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Original article

Candida auris: A bibliometric analysis of an emerging global health threat

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ABSTRACT

Background: *Candida auris* (CA) is an emerging fungus, classified as an urgent global health threat, that resists common antifungal drugs and decontamination procedures; identification requires specific tools; transmissibility and mortality are high in healthcare settings. Infection and colonisation can be long-lasting, leading to problems in isolation procedures and the risk of outbreaks. This study aims to evaluate publication and citation related metrics, identify major keywords and topics, and assess geographic distribution of published articles.

Methods: A list of all publications containing "*Candida auris*" in all fields was extracted from Web Of Science on date 2023/01/02. Bibliometric analysis was conducted using the bibliometrix and biblioshiny packages on RStudio.

Results: Total publications (TP) were 1283 with an annual growth rate of 53.91%. Total citations were 27854, with an average of 21.71 citations per paper. The core sources are 9 out of 322, according to Bradford's law. In only 42 countries where CA was identified, articles on the topic were published (89%). The origin of TP is concentrated in high-income countries (68.22%). Trending topics about CA include epidemiology, identification and resistance.

Conclusion: Our analysis shows a growing interest in scientific literature on the topic of CA, led by Europe. In some countries where CA has been identified, no papers have been published. Despite the multidrug-resistance of CA, the topic of therapy is not much debated. Our findings highlight the need to increase focus on CA in order to promote health systems' preparedness and to properly address the spread of this worrisome pathogen.

Introduction

Candida auris is an emerging fungus identified for the first time in 2009 [1]. This pathogen has a great ability to spread both directly (patient-to-patient), and indirectly (surfaces). Due to its ability to create dry biofilms, it resists to common disinfectants and can persist on nosocomial surfaces [2,3]. Colonisation and infection can occur in hospitalised patients, especially in Intensive Care Unit [4,5], and can be long-lasting, leading to problems in isolation procedures and to the risk of outbreaks. A high percentage of *Candida auris* isolates shows resistance to one or more antifungals [6–8]. *Candida auris*, unlike the other Candida types, behaves more like a "superbug" like Methicillin resistant Staphylococcus aureus [9].

In 2016 the Centers for Disease Control and Prevention (CDC) began monitoring *Candida auris*, providing global data of countries where this fungus was identified and instituting a clinical alert targeting healthcare facilities regarding its dangerousness [8–10]. These data were no longer updated since February 15, 2021, and are no longer available to date on the CDC website. CDC in 2017 began

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monitoring the development of *Candida auris* cases in each U.S. state (currently updated to May 31, 2022).

From 2009–2016 the global literature on the topic of "*Candida auris*" was poor [11]. An up-to-date mapping of the scientific literature on *Candida auris* can be essential to understand what knowledge is currently available, what place this topic occupies within the Candida landscape, as well as to foster new lines of research in the scientific community and identify possible gaps. Thus, a bibliometric analysis is performed. This study aims to:

- Conduct a performance analysis by quantifying publication and citation metrics, including variables related to the productivity of sources, authors, countries, and affiliations.
- Conduct a science mapping with enrichment techniques to understand the relationships between key research elements and to define the current intellectual and social network.

This study's results can be used to identify future research directions and collaboration opportunities.

