical Education and Research, Chandigarh-160012, INDIA.

Email id: drdevidayal@gmail.com

INTRODUCTION

Mucormycosis is an invasive fungal infection (IFI) that causes rapid tissue and angioinvasion and is associated with high morbidity and mortality.[1] Although it may occur in immunocompetent individuals, certain underlying immunocompromised conditions like diabetes, renal failure, hematological malignancies, iron overload, and immunosuppression particularly predispose patients to mucormycosis.[1] The most common forms are rhinocerebral, pulmonary, cutaneous, digestive, or disseminated infections, although any organ system may be involved.[2-4] The outcome largely depends on a multimodal approach that often involves extensive surgical removal of the affected tissues along with the use of antifungals and effective control of the underlying condition.[5-7]

Mucormycosis has presented new global challenges in the last few decades. These include changes in its epidemiology, such as an increase in overall incidence, expansion into new hosts, emergence of new pathogens, and development of multidrug resistance.[1,8] The global challenges posed by IFI, including mucormycosis, have indeed been recognized by the ECMM, representing 25 affiliated National Medical Mycology Societies. These are reflected in several significant initiatives by ECMM to improve the outcome of these patients worldwide.[8] The onset of the COVID-19 pandemic has also brought a surge in mucormycosis infections.[9] To address challenges due to mucormycosis, extensive research appears to have been conducted in several countries.[10] However, a scientometric assessment of mucormycosis research is scarce. There is only one bibliometric assessment of mucormycosis research that included publications between 1923 and 2021 indexed in the Web of Science (WoS) database.[10]

However, the retrieved publications numbered only 4451, far less than would be expected of an intensely researched topic.[10] The other bibliometric studies on antifungal resistance and other fungi did not focus on mucormycosis research.[11,12] Hence, a comprehensive bibliometric analysis of the characteristics and impact of mucormycosis studies is unavailable. In this contribution, we present a qualitative as well as quantitative assessment of global studies on mucormycosis published in the timespan from 1998-2021.

The study aimed to evaluate global research on mucormycosis by retrieving the Scopus-indexed publications from 1998 to 2021. Using select quantitative and qualitative indicators, we analyzed publications growth, the contribution of top 10 countries, the share of international collaboration, financial support, citation metrics, broad subject areas of publications, mapping of important keywords, high-yielding organizations and authors, and their collaborative linkages, productive journals, and characteristics of highly-cited papers (HCP).

MATERIALS AND METHODS

The mucormycosis publications were retrieved from the Scopus international database (http://www.scopus.com) using a defined search approach similar to our recent bibliometric studies.[13-15] Briefly, the keywords mucormycosis* OR zygomycosis* OR phycomycosis were searched in "TITLE" or "KEY" tags, and the search output was confined to the period '1998-21' using "date range tag". The search string was as

follows: [KEY (mucormycosis* OR zygomycosis* OR phycomycosis*) OR TITLE (mucormycosis* OR zygomycosis* OR phycomycosis*)] AND PUBYEAR > 1997 AND PUBYEAR < 2022.

The global research data on mucormycosis were further analyzed using Scopus's analytical provisions. Every contributing author or organization covered in multiple authorship publications was fully counted using the complete counting method. The quality of publications was assessed by using indices such as *h*-index (HI), relative citation index (RCI), and citations per paper (CPP). The total number of citations was divided by the total number of publications to obtain CPP. The RCI was calculated by dividing the number of publication's citations by the average number of citations that an article usually receives in the same field. The number so obtained is then benchmarked to the median RCI for all NIH-funded papers. *H*-index or Hirsch index was obtained by Scopus' automated calculators and is defined as the maximum value of *h* in a way that an author or journal has published at least *h* papers, and each of those has been cited at least *h* times. A publication was considered HCP if it had received more than 100 citations. We also used the activity index to understand the gradual changes in research activity with time. The study timespan was divided into two halves of 12-year periods to understand the long-term changes in publication metrics and growth. Citations to the publications were counted from the article's publication until May 22, 2021.

Ethical considerations

This study used secondary data that does not require approval from the ethics committees meant for human research. We followed all the principles of ethics prescribed for analysis of this nature through respecting citations and ideas and referencing authors and their publications.

