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A Bibliometric Analysis of *Lysinibacillus spp*. as Electrogenic Bacteria in Microbial Fuel Cells

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Microbial fuel cells (MFCs) harness microorganisms' metabolic processes to convert organic compounds into electricity, offering an eco-friendly energy solution. As the global demand for sustainable energy sources increases, MFCs have emerged as a promising technology for both bioremediation and biomass power generation. However, optimizing microbial performance remains a challenge, particularly in identifying and enhancing the role of electroactive bacteria. Among them, *Lysinibacillus sp.* has shown potential for efficient electron transfer, yet its contributions to MFC performance remain underexplored. To address this gap, bibliometric analysis provides a systematic approach to mapping research trends, identifying key contributors, and evaluating the evolution of scientific knowledge in this field. This study employs bibliometric analysis via Dimensions AI and VOSviewer to explore research on *Lysinibacillus sp.* in MFCs. The analysis identified 3029 publications from 2015 to 2024, peaking in 2022 and 2023. Dominant fields include biological sciences and microbiology, with 1210 and 571 publications, respectively. Varjani, Sunita was the most prolific author, and India was the leading contributor with 610 documents and 19,663 citations. Bioresource Technology was the top journal, and Amity University led in co-authorship. Key references are Geyer, R., and Logan, B.E. The analysis provides insights into research trends, significant publications, and future directions for advancing MFC technologies.

Keywords: Bibliometric analysis, Dimension AI, Electrical energy, *Lysinibacillus*, Microbial fuel cells, VOSviewer.

Microbial fuel cells (MFCs) harness the metabolic activities of microorganisms to convert organic substances into electricity, offering an environmentally friendly approach to energy generation. This technology has advanced significantly to address the increasing global demand for sustainable and clean energy solutions.[1] MFCs answer various environmental and energy-related issues, such as treating wastewater, contaminating pollutants, and utilizing biomass and organic waste for power production.[2] In MFCs, electroactive bacteria at the bioanode decompose organic materials, releasing electrons and protons. The electrons travel through an external circuit, generating an electrical current, while the protons move through a proton exchange

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membrane to reach the cathode. At the cathode, electrons combine with protons and an electron acceptor, typically oxygen, to complete the circuit and produce water.[3] The effectiveness of MFCs heavily depends on the microbial communities involved. Bacteria such as *Geobacter, Shewanella*, and *Lysinibacillus* species play vital roles due to their distinct metabolic pathways that facilitate direct electron transfer to the anode or through mediators. The proper selection and optimization of these microbial catalysts are crucial for enhancing MFC efficiency. MFCs present numerous benefits compared to conventional energy generation methods: MFCs make use of organic waste and renewable biomass, contributing to a sustainable energy cycle. MFCs offer a dual advantage of reducing environmental pollution and energy expenses by treating wastewater and generating electricity simultaneously.[4] MFCs function at ambient temperatures and pressures, requiring minimal external energy input. Despite the potential advantages of MFCs, several challenges must be overcome to realize their commercial and industrial potential. These challenges include enhancing power density, scaling up the technology, improving the stability and efficiency of microbial catalysts, and reducing material and construction costs.[5,6] Ongoing research efforts are focused on exploring new microbial strains, optimizing reactor designs, and integrating MFCs with other renewable energy systems. One promising area of research involves the use of *Lysinibacillus* species as biocatalysts, which may offer unique benefits in terms of electron transfer efficiency and operational stability.[7, 8] Bibliometric analysis is essential in research and academic publishing, and tools like Dimensions AI and VOSviewer play a significant role in enhancing this process. These tools help understand research trends, evaluate research impact, and identify collaboration opportunities.[9] Dimensions AI provides comprehensive data on research outputs, citations, grants, patents, and clinical trials, enabling the identification of emerging trends, popular research topics, and prolific authors or institutions. VOSviewer, on the other hand, allows for visualizing the structure and dynamics of scientific research through network data, such as co-authorship, co-occurrence, and citation networks, aiding in understanding research topic development and diffusion.[10, 11] Dimensions AI offers citation metrics and altmetrics to assess the impact of specific papers, authors, or journals, which is crucial for funding agencies, researchers, and institutions to determine the significance and reach of their research. Similarly, VOSviewer helps in visualizing citation patterns and identifying influential papers and authors within a field, providing insights into the impact and influence of research works. Dimensions AI highlights collaboration patterns between researchers, institutions, and countries, potentially leading to new collaborations and partnerships. VOSviewer maps co-authorship networks to reveal interconnected researchers and potential