Material and methods

In this study, a bibliometric analysis on *Candida auris* was performed: this technique allows the quantification and statistics of the available scientific literature and the identification of trending topics [12–14]. The literature was retrieved online through the Clarivate Analytics Web of Science database (WoS), through the "All Databases" search function. There are few differences in the data retrievable from different databases, so no one tool is considered superior to others [15]. Since all data were downloaded from a public database, no ethical approval was required. The research was performed on January 2, 2023. The term "*Candida auris*" was searched in "All fields" and the year of publication filter was applied (2009–2022). This choice was made in accordance with the objectives of the study, aiming to gain a broader perspective on the topic and to identify the most relevant themes and geographic distribution of scientific output in the field. Data were exported in plain text file format, including full records and cited references. The extracted files were analysed on RStudio using the Bibliometrix and Biblioshiny packages. Nine duplicates were removed. Timespan filter (2009–2022) was applied on biblioshiny [16]. It is important that the data extraction and analysis process is transparent and reproducible to ensure the validity and reliability of bibliometric studies. The first step of the analysis involves producing main information on publication and citation metrics, quantifying total publications and the annual publication growth rate, citations, contributing authors, references in published articles, keywords used, and the type of documents produced. The annual publication growth rate was calculated automatically through Biblioshiny to measure the change in the number of publications over time and to assess research topic development. The calculation involves averaging the annual growth rates for the given period [16]. Bradford's Law was used to identify the journals with the greatest frequency of publication, defined as "core sources", which are the sources that have published 1/3 of the total publications on the subject. This method can be used as a guide to identify the leading journals on a given topic [17]. The cited journals' impact factor (IF) was retrieved through WoS. The h-index and g-index were identified through biblioshiny. Using the World Bank's country classification for fiscal year 2021, countries were divided into low-, low-middle-, upper-middle- and high-income strata. This classification was also used to define each country's continent [18]. The WoS "All Databases" search function was also used to find all publications on "*Candida*" in order to calculate the ratio of publications on *Candida auris* to *Candida*.

In accordance with the guideline by Donthu et al., performance analysis was conducted, calculating publication-related metrics, citation-related metrics, and citation-and-publication-related metrics. Science mapping was performed through keyword co-occurrence, which explores the potential relationships between bibliographic items that appear in the same dissertation, and collaboration network analysis, which is used to understand the intellectual and social structure among countries and institutes [19,20].

The three-field plot was used to estimate the relationship between affiliations, countries, and keywords involved in studies about *Candida auris*. The height of each rectangular-shaped diagram indicates the relationship among multiple features. The larger the size of the rectangle, denotes more relationships between different items [21]. Collaboration networks between authors' countries and affiliations were visualised using the Spinglass algorithm, with a limit of 30 nodes representing countries or institutes. Node size corresponds to the frequency of collaboration occurrences, while the lines represent collaboration pathways between entities, facilitating a clear depiction of network connections. This algorithm identifies distinct communities within publication networks, revealing research subfields and aiding the understanding of scientific knowledge. It enables a comprehensive and visually appealing visualisation of collaborative relationships in the study [22,23].

Results

Main information

We found 1283 total publications (TP) published by 322 sources from 2009 to 2022 with an annual growth rate of 53.91%.

Articles related to *Candida auris* account for 2.12% of all publications on *Candida*, with an increasing trend from 2009 to 2022. The peak was reached in 2022 with a percentage of 5.52% (Fig. 1).

The number of contributing authors (NCA) was 4994, of which 65 are authors of single-author documents. Only 17.4% of authors published ≥ 3 articles on *Candida auris*. Total citations (TC) were 27854, with an average of 21.71 citations per article. Most of the published documents are articles (66%), followed by reviews (15%) and meeting abstracts (8%). Supplementary Table A1 lists the full general information of the bibliometric analysis.

Core sources

The top 9 journals identified through Bradford's Law are shown in Table 1, including TP, TC and IF for each journal.

Most cited sources

Supplementary Table A2 shows the 10 most cited sources, sorted by TC, and includes TP, year of publication start, h-index and g-index.

The 5 most cited sources are *Journal Of Clinical Microbiology* (h-index = 21; g-index = 36; TC = 2034; TP = 36), *Emerging Infectious Diseases* (h-index = 19; g-index = 22; TC = 1831; TP = 22), *Antimicrobial Agents And Chemotherapy* (h-index = 23; g-index = 41; TC = 1775; TP = 66), *Journal of Fungi* (h-index = 20; g-index = 32; TC = 1277; TP = 91), *Clinical Infectious Diseases* (h-index = 9; g-index = 15; TC = 1147; TP = 15).

Most global cited documents

The top ten most cited papers are shown in Table 2.