RESULTS

The general profile of publications

The total publications in mucormycosis research were 5658. The average annual growth and absolute growths were 3.9% and 82.6%, respectively. The average CPP was 17.4, which decreased from 28.4 to 11.4 during the two 12-yr periods (Table 1). Only 11.2% (637) publications were funded by more than 100 agencies; the funded papers increased almost five times during 1998-2009 to 2010-2021. The average CPP of funded papers was higher than the non-funded papers (37.7 versus 17.4). The leading funding agencies were the National Institute of Health, USA, U.S. Department of Health and Human Service, Pfizer Inc., National Institute of Allergy and Infectious Diseases, and Gilead Sciences, which funded 224, 213, 138, 137, and 117 papers, respectively. The publication categories were original articles (69.1%), reviews (16.7%), letters (5.5%), short notes (3.5%), conference papers (1.7%), book chapters (1.0%), editorials (0.9%), short surveys (0.8%), erratum (0.4%) and undefined (0.1%). The studied age groups were as follows: adults (42.1%), middle-aged (26.1%), elderly (17.4%), children (11.2%), and adolescents (10.3%).

Researched aspects of mucormycosis

The largest share of publications was on drug therapy (58.5%), followed by clinical studies (36.2%), diagnostics and imaging (16.3%), complications (12.3%), risk factors (9.5%), epidemiology (9.4%), pathophysiology (8.7%), etc. during 1998-21. Publications on epidemiology and risk factors received the highest and the lowest number of citations (average CPP 39.4 and 3.9, respectively).

Type of mucormycosis

The largest share of publications belonged to unclassified zygomycosis (20.6%), followed by pulmonary (13.0%), gastrointestinal (7.8%), cutaneous (6.6%), uncommon forms (4.9%), rhinocerebral (3.2%), disseminated (1.6%) and renal mucormycosis (1.2%). Publications on gastrointestinal

Table 1: Global publication output on mucormycosis, their citations, and funding during 1998-2021.

Year	Total papers	Citations	Citations per paper	Funded papers
1998	104	1834	17.6	0
1999	121	2675	22.1	1
2000	99	2745	27.7	3
2001	121	2864	23.6	2
2002	115	2851	24.7	2
2003	119	3435	28.8	1
2004	161	4986	30.9	6
2005	191	8666	45.3	14
2006	219	6266	28.6	5
2007	223	6253	28.0	13
2008	252	6385	25.3	22
2009	277	7905	28.5	31
2010	276	7510	27.2	25
2011	273	5764	21.1	34
2012	317	6252	19.7	32
2013	296	3899	13.1	35
2014	347	4679	13.4	44
2015	305	3134	10.2	28
2016	300	3245	10.8	34
2017	304	2575	8.4	45
2018	326	2165	6.6	71
2019	392	1864	4.7	86
2020	355	574	1.6	75
2021	165	57	0.3	28
1998-2009	2002	56865	28.4	100
2010-2021	3656	41718	11.4	537
1998-2021	5658	98583	17.4	637

and rhinocerebral forms registered the maximum and the least CPP of 29.2 and 13.6, respectively.

Research by underlying risk factors

The most commonly studied risk factor was diabetes mellitus contributing 17.4% of publications, followed by neutropenia (12.4%), immunocompromised host (10.2%), hematological malignancy (7.3%), corticosteroid therapy (6.1%), diabetic ketoacidosis (4.4%), renal failure (2.8%), solid organ transplantation (2.4%), HIV infection (2.2%), deferoxamine therapy (2.1%), bone marrow transplantation (1.8%), chronic kidney disease (1.8%), trauma (1.0%) and auto-immune disease (0.2%).

Significant keywords

We identified 96 keywords from the global literature on mucormycosis, which throw light on the research trends in this field (Figure 1).

Most productive countries

One hundred twenty countries participated in mucormycosis research. The USA leads in global ranking with a publication share of 30.6%, followed by India (14.1%), France, Germany, and Spain (5.4% to 5.8%), and U.K., Japan, Italy, China, and Australia (2.6% to 3.9% share).

Six countries registered RCI better than the group average of 1.29 (Table 2). The average international collaborative publications (ICP) was 63.8% (Table 2). All the top 10 countries showed one-to-one collaborative linkages; the largest number of linkages (290, 175, and 146, respectively) were established by the USA, Germany, and France. The country pairs that collaborated the highest number of times were USA-Germany, USA-UK, USA-Spain, USA-France, and USA-India with 51, 44, 44, 43, and 33 linkages, respectively (Figure 2).