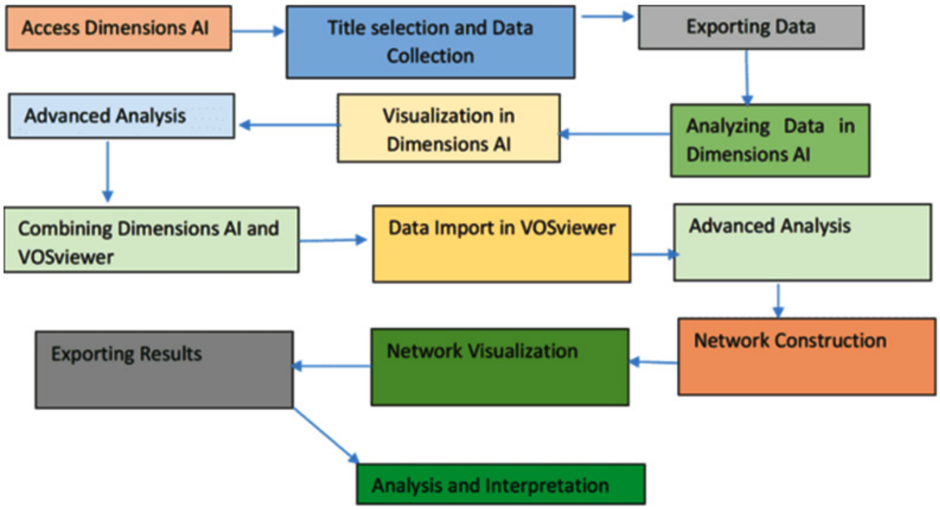

Chart 1. The outline of the methods have been represented as follows

collaborators active in specific research areas. Dimensions AI and VOSviewer offer valuable insights for strategic planning and decision-making in research institutions.[12-14] By identifying strengths and weaknesses, these tools enable better resource allocation and policy-making. Additionally, they aid in literature reviews by facilitating comprehensive searches and organizing bibliometric data efficiently. Moreover, they help in tracking research funding and outputs by visualizing the relationship between funding sources and research productivity. Overall, utilizing these tools is crucial for enhancing the effectiveness and impact of scientific research through informed decision-making. This study conducts a bibliometric analysis to assess the current state of research on *Lysinibacillus sp.* in MFCs, identifying key trends, influential publications, and potential areas for future research.[15] This analysis aims to provide a comprehensive overview of the field, guiding researchers and practitioners in advancing more efficient and sustainable MFC technologies.

MATERIALS AND METHODS

Bibliometric analysis involves quantitatively analyzing scientific literature, with tools like Dimensions AI and VOSviewercommonly used. Below are detailed steps for conducting bibliometric analysis using these tools for this study:

Bibliometric Analysis Using Dimensions AI

Accessed Dimensions AI by visiting the website and logging in with your credentials. Ensured the necessary access level for conducting bibliometric analysis.Collected data by using the search function to gather information on a specific research topic, author, or publication. Utilize filtering to refine the search results based on criteria such as year, research category, or source. Exported the gathered data in formats like CSV, Excel, or BibTeX for further analysis.Analyzed the data by importing it into bibliometric analysis software or tools like Excel.Taken advantage of Dimensions AI's built-in analytics for citation counts, altimetry scores, collaboration networks, and more.Visualized the data using the built-in tools to create graphs and charts, such as citation networks and research trends over time.For more advanced analysis, integrate Dimensions AI data with other software like VOSviewer, R, or Python, utilizing the API for custom analysis can be done, but in this study, we have gone through VOSviewer.[16]