Author country production

Papers on *Candida auris* were published in 42 of the 47 countries where *Candida auris* has been identified (89%) according to CDC [10]. The 5 countries that, despite the identification of *Candida auris*, have

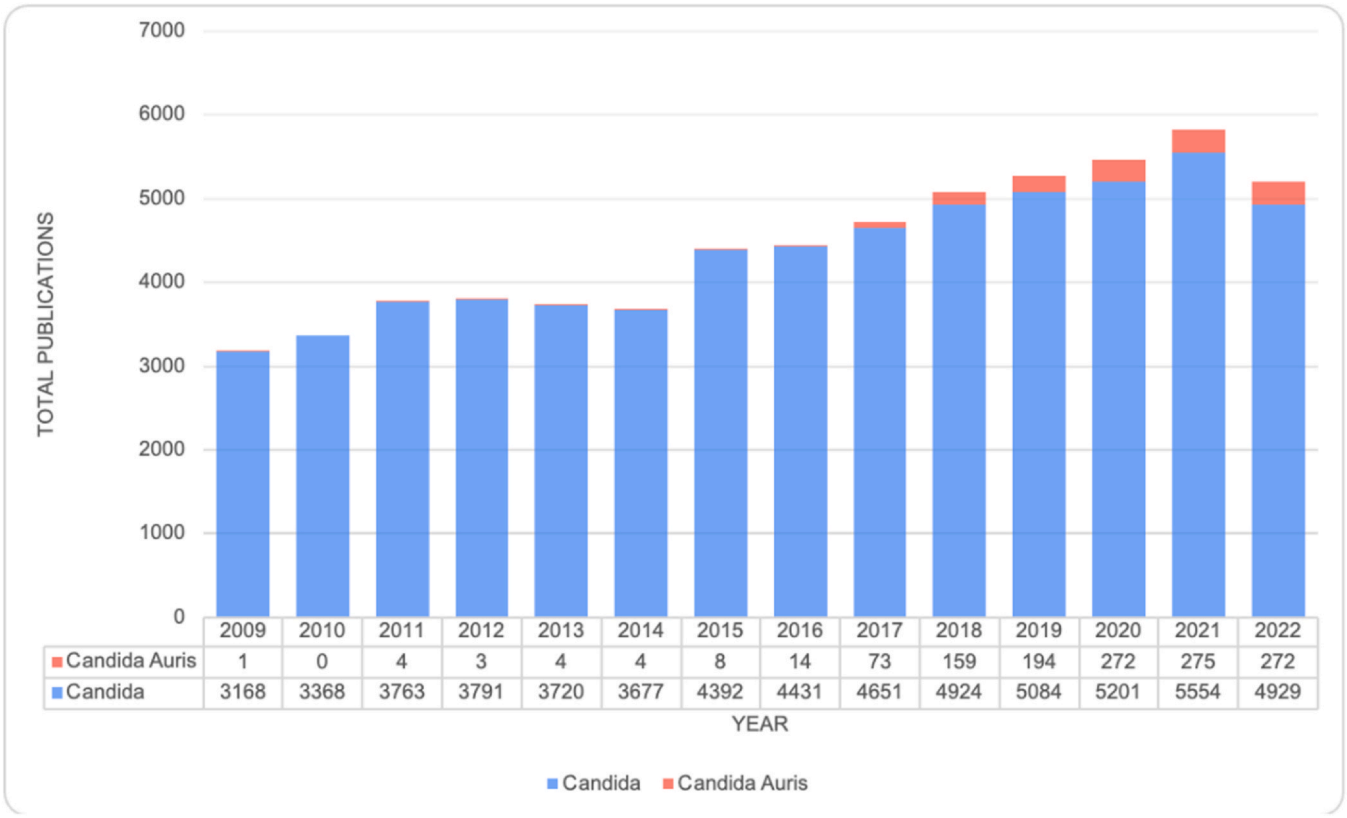

Fig. 1. Trend of total publications on *Candida* and *Candida auris* from 2009 to 2022.

Table 1
Core sources identified through Bradford's Law, sorted by number of total publications on *Candida auris*. TP = Total number of publications on *Candida auris*. IF = Impact Factor. 5yIF = 5 years Impact Factor.

