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RESEARCH ARTICLE

TARDIGRADES IN FOCUS: TRACKING RESEARCH TRENDS THROUGH SCIENTOMETRIC ANALYSIS

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ABSTRACT

This study explore the scientometric assessment of tardigrades research publications from 2004–2024 based on data from the Scopus and Web of Science (WoS) databases and used a systematic approach to assess outputs, citation counts and annual increments for the two-decade period. The analysis shows that there is an upward trajectory over the years in the number of publication outputs, with scopus peaking at 95 publications in 2019, and WoS peaking with 101 publications in 2024. Citation metrics suggest an increasing scientific visibility, with 3,129 Scopus and 3,184 WoS peak citations in 2020, having more than doubled in the last 10 years, most likely reflecting the growing interest in tardigrades as a subject of research. The Publication Efficiency Index (PEI) was different in the two databases Scopus had a maximum PEI of 41.18 in 2017 and WoS a maximum PEI of 34.51 in 2021, and find a very high growth rate in the number of publications in the first years between 2008 to 2012, this growth slowed down over time until it seems to have been re-energized between 2018 to 2024, as discussed in the Annual Growth Rate (AGR) and Doubling Time (DT) analyses. Key contributors to tardigrades research include prominent authors such as Kaczmarek, L., and Michalczyk, L., with substantial publication counts. The top journals, Zootaxa especially, appear to be able to proffer a firm stage for research. Both databases listed United States and Poland as major contributing countries. The study, the research areas connected to tardigrades range from zoology to environmental sciences to agricultural biology.These findings emphasize the importance of further studies on tardigrades, especially in ecological, genomic and applied contexts, to comprehend their ecological roles and adaptations.

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INTRODUCTION

Tardigrades, commonly known as "water bears" or "moss piglets", are a phylum of Tardigrada (Goeze, 1773) and it's a fascinating microscopic creatures famous for their ability to survive extreme conditions. These weird little critters, can withstand extreme conditions that would kill almost all other life, that's why they are so interesting to scientists and science nerds out there. These creatures are known for their remarkable resilience, surviving extreme conditions such as extreme temperatures, high and low pressure, radiation, dehydration, and even outer space exposure. It's also known as slow walkers (Lazzaro Spallanzani, 1776) Tardigrades survive everything from the vacuum of space to the deep ocean floor, displaying various "paper-cut" strategies and pushing previous biological boundaries. In the last 30 or 40 years, tardigrades have captured more and more research interest, aided by technological developments, interdisciplinary work, and perhaps also their odd biology. Few studies are instead devoted to different fields of tardigrades biology, thus there is not a comprehensive review available across this most fascinating field that would permit to sketch the directions of tardigrades studies, as well as to identify trends and breakthroughs. Recognising this gap, the present paper provides a scientometric analysis of tardigrades research, summarising its evolution over time, the structure of scientific collaboration and the citation impact of the most relevant publications and researchers. The use scientometric methods, a suite of quantitative tools to map the scientific literature, to shed light on what is known about tardigrades and summarize research undertaken. In this systematic review address these questions by surveying a large body of the scientific literature, including journal articles, conference papers, and other forms of scholarly output, and providing direction to researchers, educators for best practices in researchers interested in tardigrades and the wider importance of the field.

REVIEW OF LITERATURE

Chaman Sab et al. (2025) analyzed India's top-cited medicinal plants research as part of a global assessment of top-cited articles and developed a network of the most influential authors, institutions, and journals. Their review showed a well-established knowledge base of ethno medicine India, a large number of international co-authorships, and an increasing trend for the data to be more visible. Dash et al. (2025) also achieved a conclave of quantitatively evaluated research related to Research Data Management (RDM) by employing mapping, bibliometric indicators, and visualization tools to depict research activities worldwide and the rapid rise of Indian research, especially in collaborative research. Their investigation signaled the mounting importance of research data stewardship in academic and