Table 1. Top 16 Field of Research, and Co-authorship Analysis

Field of Research		Type of analysis: Co-authorship Unit of analysis: Authors		
Research category	Publications	Author	Documents	Citations
Biological Science	1210	Varjani, Sunita	17	1416
Microbiology	571	Kumar, Vikash	13	491
Industrial Biotechnology	519	Yaqoob, Asim Ali	12	609
Agricultural, Veterinary and Food Sciences	194	Sun, Jianzhong	11	1963
Environmental Sciences	171	Bilal, Muhammad	11	759
Crop and Pasture Production	90	Gaur, Vivek Kumar	10	641
Engineering	84	Ahmad, Akil	10	355
Biomedical and Clinical Sciences	80	Pandey, Ashok	9	939
Ecology	77	Ngo, Huuhao	9	804
Biochemistry and Cell Biology	49	Bharagava, Ram Naresh	9	641
Plant Biology	49	Yaakop, Amira Suriaty	9	333
Pollution and Contamination	47	Das, Alok Prasad	9	293
Genetics	42	Nandy, Arpita	9	270
Chemical Sciences	37	Awasthi, Mukesh Kumar	9	253
Chemical Engineering	35	Yan, Huaxiao	9	243
Agricultural Biotechnology	34	Zhao, Hui	9	243

Bibliometric Analysis Using VOSviewer

VOSviewer is a software tool designed for the creation and visualization of bibliometric networks. These networks can encompass journals, researchers, or individual publications.[17-19] Below are the steps to utilize VOSviewer for bibliometric analysis:

Data Preparation

Gathered the bibliometric data from source as Dimensions AI. Ensured that the data is in a compatible format (CSV, RIS, or BibTeX).

Importing Data

Launched VOSviewer and specified the type of data being imported (e.g., bibliographic data, citation data), and followed the instructions to import your dataset.

Network Construction

Selected the type of analysis wished to conduct (e.g., co-authorship, co-citation, or bibliographic coupling). Then, adjusted the settings for network construction, including thresholds for inclusion and the normalization type.

Network Visualization

VOSviewer created a visualization of the bibliometric network. Personalized the visualization by utilizing options for node size, color, and label display. Then, the clustering algorithms to identify groups or communities within the network have been utilized.

Analysis and Interpretation

Examined the network to pinpoint key authors, papers, and research trends. Utilized VOSviewer's integrated tools to assess network properties like density, centrality, and modularity.

Exporting Results

Exported the visualizations and analysis outcomes for reporting or further examination. VOSviewer enabled exporting in formats such as PNG, SVG, and plain text for network data. By utilizing both Dimensions AI and VOSviewer, acquired a more profound understanding of research trends, collaboration networks, and the influence of scientific literature.

The 'csv' and 'ris' file link provided by Dimension AI were as: https://export.digital-science.com/2024-07-12/b468c72b2d07869d1292e96cdce63cb3/Dimensions-Publication-2024-07-12_04-55-23.csv.zip and https://export.digital-science.com/2024-07-12/cbd66ab2c780ceb738a972d6ec5398be/Dimensions-Publication-citations-2024-07-12_04-57-06.ris.

Table 2. Major Contributing Countries and Journals

Type of analysis: Co-authorship, Unit of analysis: Country			Type of analysis: Citations, Unit of analysis: Source		
Country	Documents	Citations	Source	Documents	Citations
India	610	19663			
China	427	15148	Bioresource Technology	52	3535
United States	143	6798	Environmental Science and Pollution Research	47	934
Malaysia	91	3342	Journal of Hazardous Materials	43	2919
South Korea	90	4426	Frontiers in Microbiology	43	2689
Brazil	79	2798	Chemosphere	41	1685
Pakistan	78	2088	The Science of the Total Environment	37	1581
United Kingdom	76	5846	Journal of Environmental Management	32	2435
Saudi Arabia	71	2885	Microorganisms for Sustainability	32	365
Australia	62	4126	Chemical Engineering Journal	27	1089
Egypt	59	2718	Journal of Environmental Chemical Engineering	22	928
Germany	51	1899	SSRN Electronic Journal	17	5
Iran	47	1652	Molecules	16	657
Nigeria	42	1052	International Journal of Hydrogen Energy	16	586
Mexico	39	2379	Journal of Water Process Engineering	16	557
Canada	38	2077	Microorganisms	16	492
Italy	37	1070	Environmental Pollution	16	315
South Africa	36	1536	Environmental Research	16	290
Spain	36	1428	Environmental Science and Engineering	16	74