Rank	Core sources	TP	TC	IF	5yIF
1	*Journal Of Fungi (MDPI)*	91	1277	5.724	6.413
2	*Medical Mycology (Oxford Academic)*	79	573	3.747	3.91
3	*Antimicrobial Agents And Chemotherapy (ASM Journals)*	66	1775	5.938	5.706
4	*Mycoses (Wiley)*	59	1047	4.931	4.272
5	*Infection Control And Hospital Epidemiology (Cambridge Core)*	37	387	6.52	4.908
6	*Journal Of Clinical Microbiology (ASM Journals)*	36	2034	11.677	8.075
7	*mBio (ASM Journals)*	27	771	7.786	8.483
8	*mSphere (ASM Journals)*	24	705	5.029	5.492
9	*Frontiers In Microbiology (Frontiers)*	23	494	6.064	6.843

not published on the topic are Costa Rica, Norway, Peru, Taiwan and the United Arab Emirates. The comparison of countries where *Candida auris* papers have been published and *Candida auris* cases have been reported can be visualised in Fig. 2.

Top 5 countries by NCA are the United States of America (1310), India (402), China (321), the United Kingdom (315) and Spain (233). Full results are shown in supplementary table A3. Publications are provided by 82 countries.

International collaboration network

The supplementary Fig. A1 shows the collaboration network between countries in *Candida auris* publications. The spinglass algorithm was used to cluster countries, finding communities in a graph (a set of nodes with many edges inside the community and few edges outside). Among the top 15 countries, the USA has the highest betweenness centrality (315.9631), which means a node's ability to carry information between unconnected groups of nodes in a network (supplementary table A4).

Author's country production by income economy areas and by continent

The NCA is 3553 for high-income countries (68.22%), 1001 for upper-middle income (19.22%), 641 for lower-middle income (12.31%), 5 for

Table 2
Top ten most cited papers on *Candida auris*. TC = Total Citations. TCPY = Total Citations Per Year.

Rank	Paper	DOI	TC	TCPY
1	Lockhart Sr, 2017, *Clin Infect Dis*,[6]	10.1093/cid/ciw691	728	104
2	Fisher Mc, 2018, *Science*, [24]	10.1126/science.aap7999	571	95.17
3	Satoh K, 2009, *Microbiol Immunol*, [1]	10.1111/j.1348–0421.2008.00083.x	561	37.4
4	Perlin Ds, 2017, *Lancet Infect Dis*, [25]	10.1016/S1473–3099(17)30316-X	431	61.57
5	Schelenz S, 2016, *Antimicrob Resist In*, [26]	10.1186/s13756–016–0132–5	403	50.38
6	Chowdhary A, 2017, *Plos Pathog*, [27]	10.1371/journal.ppat.1006290	368	52.57
7	Kathuria S, 2015, J *Clin Microbiol*, [28]	10.1128/JCM.00367–15	310	34.44
8	Arendrup Mc, 2017, *J Infect Dis*, [29]	10.1093/infdis/jix131	287	41
9	Jeffery-Smith A, 2018, *Clin Microbiol Rev*, [30]	10.1128/CMR.00029–17	278	46.33
10	Pfaller Ma, 2019, *Open Forum Infect Dis*, [31]	10.1093/ofid/ofy358	270	54

