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Review Article

Scientometric Mapping of Mucormycosis Research in Relation to the COVID-19 Pandemic

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ABSTRACT

Background: Mucormycosis is an invasive fungal infection that has shown a surge during the COVID-19 pandemic. A comprehensive assessment of COVID-19 associated mucormycosis (CAM) research is lacking. **Methods:** We searched Elsevier's Scopus database for publications on CAM using a pre-defined search strategy. Data on publications numbers, citation metrics, contributing countries, institutions, authors, journals, and the most cited articles were analyzed using select bibliometric tools. **Results:** Published CAM research included 253 publications. These were cited 1560 times, averaging 6.1 citations per paper. Only 33 (13%) were funded. Original articles (55.7%) and reviews (17.7%) constituted the major share of global output. The studied age groups included adults (22.5%), middle-aged (19.3%), elderly (10.6%), and adolescents (0.8%). Studies on treatment accounted for the largest share (58.5%), followed by clinical studies (28.0%), complications (17.3%), risk factors (11.7%), epidemiology (7.9%), and pathophysiology (3.1%). The participating countries were 64; India, the USA, and Egypt led in productivity, whereas France, the USA, and Iran were more impactful. Of the 84 organizations, the leading organizations were PGIMER-Chandigarh, AIIMS-New Delhi and Cairo University, Egypt. A. Chakrabarti, V. Muthu, and S.M. Rudramurthy were the most productive of 160 participating authors. Indian Journal of Ophthalmology, Indian Journal of Otolaryngology and Head and Neck Surgery, and Journal of Fungi were the most active journals that published CAM research. **Conclusion:** Research on CAM has primarily been conducted in middle-income countries and is low on quality. High-income countries need to collaborate with low- and middle-income countries for a sustainable and universal CAM research impact. There is also a need to focus on research gaps such as pathophysiology and epidemiology in future CAM research.

Key words: Coronavirus disease 2019, Fungal infections, COVID-19 associated mucormycosis, CAM, Bibliometrics.

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INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has resulted in over five million deaths worldwide since its beginning in 2019.[1] The mortality in those with comorbid conditions such as diabetes, obesity, or other prior chronic illnesses has been particularly massive.[2-4] In addition, a host of life-saving interventions and prolonged hospitalizations also contribute to co-infections by various bacterial, viral, and fungal pathogens.[5] The fungal co-infections in COVID-19 infected patients, in particular, produce devastating effects in affected patients with a several-fold increase in morbidity and mortality.[6] Several fungi such as *Aspergillus*, *Candida* species, *Cryptococcus neoformans*, and the *Mucorales* have been reported to co-infect patients with COVID-19.[7] The distribution of these co-infecting fungi, particularly *Mucormycosis*, has been found to be markedly skewed towards low- and middle-income countries, similar to their prevalence during the pre-COVID times.[7-9]

There are several challenges in the management of COVID-19 associated mucormycosis (CAM).[10] Similar to patients with non-COVID-19 conditions, the mainstay of treatment of CAM involves extensive surgical debridement of the affected tissues and antifungals along with adequate control of the associated illness.[11,12] An early diagnosis is also crucial for survival outcomes.[12-14] However, the diagnosis of CAM is often delayed due to its non-specific initial symptoms and signs.[10,12] Additionally, surgical debridement is often a challenge during pandemic times. In a recent report from India, surgery could be performed only in less than 50% of CAM-affected patients.[15] Furthermore, a reversal of the predisposing immunosuppressed state often requires withdrawal of immunomodulatory drugs, which are the cornerstone for managing the cytokine storm in COVID-19 patients.[10,12] To overcome these challenges, further research aimed at identifying risk factors for CAM, developing technologies for early and rapid diagnosis of CAM, and measures

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to minimize the dosage and duration of drugs such as corticosteroids, immunosuppressants, and antibiotics, has been suggested.[7,10,12,15] Research is also needed to understand region-specific epidemiological and pathophysiological factors for a disproportionately increased incidence of CAM in certain countries.[16]