Table 3. Major Contributing Organizations and Co-Citation Analysis

Type of analysis: Co-authorship, Unit of analysis: Organization			Type of analysis: Co-Citation, Unit of analysis: Cited References	
Name of Organization	Documents	Citations	Cited reference	Citations
Amity University	38	1435	geyer,r,etal.(2017). Science Advances,3(7),e1700782	66
Universiti Sains Malaysia	33	1100	azubuike,cc,etal.(2016). world journalof microbiology and biotechnology,32(11),180	52
Jiangsu University	24	2256	logan, be, et al. (2006). environmental science and technology,40(17),5181-5192	51
Banaras Hindu University	23	1553	saratale,rg,etal.(2011).journal of the taiwan institute of chemicalengineers,42(1),138-157	51
Academy of Scientific and Innovative Research	23	323	yang, j, et al. (2014). environmental science and technology, 48(23),13776-13784	41
University of Chinese Academy of Sciences	19	751	gaur,vk,etal.(2018). bioresource technology, 27219-25	39
University of Calcutta	19	681	he, m,etal.(2010). journal of hazardous materials,185(2-3),682-688	39
King Saud University	19	438	bahuguna, a, et al. (2011). journal of environmental sciences, 23(6),975-982	35
Babasaheb Bhimrao Ambedkar University	17	886	wei, r, et al. (2017). microbial biotechnology, 10(6),1308-1322	32
Anna University, Chennai	17	595	wang,j,etal.(2008). biotechnologyadvances,27(2),195-226	31
University of Technology Sydney	16	1079	yaqoob,aa,etal.(2021). chemicalengineering journal,417128052	26
University of Delhi	16	704	demuynck, w,etal.(2010). ecologicalengineering,36(2),118-136	23
Lovely Professional University	15	711	vanhamme,jd,etal.(2003). microbiology and molecular biology reviews,67(4), 503-549	21
Saveetha Institute of Medical and Technical Sciences	15	176	shi,l,etal.(2016).nature reviews microbiology,14(10),651-662	21
Indian Institute of Technology Guwahati	15	462	bharagava, rn, et al. (2017). ecotoxicology and environmental safety, 147102-109	20
Indian Institute of Toxicology Research	14	1065	singh,rl,etal.(2015). internationalbiodeterioration & biodegradation,10421-31	19
China University of Geosciences	14	719	davoodi-dehaghani, f, et al. (2009). bioresource technology,101(3),1102- 1105	19
University of Petroleum and Energy Studies	14	277	jahromi,h,etal.(2014).fuel,117230-235	17
Zhejiang University	13	380	tavassoli,t,etal.(2012).fuel,93142-148	15
Universidade De SãoPaulo	13	378	ayangbenro,as,etal.(2020). scientificreports,10(1),19660	14

The outline of the methods have been represented as follows:

RESULTS

Research on Lysinibacillus sp. as a biocatalyst in microbial fuel cells (MFCs) has seen a remarkable surge in interest and scholarly output since 2015. This trend has been particularly pronounced in the years 2022 and 2023, where the number of publications reached 517 and 462 articles, respectively, as illustrated in Figure 1b. To gain a deeper understanding of this growing body of work, a comprehensive analysis was conducted, encompassing a total of 3029 publications. This dataset included 1500 peer-reviewed articles and 904 book chapters, highlighting the extensive exploration of this topic across various formats. Notably, the fields of biological sciences and microbiology emerged as the most prominent areas of research, with 1210 and 571 publications, respectively, as shown in Figure 1a.