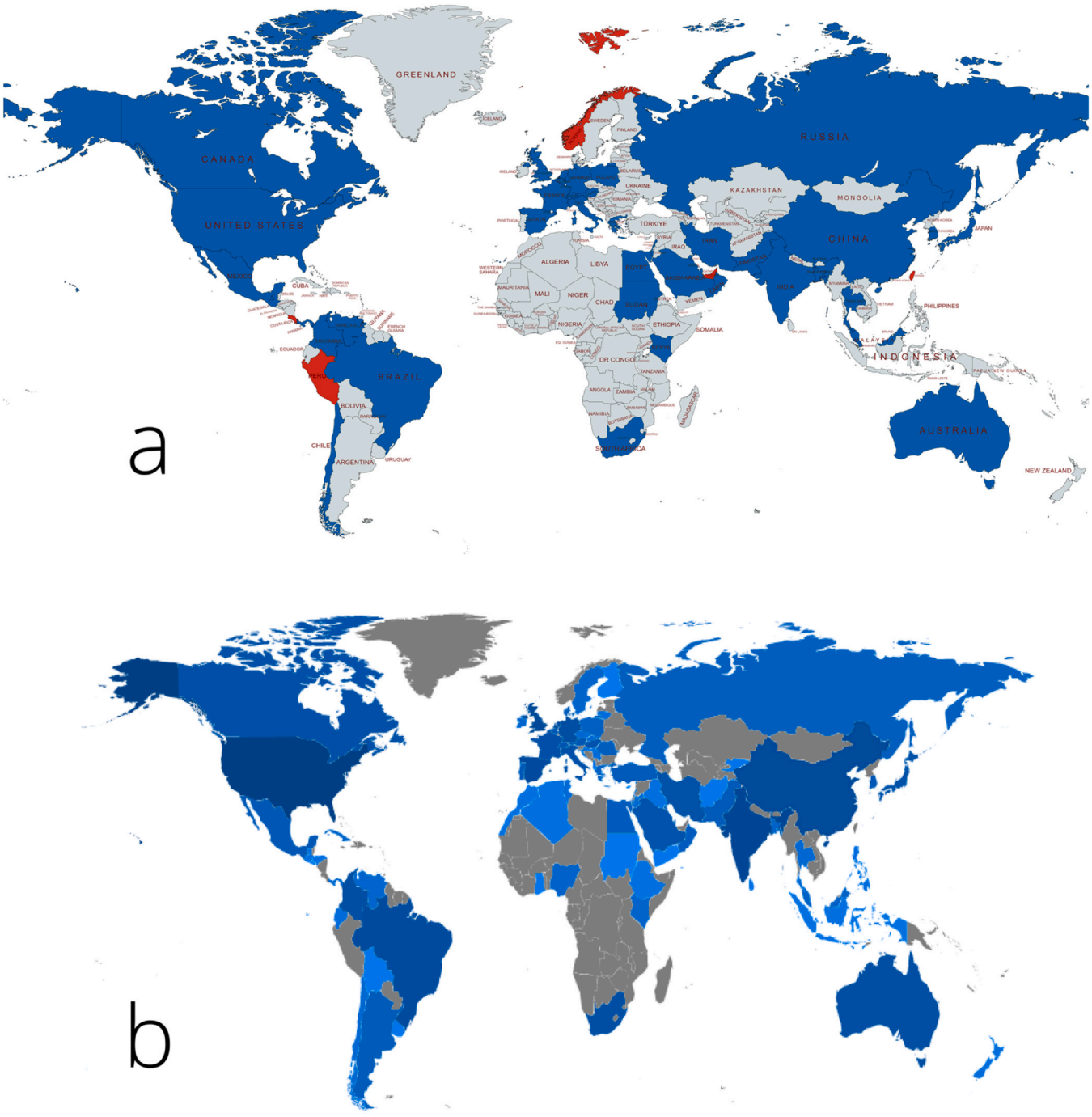

Fig. 2. Comparison of countries where *Candida auris* cases have been reported by CDC (a) and countries where *Candida auris* papers have been published (b). In the map (a), countries where *Candida auris* cases have been reported and papers on the topic have been published are shown in blue, while in red are shown those countries where despite the identification of *Candida auris*, no papers have been published on the topic. In the map, the blue gradient indicates the number of publications produced by each country. The maps were produced using mapchart.net (a) and biblioshiny (b).

lower income (0.1%), 8 for Unclassified economy (0.15%). Venezuela has been temporarily unclassified as of July 2021 pending release of revised national accounts statistics (supplementary table A5) [18].

The NCA by continent are shown in Table 3.

Leading continents in publications on *Candida auris* are Europe, Central Asia and North America that contribute 58.83% of total publications.

Most relevant affiliations

Top 5 affiliations for TP on *Candida auris* are CDC (99), University of Delhi (67), University of Debrecen (58), University of Wisconsin (54) and Canisius Wilhelmina Hospital (41). Full results are shown in supplementary table A6.