An assessment of the previously accomplished research is essential to guide future research in any field. Such an appraisal, usually achieved through scientometric or bibliometric analyses, helps the researchers to identify the research gaps and hotspots, thus allowing them to focus on areas that require more attention as compared to others.[17] It also helps to identify researchers, organizations, funding agencies, and regions that share research interests which is necessary to foster collaborations leading to more impactful research.[18-20] In connection with CAM, even though extensive research appears to have been conducted during the pandemic, scientometric assessment studies are scarce. Bibliometric studies on COVID-19 did not attempt to analyze research on CAM separately.[21,22] Similarly, recent analyses of mucormycosis research included publications before the global surge in CAM infections.[23-25] Two other bibliometric studies that focussed on CAM and included publications till May and August 2021, respectively, provided analyses of 154 and 51 publications only, far lower than would be expected of an intensely researched topic.[26,27] Thus a comprehensive mapping of CAM research is still lacking. In the present contribution, we attempted to provide a bibliometric assessment of published research on CAM using the Scopus database.

OBJECTIVES

We aimed to evaluate published research on CAM as covered in the Scopus database since the onset of the COVID-19 pandemic until November 15, 2021. The study focussed on the contribution of top countries, organizations, authors, journals, research collaborations, funding support, the impact of publications, and features of highly-cited papers (HCP).

MATERIALS AND METHODS

The relevant publications on CAM research were retrieved from the Scopus database (http://www.scopus.com) using a pre-defined search strategy similar to previous bibliometric studies.[28-30] The following search string was used:

TITLE ("covid 19" OR "2019 novel coronavirus" OR "coronavirus 2019" OR "coronavirus disease 2019" OR "2019-novel CoV" OR "2019 nov" OR covid 2019 OR corvidae OR "corona virus 2019" OR ncov-2019 OR ncov2019 OR "nov 2019" OR 2019-ncov OR covid-19 OR "Severe acute respiratory syndrome coronavirus 2" OR "SARS-CoV-2") OR KEY ("covid 19" OR "2019 novel coronavirus" OR "coronavirus 2019" OR "coronavirus disease 2019" OR "2019-novel CoV" OR "2019 nov" OR covid 2019 OR corvidae OR "corona virus 2019" OR ncov-2019 OR ncov2019 OR "nov 2019" OR 2019-ncov OR covid-19 OR "Severe acute respiratory syndrome coronavirus 2" OR "SARS-CoV-2") and Key (mucormycosis*) OR Key (black fung*)

The data obtained were further examined using analytical provisions of the Scopus database. Using the complete counting method, each author or organization of multi-author publications was fully counted. To settle the issue of synonyms or homonyms in the names of authors, other specific fields such as affiliations were used. The qualitative assessment of publications was based on indices such as the Hirsch index (HI), citations per paper (CPP), and relative citation index (RCI). The CPP was obtained by mathematically dividing the number of citations by the number of publications. The RCI was derived by dividing the number of publication's citations by the average citations usually received by an article in the same field and then benchmarking that number against the median RCI for all NIH-funded papers. The HI was calculated by counting the number of publications for which an author has been cited the same number of times. A publication was considered HCP if it had received more than 30 citations. The citations were counted from the date of publication until November 15, 2021.

Ethical considerations

The present study used secondary data for which approval from the ethics committees is not required. We, nevertheless, followed all the ethical principles recommended for analysis of this nature through respecting ideas, and citations, and referencing authors and publications.