A closer examination of co-authorship patterns revealed that Varjani, Sunita stands out as

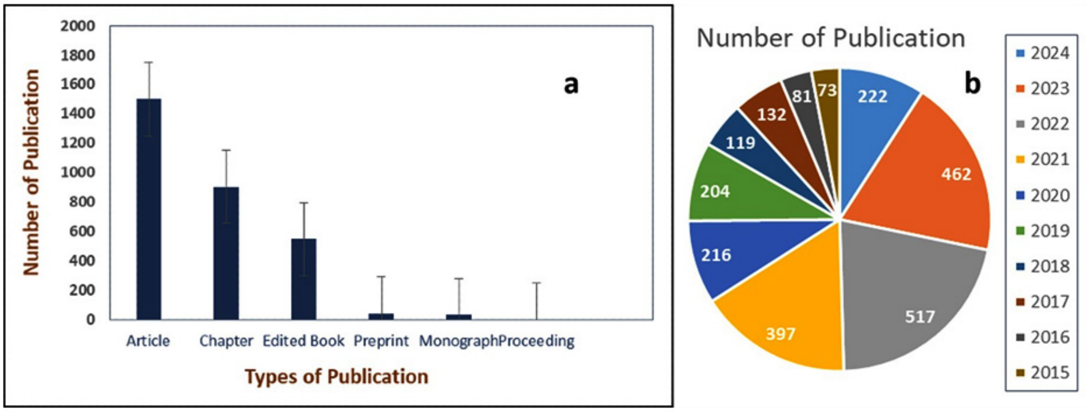

Fig. 1. 'a' – Types of Publication; 'b' – Number of publications in different year

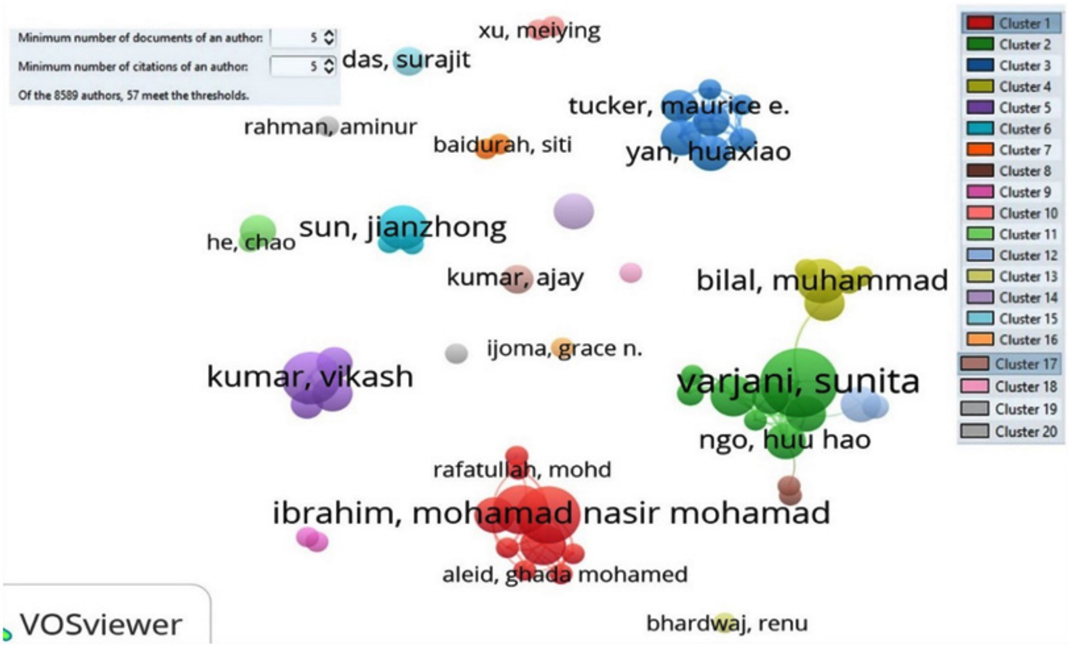

Fig. 2. Co-authorship analysis as a unit of analysis of contributing authors

the leading author in this field, having contributed 17 documents that collectively garnered an impressive 1416 citations. This indicates not only the author's prolific output but also the significant impact of their work on the research community. Geographically, India has established itself as the leading contributor to this body of research, with a total of 610 documents and an impressive