Most productive research organizations

Nine hundred thirty-one organizations participated in global research on mucormycosis. The top 20 organizations produced 60 to 154 publications per organization; together, they contributed 25.0% (1418 publications) and 69.5% (68605 citations) to the global publications and citations, respectively. Seven organizations registered their publication output above the group average of 70.9, whereas 12 registered their CPP and RCI above the group average of 48.3 and 2.7, respectively. The scientometric profile of the top 10 most productive and most impactful organizations is shown in Table 3.

All the top 20 organizations showed collaborations; the University of Paris, France, Institut Pastaur Paris, France, and Hopital Necker Enfants Malades, France were the three with the largest collaborative linkages, i.e., 246, 246, and 204 respectively. The organization to organization

Figure 1: WordCloud portrayal of co-occurrence of significandt keywords in mucormycosis research. The significance of each tag is displayed with text dimension or shading. The greater term implies more noteworthy weight.

collaboration was highest between David Geffen School of Medicine at UCLA, USA and University of California, Los Angles, USA (64 linkages), followed by University of Paris, France, and Institut Pastaur Paris, France (58 linkages), University of Paris, France and Hopital Necker Enfants Malades, France (50 linkages), University of Paris, France and AP-HP Assistance Publique-Hopitaux de Paris, France (47 linkages), etc. (Figure 3).

Most productive authors

Of the 1123 authors who researched mucormycosis, the top 20 contributed 25 to 119 publications per author. Their share of publications and citations was 15.5% (877 papers) and 60.1% (59298 citations) in the global output. The publications output of eight authors was better than the group average of 43.8, whereas another eight had better CPP and RCI than the group average of 67.6 and 3.8, respectively. Table 4 shows the profile of the top 10 most productive and most impactful authors. Three authors with the largest collaborative linkages (104, 73, and 68) were D.P. Kontoyiannis, T.J. Walsh, and A.S. Ibrahim (Figure 4).

Top journals

98.5% (5577) of mucormycosis papers were published in 772 journals; the rest were books, book series, reports, or undefined. The 20 most prolific journals contributed 30 to 187 papers and together accounted for 21.7% share of global output (Table 5).

Highly cited publications

3.0% (173) publications were HCPs; these had received 38708 citations (average CPP 223.7). The USA published a majority of the HCPs (119 publications), followed by France (27 papers), Germany (20 papers), the U.K. (19 papers), Greece (14 papers), Italy (13 papers), India (12 papers), Austria (11 papers), Belgium and Switzerland (10 papers each), etc. The authors from the USA contributed the maximum number of HCPs (Figure 5).

DISCUSSION

Our bibliometric analysis demonstrates that global mucormycosis research showed impressive growth during the last about two decades. However, the research quality as judged by the CPP showed a decline

Table 2: Most productive countries in global mucormycosis research during 1998-2021.

S.no.	Country	Total number and share (%) of publications			TC	CPP	ICP	ICP%	RCI
		1998-2009	2010-2021	1998-2021			1998-2021		
1	USA	639 (31.9)	1097 (30.0)	1736 (30.6)	52966	30.5	358	56.0	1.7
2	India	213 (10.6)	586 (16.0)	799 (14.1)	7711	9.6	70	32.8	0.5
3	France	105 (5.2)	228 (6.2)	333 (5.8)	9773	29.3	94	89.5	1.6
4	Germany	104 (5.1)	209 (5.7)	313 (5.5)	7741	24.7	134	128.8	1.4
5	Spain	108 (5.3)	201 (5.5)	309 (5.4)	2149	6.9	15	13.8	0.4
6	U.K.	62 (3.1)	160 (4.3)	222 (3.9)	6298	28.3	108	174.1	1.6
7	Japan	84 (4.2)	122 (3.3)	206 (3.6)	2331	11.3	24	28.5	0.6
8	Italy	66 (3.3)	135 (3.6)	201 (3.5)	5877	29.2	62	93.9	1.6
9	China	34 (1.7)	156 (4.2)	190 (3.3)	1467	7.7	34	100.0	0.4
10	Australia	59 (2.9)	93 (2.5)	152 (2.6)	3614	23.7	42	71.1	1.3
	Total of 10	1474 (73.6)	2987 (81.7)	4461 (78.8)	99927	22.4	941	63.8	1.2
	Global total	2002	3656	5658	98583	17.4	---	---	---

Abbreviations: TC, total citations; CPP, citations per paper; ICP, international collaborative papers; RCI, relative citation index.