RESULTS

General description of CAM publications

A majority (239, 94.4%) of the total 253 publications on CAM research were reported in the year 2021. The total citations and average CPP were 1560 and 6.1, respectively. Only 33 (13.0%) were externally funded; these received 155 citations, averaging 4.7 CPP. The major funding agencies were the National Institute of Health, USA (4 papers), Gilead Sciences and Pfizer (3 papers each), Department of Science and Technology, India, Hyderabad Eye Research Foundation, and Science and Engineering Board India (2 papers each). The publication categories were original articles (55.7%), reviews (17.8%), letters (13.8%), editorials (5.5%), notes (4.3%), short surveys (1.5%) and conference papers (1.2%). The distribution of publications by the studied age groups was as follows: adults (22.5%), middle-aged (19.3%), elderly (10.6%), and adolescents (0.8%). The most researched aspects of CAM were treatment (51.7%), followed by clinical studies (28.0%), complications (17.4%), and risk factors (11.8%). Epidemiology (7.9%), and pathophysiology (3.1%), were the least studied aspects of CAM. Research on complications and treatment registered the highest and lowest citation impact with average CPP of 16.8 and 7.7, respectively. According to the type of CAM, rhino-orbital-cerebral, cutaneous, pulmonary, and renal forms constituted 12.6%, 5.2%, 5.1%, and 4.7%, respectively. Diabetes mellitus was the most commonly studied risk factor (32.4% publications), followed by corticosteroid therapy (12.2%), diabetic ketoacidosis and immunocompromised host (3.5% each), chronic kidney disease (3.1%), neutropenia (2.3%), and hemodialysis (1.6%). To elucidate focus and trends in CAM research, we identified several significant keywords, as shown in Figure 1.

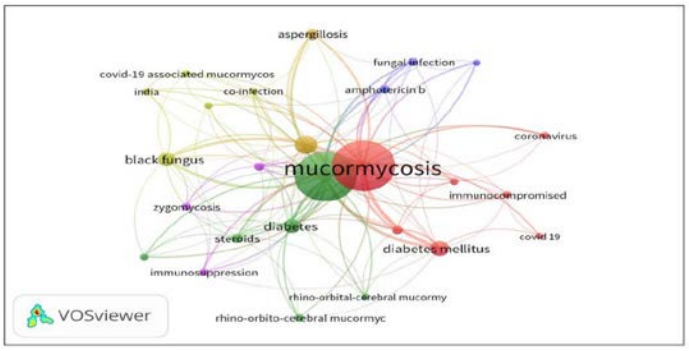

Figure 1: Network author keywords in COVID-associated mucormycosis (CAM) research. Each colour represents repetition of keywords occurring at least 5 times. The size of the node and the thickness of connecting lines represent their importance in CAM research.

Table 1: Most productive countries in COVID-associated mucormycosis research.

S.no.	Country	TP	TC	CPP	HI	ICP	%ICP	RCI
1	India	153	799	5.2	16	35	22.8	0.8
2	USA	30	421	14.0	12	13	43.3	2.2*
3	Egypt	12	21	1.7	2	7	58.3	0.2
4	Iran	9	88	9.7	4	2	22.2	1.5*
5	Bangladesh	8	22	2.7	2	4	50.0	0.4
6	Pakistan	7	3	0.4	1	5	71.4	0.1
7	Saudi Arabia	7	3	0.4	1	7	100.0	0.1
8	Australia	5	12	2.4	2	4	80.0	0.4
9	France	5	146	29.2	4	2	40.0	4.7*
10	Italy	5	27	5.4	2	2	40.0	0.8

*More impactful than others

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

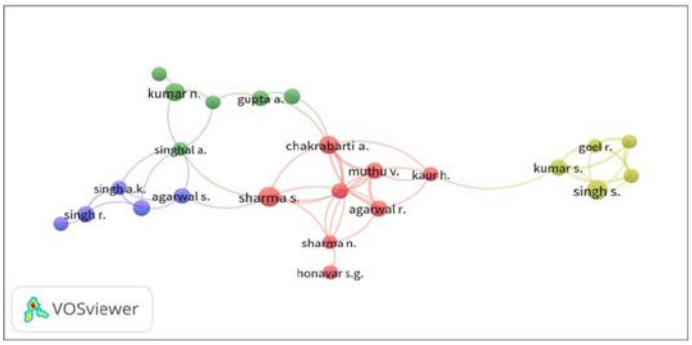

Figure 2: Authors collaborative netwok. Of the four clusters of at least 4 publications, the largest red cluster represents eight authors who worked closely together.