Affiliation collaboration network

The supplementary Fig. A2 shows the collaboration network between affiliations (institutes) in *Candida auris* publications. The spinglass algorithm was used to cluster affiliations. Among the top 15 affiliations, The University of Delhi has the highest betweenness centrality (67.897), which means a node's ability to carry

Table 3
Author's country production by continent.

Continents	Number of Countries	Number of authors	Frequency (%)
East Asia and Pacific	10	674	12.94%
Europe and Central Asia	29	1634	31.37%
Latin America and the Caribbean	15	480	9.22%
Middle East and North Africa	15	376	7.22%
North America	2	1430	27.46%
South Asia	5	449	8.62%
Sub-Saharan Africa	6	165	3.17%
Total	82	5208	100%

information between unconnected groups of nodes in a network (supplementary table A7).

Most relevant authors and impact

The 5 most relevant authors identified, sorted by TP, are Meis J (TP=70, TC=4429), Chowdhary A (TP=59, TC=4537), Lockhart S (TP=49, TC=2988), Chakrabarti A (TP=33, TC=913), Berkow E (TP=32, TC=2725). Full results of 10 most relevant authors with h-index and g-index are shown in supplementary table A8.

Keywords and trending topics

Supplementary table A9 shows the top 15 words for number of occurrences. The top 5 words are *Albicans* (N = 142), *Identification* (N = 129), *Clonal Strain* (N = 108), *Candida-auris* (N = 97), *Epidemiology* (N = 97) and *Antifungal Susceptibility* (N = 96).

A graphical representation of word frequency can be found in supplementary Fig. A3.

Top country, keywords and affiliations relations

The three fields plot (TFP) was used to visualise the relationship between countries, keywords, and affiliations (Supplementary Fig. A4).

Keywords co-occurrence network

The keywords co-occurrence network analysis between the 20 most frequently used keywords is shown in supplementary Fig. A5. The spinglass algorithm was used to cluster keywords. The limit was set to 20 nodes, each representing a keyword. Each node's size symbolises the number of occurrences of keywords of publications on *Candida auris* and the lines branching off from each node represent the co-occurrences between each keyword.

Discussion

Bibliometric analysis is an increasingly popular research methodology, which owes its spread to the growing improvement and accessibility of scientific databases and bibliometric software [12–14,19]. It provides a general picture but limited to the date of extraction for analysis. To reduce this limitation, we performed data extraction on January 2, 2023, considering all articles published up to the end of December 2022.

Given the continuous increase in scientific publications and the fragmented nature of the information that can be found, this technique is essential to summarise large amounts of bibliometric data to present the state of intellectual structure, emerging trends and providing a science mapping in a topic or field of research [19]. This method makes it also possible to check whether there is adequate attention to the issue under study.

The results of this study show an important growing rate (53.91%) in the number of scientific publications on *Candida auris* from its emergence to the present, confirming the growing interest of the scientific community in this topic. In addition, the percentage of publications on *Candida auris* compared to all publications on *Candida* is increasing sharply and peaked (5.52%) in 2022. The increase in publications may probably be due to an increase in *Candida auris* cases and the recognition of its dangerous antimicrobial resistance. On the other hand, the COVID-19 pandemic has also contributed to increased attention on emerging pathogens.

Journals identified both as core and most-cited sources are the primary sources of information and lead the research on the topic of *Candida auris*: *Journal of Fungi*, *Antimicrobial Agents and Chemotherapy*, *Mycoses*, *Journal Of Clinical Microbiology*, *mBio*, *mSphere*. These are mostly microbiology journals, and this is an indication of the scientific interest of this branch in *Candida auris*. On the other hand, we can speculate that there is less attention on the topic from the clinical world, and these may be the next steps toward which scientific production will move. Among the core sources, only *Infection Control and Hospital Epidemiology* has a Journals Citation Report category indexed as public, environmental and occupational health.

The most cited articles were identified. We argue that these results can be used as a starting point to understand the state of the art and current knowledge on *Candida auris* and its global spread.