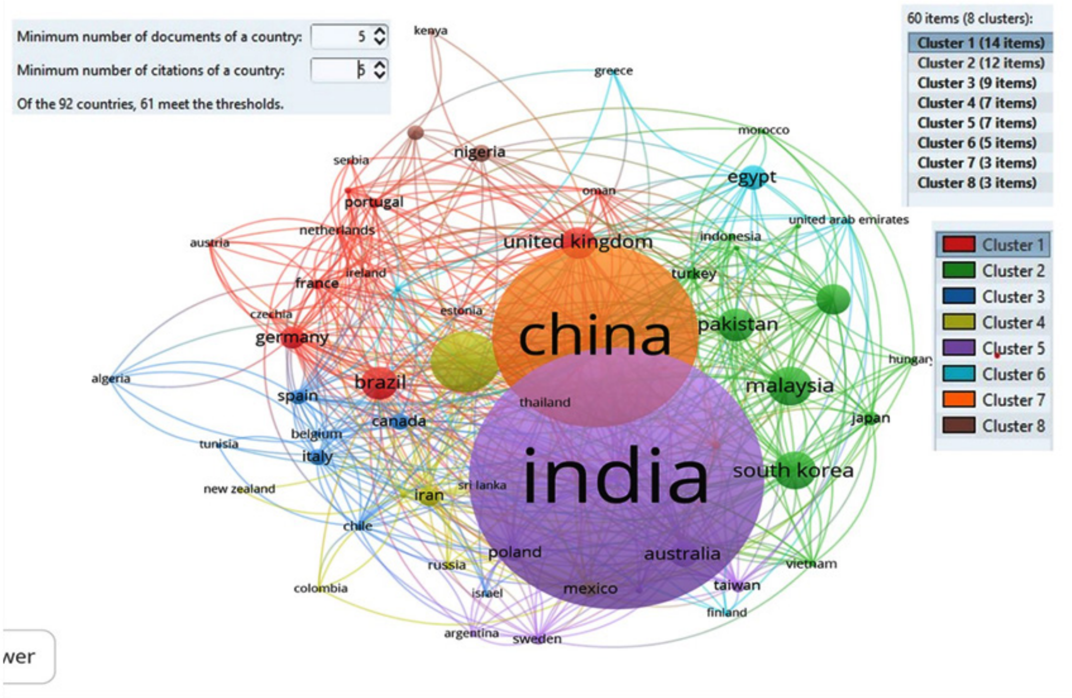

Fig. 3. The unit of analysis as contributing countries

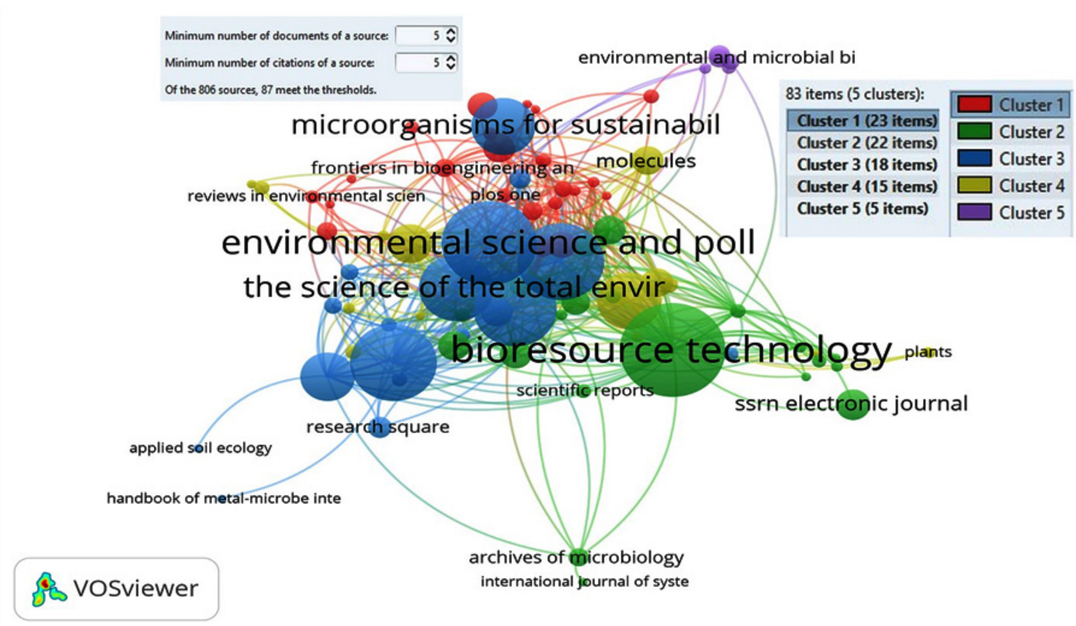

Fig. 4. Major contributing journals

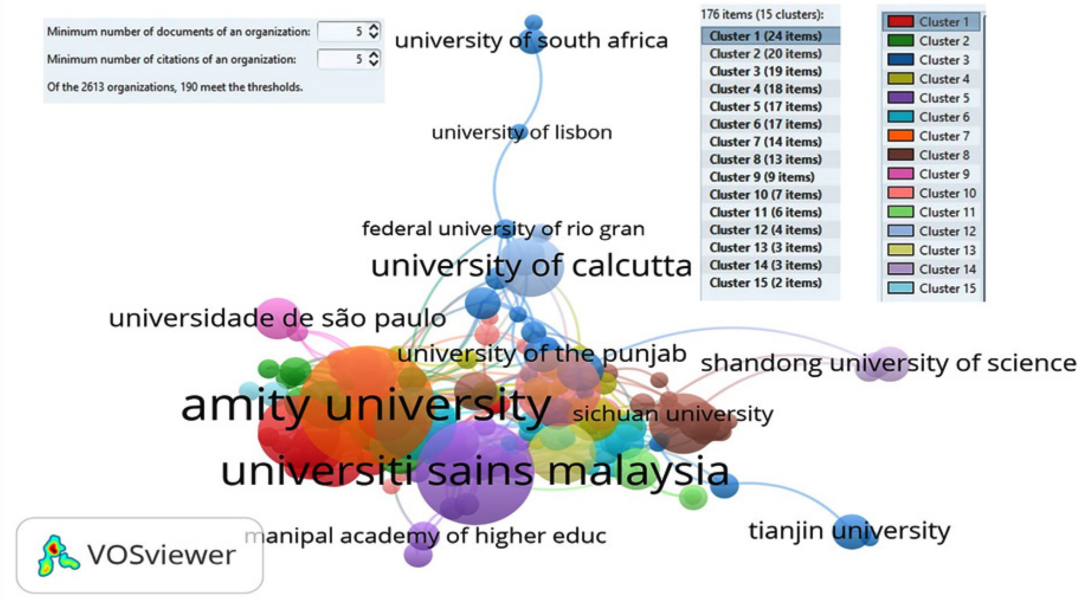

Fig. 5. Major contributing organizations

citation count of 19,663. Following India, China has also made substantial contributions, with 427 documents and 15,148 citations, as detailed in Table 2 and illustrated in Figure 3.

In terms of journal contributions, Bioresource Technology has emerged as the leading publication outlet for research on Lysinibacillus sp. in MFCs, having published 52 documents that have collectively received 3535 citations, as depicted in Figure 4 and summarized in Table 2. Additionally, Amity University has been recognized for its collaborative efforts in this research area, producing 38 documents that have accumulated 1435 citations, as shown in Table 3 and Figure 5. The co-occurrence analysis revealed 172 distinct elements grouped into three clusters based on their relationships and frequency, enhancing understanding of term connections. The term "microbial fuel cell" was the most frequent, appearing 151 times, while "Lysinibacillus" was mentioned 88 times, indicating their significance in the research. This analysis provides insights into thematic organization, guiding future research directions and fostering advancements in the field.