during the second 12-year time period. This observation is consistent with a decrease in the medical research quality in general during the last few decades due to several factors, such as a substantial increase in the number of researchers and the priority given to quantity and not quality during hiring or job promotions.[16] Surprisingly, the decline in the mucormycosis research quality was noted despite a 3-fold increase in the proportion of funded publications (4.9% to 14.6%) and an overall better CPP of funded publications (37.7 versus 17.4). This observation indicates that even the better funding support during the latter half of

the study span was unable to sustain the previous high quality of mucormycosis research and is contrary to the generally accepted view that research funding is an important determinant of citations and impact.[16-18] In a recent study, we observed a considerable difference between the CPP of non-funded and funded publications (18.6 versus 77.2).[19]

The mucormycosis research is dominated by high-income countries in the North-American and Western-European regions, an observation noted in several previous scientometric studies.[20-22] Such high productivity and quality result from the availability of financial support and commitment to research by the national governments. Additionally, the high-income countries provide the infrastructure and funding required for conducting such highly organized research activity.[17] Among the
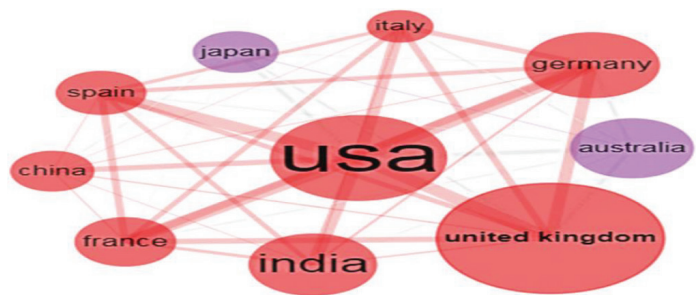

Figure 2: Collaboration network of the 10 countries generated form the Boblioshiny app. The countries with the same colour belong to a single cluster. The thickness of the links berween the countries and the distance between them represents the degree of their research collaboration. The bigger the diameter of a nerwork node and its font size, the bigger its weight in research collaboration.
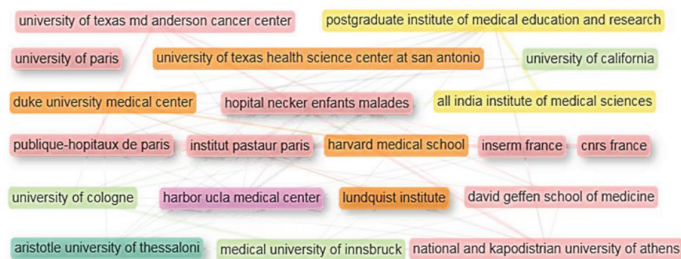

Figure 3: Collaboration network of the top 20 organizations in mucormycosis research. Six groups are represented with different colours. The box size and text dimension of every hub are relative to its distribution output in the same field.

Table 3: Top ten most productive and most impactful organizations in global mucormycosis research during 1998-2021.

S.no.	Organization	TP	TC	CPP	HI	ICP	ICP%	RCI
	Top 10 most productive organizations							
1	University of Texas MD Anderson Cancer Center, USA	154	12018	78.0	48	62	40.2	4.4
2	Postgraduate Institute of Medical Education and Research, Chandigarh, India	150	2946	19.6	29	22	14.6	1.1
3	University of Paris, France	89	3913	43.9	32	31	34.8	2.5
4	Institut Pastaur Paris, France	78	3472	44.5	29	30	38.4	2.5
5	David Geffen School of Medicine at UCLA, USA	76	4650	61.1	33	17	22.3	3.5
6	University of California, Los Angles, USA	73	4825	66.1	31	17	23.2	3.7
7	University of Texas Health Science Center at San Antonio, USA	72	3559	49.4	30	31	43.0	2.8
8	AP-HP Assistance Publique-Hopitaux de Paris, France	67	2099	31.3	25	19	28.3	1.8
9	All India Institute of Medical Sciences, New Delhi, India	66	524	7.9	12	2	3.0	0.4
10	Duke University Medical Center, USA	61	3405	55.8	28	22	36.0	3.2
	Top 10 most impactful organizations							
1	University of Texas MD Anderson Cancer Center, USA	154	12018	78.0	48	62	40.2	4.4
2	Harbor UCLA Medical Center, Los Angles Biomedical Center, USA	52	3468	66.6	29	18	34.6	3.8
3	University of California, Los Angles, USA	73	4825	66.1	31	17	23.2	3.7
4	National and Kabedistrian University of Athens, Greece	53	3439	64.8	27	35	66.0	3.7
5	Medizinische Universitat Innsbruck, Austria	54	3322	61.5	27	40	74.0	3.5
6	David Geffen School of Medicine at UCLA, USA	76	4650	61.1	33	17	22.3	3.5
7	The Lundquist Institute, USA	52	3054	58.7	27	14	26.9	3.3
8	Hopital Necker Enfants Malades, France	60	3384	56.4	26	19	31.67	3.2
9	Duke University Medical Center, USA	61	3405	55.8	28	22	36.0	3.2
10	Aristotle University of Thessaloni, Greece	53	2893	54.5	24	37	69.8	3.1

Abbreviations: TP, total publications; TC, total citations; CPP, citations per paper; HI, Hirsch-index; ICP, international collaborative papers; RCI, relative citation index.