Through country stratification it was found that 5 countries where *Candida auris* was identified did not produce articles on the topic. It should also be noted that the list of countries where identification occurred is partial because it was no longer updated after February 2021 due to an increasing spread of the pathogen. Therefore, the ratio between countries with identification and countries with publication might be different.

Stratification by income economy and continent showed that out of 82 countries with publications on *Candida auris*, 40 of them are classified as high-income and contributed 68% of the total publications. Europe, Central Asia, and North America contributed to the biggest part of the production (58.83%). High-income countries have greater resources both for the purpose of identifying uncommon and lesser-known pathogens and for the purpose of research on these pathogens [32]. This, added to the greater economic availability in science, could therefore explain the greater productivity on this topic by countries with high-income economies.

The collaboration network analysis showed countries and affiliations with the highest betweenness centrality. The high importance of the United States, both in terms of productivity and collaborations with other countries, may be linked to the presence of the CDC in Atlanta, which has implemented the monitoring of *Candida auris* cases and gives more attention to the issue of this emerging pathogen [10]. The countries and institutes identified are those leading the research on *Candida auris*.

In this study we used the h-index and the g-index to find the authors with highest influence and impact. The results obtained can be useful to retrieve the most relevant authors who wrote papers on *Candida auris*.

Trending topics and keywords for Candida auris include epidemiology, identification, and resistance. The prominence of

"identification" and "resistance" aligns with the pathogen's characteristics. Identification was crucial in the early stages of its spread, serving dual purposes: raising awareness of *Candida auris* in new countries and defining identification techniques. The high frequency of the keyword "resistance" alerts us on how important this issue is. *Candida auris* exhibits a higher prevalence of multi-drug resistance compared to other *Candida species*, with around 90% of tested isolates in the US being resistant to at least one antifungal drug. For common *Candida species*, reported resistance rates in the US are lower. According to Pfaller et al.'s study (2006–2019), resistance rates were 5.2% for *Candida albicans* (1997–2004), 41.4% for *Candida glabrata* (2011–2017), 1.5% for *Candida tropicalis*, 2.9% for *Candida parapsilosis*, and 7.2% for *Candida krusei* [31].

International surveillance that can provide epidemiological data on the spread of *Candida auris* would be useful to deepen studies on the subject.

Bibliometric analysis is an effective method for mapping the scientific landscape and understanding publication trends on a specific topic. Nevertheless, this methodology is not without limitations. Firstly, its scope is limited to the scientific literature, disregarding gray literature, which can yield crucial insights. Furthermore, impact assessment relies on citation counts, which can be higher for older studies but may not capture the latest research hotspots. Despite these limitations, our study represents the first bibliometric analysis on *Candida Auris*, providing valuable insights into quantifying scientific output in this field and understanding the most relevant topics of interest. A systematic review of the literature may be useful to deepen and characterise the topic in order to gather the best available evidence in the literature.

Conclusion

This study provides an overview of the available literature on *Candida auris*; quantitative and qualitative analyses of the leading journals, most cited published articles, and most relevant authors in publications on *Candida auris* from 2009 to 2022 were conducted. Furthermore, the performed analyses revealed differences in publications at the geographic level. The United States of America and the University of Delhi are respectively the country and the institute with the highest betweenness centrality. The global trend of publications on *Candida auris* is growing, but there are differences by continent and income economies. Our analysis shows a growing interest in scientific literature on the topic of *Candida auris*, led by Europe, Central Asia, and North America. According to stratification by income economy, most publications come from countries with high-income economies. In some countries where *Candida auris* has been identified, no papers have been published, suggesting a lack of knowledge in this area. The analysis of trending topics and co-occurrence network highlighted the interest in the topic of identification, epidemiology and multidrug resistance. Despite this, the topic of therapy is not much debated. Our findings highlight the need to increase focus on *Candida auris* in order to promote health systems' preparedness and to properly address the spread of this worrisome pathogen.

The exponential increase in data in the literature is a demonstration that this pathogen is currently still poorly understood and understudied. Nevertheless, it is definitely an emerging public health threat that, if not adequately studied and explored, can become a real global health hazard.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jiph.2023.08.012.

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