Most productive countries

Sixty-four countries participated unevenly in global CAM research; 57 contributed 1-5 papers each, four countries 6-10 papers each, two countries 11-30 papers, and one country 153 papers. The top 10 countries together contributed 241 (95.2%) publications and 1542 (98.9%) citations. Table 1 shows the productivity and impact of countries. France, the USA, and Iran produced more impactful research registering their CPP and RCI above the group average of 6.4 and 1.0, respectively. The average international collaborative papers (ICP) was 33.6%. All the top 10 countries showed one-to-one collaboration; India, the USA, and Saudi Arabia established the largest number of linkages (25, 14, and 8, respectively). The country pairs that collaborated the highest number of times were India-USA (6 linkages), and India-Bangladesh, India-Pakistan, and India-Australia (4 linkages each).

The output of research organizations

Eighty-four organizations participated in CAM. Five organizations registered their publication output above the group average of 4.7, whereas five others recorded their CPP and RCI above the group average of 6.3 and 1.0, respectively (Table 2). The highest number of collaborations were shown by PGIMER-Chandigarh, AIIMS-New Delhi, and Saveetha Dental College and Hospital (5, 4, and 4 respectively). The organizations that paired maximally for collaboration were Saveetha Dental College and Hospital and Saveetha Institute of Medical and Technical Sciences (4 times), followed by MAMC-Delhi and Lok Nayak Hospital, New Delhi (3 times), and BJ Medical College, Ahmedabad and

Table 2: Productivity and impact of top 10 organizations in COVID-associated mucormycosis research.

S.no.	Organization	TP	TC	CPP	HI	ICP	%ICP	RCI
Most productive organizations								
1	PGIMER-Chandigarh	13	134	10.3	4	3	23.0	1.6
2	AIIMS-New Delhi	13	66	5.0	3	1	7.6	0.8
3	Cairo University, Egypt	5	2	0.4	1	4	80.0	0.0
4	AIIMS-Jodhpur	5	0	0.0	0	0	0.0	0.0
5	Saveetha Dental College and Hospital	5	17	3.4	2	4	80.0	0.5
6	Maulana Azad Medical College, New Delhi	4	0	0.0	0	0	0.0	0.0
7	Ain Shams University, Egypt	4	19	4.7	2	0	0.0	0.7
8	PD Hinduja National Hospital and Medical Research Center, Mumbai	4	28	7.0	2	0	0.0	1.1
9	BJ Medical College, Ahmedabad	4	36	9.0	2	1	25.0	1.4
10	Saveetha Institute of Medical and Technical Sciences	4	15	3.7	1	4	100.0	0.6
Most impactful organizations								
1	Center for Sight, Hyderabad	3	123	41.0	3	0	0.0	6.6
2	Lilavati Hopital and Research Center, Mumbai	3	80	26.6	2	0	0.0	4.3
3	PGIMER-Chandigarh	13	134	10.3	4	3	23.0	1.6
4	BJ Medical College, Ahmedabad	4	36	9.0	2	1	25.0	1.4
5	PD Hinduja National Hospital and Medical Research Center, Mumbai	4	28	7.0	2	0	0.0	1.1
6	AIIMS-New Delhi	13	66	5.0	3	1	7.6	0.8
7	Ain Shams University, Egypt	4	19	4.7	2	0	0.0	0.7
8	Saveetha Institute of Medical and Technical Sciences	4	15	3.7	1	4	100.0	0.6
9	Saveetha Dental College and Hospital	5	17	3.4	2	4	80.0	0.5
10	Civil Hospital, Ahmedabad	3	10	3.3	1	1	33.3	0.5

Abbreviations: TP=Total papers; TC=Total citations; HI=Hirsch Index; CPP=Citations per paper; ICP=International collaborative papers; RCI=Relative citation index.