Table 4: Top 10 most productive and most impactful authors in global mucormycosis research.

S.no.	Author	Affiliation	TP	TC	CPP	HI	ICP (%)	RCI
		Top 10 most productive authors						
1	D.P. Kontoyiannis	University of Texas MD Anderson Cancer Center, USA	119	10879	91.4	46	48 (40.3)	5.2
2	T.J.Walsh	National Cancer Institute, USA	76	7789	102.4	33	35 (46.0)	5.8
3	O.A.Cornely	University of Colgne, Germany	58	2303	39.7	23	29 (50.0)	2.2
4	A.S. Ibrahim	David Geffen School of Medicine at UCLA, USA	57	3580	62.8	30	14 (24.5)	3.6
5	O. Lortholary	University of Paris, France	50	3476	69.5	26	15 (30.0)	3.9
6	E. Rollides	Aristotle University of Thessaloni, Greece	50	2945	58.9	24	37 (74.0)	3.3
7	A.Chakrabarti	Postgraduate Institute of Medical Education and Research, Chandigarh, India	47	1831	38.9	21	14 (29.7)	2.2
8	R.E. Lewis	University of Texas MD Anderson Cancer Center, USA	45	3195	71.0	25	24 (53.3)	4.0
9	C. Lass-Florl	Medizinische Universitat Innsbruck, Austria	40	2615	65.3	23	29 (72.5)	3.7
10	F. Lanternier	University of Paris, France	35	1983	56.6	18	5 (14.2)	3.2
		Top 10 most impactful authors						
1	B. Spellberg	University of California, Los Angles, USA	34	3986	117.2	28	5 (14.7)	6.7
2	T.J.Walsh	National Cancer Institute, USA	76	7789	102.4	33	35 (46.0)	5.8
3	L. Pagano	Universita Ca Holica, Italy	28	2758	98.5	16	11 (39.2)	5.6
4	D.P. Kontoyiannis	University of Texas MD Anderson Cancer Center, USA	119	10879	91.4	46	48 (40.3)	5.2
5	A.H. Groll	Universitat Klinikum Munster, Germany	26	1887	72.5	18	20 (76.9)	4.1
6	R.E. Lewis	University of Texas MD Anderson Cancer Center, USA	45	3195	71.0	25	24 (53.3)	4.0
7	O. Lortholary	University of Paris, France	50	3476	69.5	26	15 (30.0)	3.9
8	R.Herbrecht	Hopital de Hautepierre, France	34	2302	67.7	20	13 (38.2)	3.8
9	C. Lass-Florl	Medizinische Universitat Innsbruck, Austria	40	2615	65.3	23	29 (72.5)	3.7
10	A.S. Ibrahim	David Geffen School of Medicine at UCLA, USA	57	3580	62.8	30	14 (24.5)	3.6

Abbreviations: TP, total publications; TC, total citations; CPP, citations per paper; HI, Hirsch Index; ICP, international collaborative publications; RCI, relative citations index.
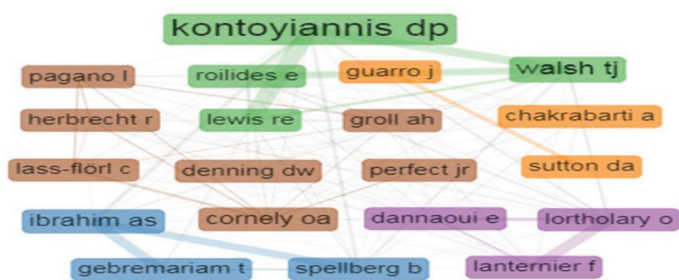

Figure 4: Collaboration network of top 20 authors grouped into five cluster comparising of 4 (cluster 1), 3 each (cluster 2, 3, and 4) and 7 authors (cluster 5).

low-income countries, only India figures in the list of top 10 countries partly due to collaborative research initiatives of a few dedicated organizations and researchers in fungal diseases.[8,23] In general, the paucity of research funding and infrastructure in low-income countries hinders impactful research.[18] The wide disparity in mucormycosis research between high-income and low-income countries needs to be addressed through supportive research endeavors and collaborations.[24] The high-income countries, their organizations, and researchers should strengthen research collaboration with their counterparts in low-income countries to improve long-term impact and sustainability in global mucormycosis research.[24] In the present study, too, the research partnerships between high- and low-income countries were far fewer than those amongst high-income countries.