DISCUSSION

The research trend on *Lysinibacillus sp.* as a biocatalyst for microbial fuel cells has seen a remarkable rise, particularly in the years 2022 and 2023. This increase underscores the growing interest in microbial fuel cells and their potential in green energy generation. The significant contributions from the field of biological science, followed closely by microbiology, highlight the interdisciplinary nature of this research. Biological science's dominance in publications (1210) reflects the importance of microorganisms in developing sustainable energy solutions, while microbiology's prominent role (571 publications) demonstrates its specific relevance to microbial fuel cell research. The co-authorship analysis indicates that Varjani, Sunita has become a leading figure in this research, with many citations and documents produced.[20] This suggests that individual researchers are playing a pivotal role in advancing the field. The dominance of India and China in terms of publication output and citations further emphasizes the strong academic interest in microbial fuel cells in these countries.[21, 22] India, in particular, stands out with its large number of documents (610) and citations (19663), suggesting that it is a global leader in this area of research. The Bioresource Technology journal's significant impact, with 52 documents and 3535 citations, highlights its crucial role in disseminating research related to microbial fuel cells and biocatalysts.[23] This journal's prominent position suggests that it is a leading platform for scholarly work in the field. Amity University's top ranking in co-authorship with 38 documents and 1435 citations also signals the importance of specific academic institutions in driving forward the research agenda on microbial fuel cells.[24] This finding aligns with the global trend where universities and research organizations are central to the development of green technologies. The co-citation analysis reinforces the importance of certain key references in shaping the research discourse. Geyer, R., (2020), Azubuike, CC., (2016), Logan, BE. (2006), and Saratale, RG. (2011) are recognized as key foundational studies in the field, indicating that their findings have had a significant impact on subsequent research on microbial fuel cells.[25-27] Finally, the co-occurrence analysis highlights the centrality of terms like "microbial fuel cell" and *"Lysinibacillus,"* which appear frequently in the research literature. These terms' frequent mention (151 and 88 times, respectively) signifies their foundational role in the discourse surrounding microbial fuel cells and green energy production.[28, 29] The emphasis on these terms suggests that future research may continue to focus on optimizing the use of *Lysinibacillus sp*. in microbial fuel cells to improve energy generation efficiency and sustainability.

CONCLUSIONS

The bibliometric examination underscores the necessity for ongoing research and interdisciplinary collaborations within the realm of MFCs. Subsequent investigations ought to concentrate on rectifying the recognized constraints and delving into the encouraging domains delineated in the forthcoming scope. While this analysis provides valuable insights into the research landscape on Lysinibacillus sp. in MFCs, it is limited by its reliance on publication metadata, which may not fully capture experimental advancements and unpublished innovations. Additionally, the scope of this study does not assess the practical applicability, scalability, or techno-economic feasibility of MFC technologies utilizing Lysinibacillus sp. Future research should address these gaps by conducting experimental validations alongside bibliometric trends to correlate microbial efficiency with real-world performance. Moreover, a more in-depth examination of genetic and metabolic pathways in Lysinibacillus sp. could provide mechanistic insights into its role in electron transfer. Researchers should also explore new microbial strains, optimize reactor designs, and integrate MFCs with hybrid renewable energy systems to enhance their efficiency and sustainability. By leveraging bibliometric tools, scholars can strategically design studies that bridge existing knowledge gaps and accelerate the transition of MFCs from research labs to industrial applications. Addressing these limitations will be crucial in unlocking the full commercial and environmental potential of MFC technologies. Through the utilization of bibliometric instruments, scholars can tactically devise and execute studies that amplify the effectiveness and durability of MFC technologies. The bibliometric analysis presents a detailed overview of the research landscape on Lysinibacillus sp. in MFCs, providing valuable insights for researchers and industry professionals to enhance the efficiency and sustainability of MFC technologies. Future research endeavors should prioritize the exploration of new microbial strains, optimization of reactor designs, and integration of MFCs with other renewable energy systems to overcome current challenges and unlock the full commercial and industrial potential of MFCs.

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Conflict of interest

The authors do not have any conflict of interest.

Data Availability Statement

The used data stored in MEGA (https://mega.io/storage) as a data repository in the following link.
https://mega.nz/folder/GZs2nRyK#OJe55Q-PEdvacEcmCNLPVQ

Ethics Statement

This research did not involve human

participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration

This research does not involve any clinical trials.

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Not Applicable.

Authors' Contribution

Palash Pan: Conceptualization, Methodology, Data Collection, Writing – Original Draft; Abhishek Samant): Review & Editing; Kajari Roy: Visualization, Formatting of Table and Figure; Nandan Bhattacharyya: Supervision.

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