Table 3: Most productive and most impactful authors in COVID-associated mucormycosis research.

S.no.	Name	Affiliation	TP	TC	CPP	HI	ICP	%ICP	RCI
Most prolific authors									
1	A. Chakrabarti	PGIMER-Chandigarh	6	116	19.3	3	2	33.3	3.1
2	V. Muthu	PGIMER-Chandigarh	5	112	22.4	3	1	20.0	3.6
3	S.M. Rudramurthy	PGIMER-Chandigarh	5	42	8.4	2	2	40.0	1.3
4	R. Agarwal	PGIMER-Chandigarh	4	98	24.5	2	0	0.0	3.9
5	K. Dhama	IVRI-Bareilly	3	5	1.6	2	3	100.0	0.2
6	R. Goel	MAMC-Delhi	3	0	0.0	0	0	0.0	0.0
7	T. Gokhale	JIPMER-Pondicherry	3	64	21.3	2	0	0.0	3.4
8	M.M. Hasan	Mawlana Bhashani S&T University, Bangladesh	3	17	5.6	2	3	100.0	0.9
9	S.G. Honacar	Center for Sight, Hyderabad	3	123	41.0	3	0	0.0	6.6
10	J. Kumat	MAMC-Delhi	3	0	0.0	0	0	0.0	0.0
Most impactful authors									
1	S.G. Honacar	Center for Sight, Hyderabad	3	123	41.0	3	0	0.0	6.6
2	M. Sen	Center for Sight, Hyderabad	3	121	40.3	3	0	0.0	6.5
3	I.S. Sehgal	PGIMER-Chandigarh	3	96	32.0	2	0	0.0	5.1
4	A. Misra	Fortis-Doc, Gurgaon	3	92	30.6	3	0	0.0	4.9
5	R. Agarwal	PGIMER-Chandigarh	4	98	24.5	2	0	0.0	3.9
6	V. Muthu	PGIMER-Chandigarh	5	112	22.4	3	1	20.0	3.6
7	T. Gokhale	JIPMER-Pondicherry	3	64	21.3	2	0	0.0	3.4
8	A. Chakrabarti	PGIMER-Chandigarh	6	116	19.3	3	2	33.3	3.1
9	A. Sunavala	PD Hinduja National Hospital and Medical Research Center, Mumbai	3	26	8.6	1	0	0.0	1.4
10	S.M. Rudramurthy	PGIMER-Chandigarh	5	42	8.4	2	2	40.0	1.3

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

Civil Hospital, Ahmedabad (3 times), and PGIMER-Chandigarh and AIIMS-New Delhi (2 times).

Leading authors

Of the 160 authors who participated in CAM research, the top four in productivity were A. Chakrabarti (6 papers), V. Muthu and S. Rudramurthy (5 papers each), and R. Agarwal (4 papers). Table 3 shows the profile of the most prolific and influential authors. All the leading authors showed collaborations; V. Muthu, A. Chakrabarti, and R. Agarwal had the largest linkages, i.e., 14, 13, and 11. Figure 2 shows the networking between authors for CAM research.

Top journals

All 253 papers on CAM research were published in 140 journals. Only two journals published 15-18 papers, three published 6-10, and the rest 135 published 1-5 papers each. The top 15 most productive journals accounted for a 37.1% share of global output (Table 4).

Impactful publications

Seventeen (6.72%) publications had received 30 to 91 citations each and were assumed to be HCPs. Their total and average citations were 931 and 54.7, respectively. India and the USA contributed eight and six publications, respectively, while Brazil, China, France, Greece, Iran, and Nigeria contributed one HCP each. Eleven HCPs were published as original articles, three as reviews, two as editorials, and one as a letter. Nine HCPs involved collaborative research; eight of these were national and one international collaborative. Eight HCPs were non-collaborative. The 17 HCPs were published in 14 journals; the Indian Journal of Ophthalmology was the leading journal that published three HCPs, whereas Journal de Mycologie Medicale published the most cited (91 times) article on CAM.