We used a single database similar to the previous bibliometric analyses.[20,21,25] Therefore, our study may not have captured all publications or citations. Some authors have suggested conducting a simultaneous search in PubMed, Scopus, and WoS, but some data may still be missed.[26,27] Despite the limitation of using a single database, our study could identify the research lacunae and trends in mucormycosis research.[28] Thus, the study provides the global architecture of research in mucormycosis and a framework for authors, organizations, and countries to develop focus and collaborations on further research in this area.

CONCLUSION

The North-American and Western-European countries dominate the mucormycosis research landscape, and a wide gap exists between high- and low-income countries. The quantity of mucormycosis research has increased during 1998-2021, but the quality has suffered despite better funding over the last decade. It is necessary to increase collaboration between high- and low-income countries to improve the impact and sustainability of global mucormycosis research.

Contributors' List

BMG, Concept, and design of the study, and acquisition, analysis, and interpretation of data; GMM, Data analysis, and intellectual inputs during the revision of the manuscript; SG and LR, Important intellectual inputs during manuscript preparation; DD, Manuscript preparation and critical revision for important intellectual content. All authors approved the final version of the manuscript.

Table 5: Leading journals that published mucormycosis research during 1998-2021.

S.no.	Journal	Total papers			Cited	CPP*
		1998-2009	2010-2021	1998-2021	1998-2021	
1	Mycoses	55	132	187	3163	16.9
2	Clinical Infectious Diseases	52	44	96	12413	129.3#
3	Medical Mycology	34	57	91	2103	23.1#
4	Clinical Microbiology and Infection	35	37	72	4194	58.2#
5	Mycopathologia	11	60	71	520	7.3
6	Antimicrobial Agents and Chemotherapy	28	41	69	3823	55.4#
7	Journal of Clinical Microbiology	29	40	69	2429	35.2#
8	Current Fungal Infection Reports	5	58	63	395	6.2
9	Medical Mycology Case Reports	0	61	61	182	2.9
10	Transplant Infectious Disease	17	42	59	1168	19.8
11	Journal De Mycologie Medicale	13	42	55	273	4.9
12	BMJ Case Reports	2	50	52	119	2.2
13	Journal of Antimicrobial Chemotherapy	8	35	43	1842	42.8#
14	Revista Iberoamericana De Micologia	5	32	37	291	7.8
15	Journal of Fungi	0	34	34	250	7.3
16	Infectious Diseases in Clinical Practice	11	22	33	41	1.2
17	Indian Journal of Otolaryngology and Head and Neck Surgery	12	19	31	102	3.2
18	Transplant Proceedings	10	21	31	187	6.0
19	Bone Morrow Transplantation	21	9	30	884	29.4#
20	Pediatric Infectious Disease Journal	12	18	30	704	23.4#
	Total of top 20 journals	360	854	1214	35083	28.9

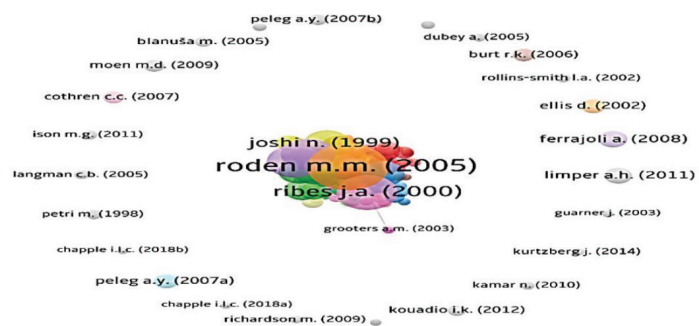*CPP=citations per paper; #most impactful journals

Figure 5: Network visualization of the top 173 highly-cited papers grouped into 38 cluster. The size of the nodes represents the number of citations.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ABBREVIATIONS

ECMM: European Confederation of Medical Mycology; **COVID-19:** The Coronavirus Disease of 2019.

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