DISCUSSION

Our analysis revealed that the COVID-19 related mucormycosis research was mainly carried out in the low- and middle-income countries, unlike research in several other medical fields during COVID-19 pandemic or even during pre-COVID-19 times, which shows domination by high-income countries of North America or Western Europe.[21-24,30-32] This is understandable as the low- or middle-income countries were particularly hit by the dual burden of COVID-19 and CAM.[6,7] But even while the productivity of organizations and authors from low- and middle-income countries was substantial, it was the high-income countries such as France and the USA that led in CAM research impact. The high quality of research from high-income countries may be attributed to the availability of infrastructure and financial support and commitment to research by the national governments.[33] In contrast, the paucity of funding and infrastructure in low-income countries affects the research quality.[34] It is

Table 4: Leading journals that published COVID-associated mucormycosis research.

S.no.	Journal	TP	TC	CPP
1	Indian Journal of Ophthalmology	18	230	12.7
2	Indian Journal of Otolaryngology and Head and Neck Surgery	15	35	2.3
3	Journal of Fungi	10	100	10.0
4	Mycoses	9	86	9.5
5	Diabetes and Metabolic Syndrome.Clinical Research and Review	8	96	12.0
6	BMJ Case Reports	5	37	7.4
7	IDcases	4	9	2.2
8	International Journal of Allergy and Rhinology	4	20	5.0
9	Egyptian Journal of Radiology and Nuclear Medicine	3	1	0.3
10	Emerging Infectious Diseases	3	34	11.3
11	Indian Journal of Critical Care and Medicine	3	1	0.3
12	International Journal of Surgery	3	2	0.6
13	Journal of Laryngology and Otology	3	47	15.6
14	Journal of Maxillofacial and Oral Surgery	3	46	15.3
15	Journal of Medical Virology	3	18	6.0
Total of top 15 journals		94	762	8.1
Global total		253	1560	6.1
Share of top 15 journals in global total		37.1	48.8	---

Abbreviations: TP=total publications; TC= total citations; CPP=citations per paper.

thus imperative that high-income countries support research endeavors and collaborations with low- and middle-income countries to produce a more meaningful universal research in CAM, similar to research capacity strengthening initiatives for other diseases.[35]

A notable finding of our study was the meager quantity of research on CAM pathophysiology and epidemiology. Several experts have highlighted the importance of studying these aspects of CAM in order to understand several complexities associated with this co-infection in COVID-19 patients.[36,37] This research gap needs to be addressed in future studies on CAM.

Additionally, there is a need to provide more financial support by the various funding agencies; only 13% of the published CAM research was funded. Although the impact of funded CAM research in terms of CPP was marginally lower than non-funded publications, the reverse is a consistent observation in medical research.[38] In a recent scientometric analysis, we also documented a considerably higher CPP of funded than non-funded research (77.2 versus 18.6).[20]

Limitations

Using a single database was a limitation of our analysis as we could have missed a few publications and citations. Although some authors have suggested that a simultaneous search may be conducted in the major medical databases such as Web of Science, PubMed, and Scopus to improve research mapping, such an approach may not only be cumbersome but also make interpretation of results difficult due to the lack of uniformity in analytical provisions across different databases.[39] It may be mentioned that most bibliometric studies use a single database, and our choice of the Scopus database was based on its broader content coverage, accuracy, availability of funding information, and citation analysis tools.[40]

CONCLUSION

Research on mucormycosis in relation to the COVID-19 pandemic has largely been conducted in middle-income countries and lacks quality. There is a need for high-income countries to collaborate with low-and middle-income countries for a sustainable and universal CAM research impact. Pathophysiology and epidemiology also need attention in future CAM research.

CONFLICT OF INTEREST

The authors declare no conflict of interest

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