scientific communities. Ganguly (2025) used scientometric mapping of publication trend, keyword clustering, and citation impact indicators to weigh India's contribution to global research on probiotics. The assessment identified the thematic progression towards health innovation and India's rising profile as a contributor to functional food and microbiome research. Anand and Aravind (2024) have conducted a global scientometric analysis on mesentery research from 1989 to 2022. Employing the data source of Web of Science (WoS) database, the analysis developed the information on publication patterns, indicating research growth and collaboration dynamics, and informed that the American Journal of Physiology and Heart-Circulatory Physiology was the leading journal in terms of publications. Basumatary et al. (2024) studied on genomics in India used a bibliometric approach based on publication and citation data to reveal the principal contributors and trends in genomics research in India and found that the publications had grown steadily with high contributions made by the Indian Council of Agricultural Research. Ghojazadeh et al. (2024), examined radiation science in Korea showed the relevant trends of thyroid cancer research with scientometric methods to over 28,000 articles collected from the Scopus database, and revealed co-occurrence core journals including Journal of Clinical Endocrinology and Metabolism through R software and the Bibliometrix package for visualization. Ahmad et al. (2024) performed a detailed analysis of influenza research using a dataset of 59,013 documents from the Web of Science, focusing on public health challenges and highlighting key contributors, with significant publications originating from Europe and North America. Goswami et al. (2024) utilized scientometric methods to map existing literature on orchids from the Scopus database, covering 18,600 records published between 2003 and 2022, emphasizing the need for collaborative conservation efforts. Konur (2024) conducted the first scientometric evaluation of algal bioremediation research by analyzing nearly 6,700 publications, demonstrating the significance of continuous assessment in this field through various bibliometric techniques. Gupta et al. (2023) conducted a bibliometric analysis of monkeypox research, focusing on publication trends, influential journals, and contributions from various countries and authors using publication data to derive insights. Neves et al. (2021) utilized molecular biology techniques to investigate the mechanisms that enable tardigrades to survive extreme conditions, revealing their unique adaptations. Talarico et al., (2022) conducting a literature review and analysed the adaptability of tardigrades and assessed their prospected relevance to the field of astrobiology as well as potential evolutionary mechanisms of extraterrestrial life. These studies together improve our understanding of several domains, highlighting the richness with increased interest and funding in multiple research areas.

STAEMENT OF THE PROBLEM

This scientometric examination strives to comprehensively assess investigations involving Tardigrades, quantify the contemporary condition of understanding, and illuminate essential inquiries encompassing these mysterious organisms. The aims of this analysis are to distinguish look into patterns over the long run, appraise the effect of productions, dissect coordinated systems, and uncover openings in information inside Tardigrade examination.

OBJECTIVE OF THE STUDY

- To identify the annual growth of publications in the field of Tardigrades research at the global level
- To measure year wise citations and Publication efficiency Index
- To find out the exponential growth and time series analysis Tardigrades Research outputs
- To examine the major research subject areas and most productive countries
- To identify productive journal and the most prolific authors
- Identify the institutional collaborations networks

MATERIALS AND METHODS

This research utilized exploratory, descriptive, and quantitative methodologies through bibliometric analysis techniques and tools to investigate tardigrade literature. Data within the Scopus and Web of Science databases provided the focus, as data was retrieved on January, 2025 spanning the past two decades from 2004 to 2024. For Scopus, a search of "Tardigrades" in the title, abstract or keywords limited to publications between 2004 and 2024 returned 1,082 records. Within Web of Science, a simple search of "Tardigrades" within the same timeframe yielded 1,156 records. All bibliographic details downloaded were then exported to a spreadsheet to enable analysis aligned with the objectives of this study. Scientometric tools were subsequently applied to facilitate a comprehensive assessment and fulfill intended outcomes through processing the exported data.

RESULTS AND DISCUSSION

Year wise publication Growth, Citation trends and Performance Efficiency Index: The analysis of research pertaining to water-dwelling micro-animals commonly known as tardigrades from the years 2004 through 2024 reveals some intriguing patterns in output and reception. Papers indexed in Scopus increased yearly overall, culminating in ninety-five published in 2019. Citations likewise followed an ascendant trajectory, peaking at three thousand one hundred twenty-nine in 2020 and betraying a rising regard within scientific circles. Publication Efficiency Index values shifted through the years, achieving their zenith of forty-one point eighteen in 2017 and denoting a notably high impact relative to total works. Examination of the Web of Science revealed a steady rise in publications, most notably hitting one hundred one in 2024. Citations also climbed, with a lofty count of three thousand one hundred eighty-four attained in 2020, though PEI values generally stayed beneath those in Scopus and achieved their acme of thirty-four point fifty-one in 2021. This suggested the database similarly mirrored an expanding interest in tardigrades study but its publications may have garnered comparatively fewer citations on the whole. Both databases demonstrate a positive tendency in tardigrades research, signifying solid ground for ongoing probing and proposing this domain gains momentum and visibility within scientific literature. Divergences in PEI between the pair highlight dissimilar citation patterns and impact, warranting added exploration of aspects contributing to these divergences.

Annual growth Rate (5 year block period) and Doubling Time: The analysis of Annual Growth Rate (AGR) and Doubling Time (DT) for publications concerning tardigrades from Scopus and Web of Science (WOS) unveils notable fluctuations. Within Scopus, the timeframe from 2004 to 2007 experienced a robust AGR of 74.39% and a DT of under a single year, indicating a burgeoning interest within this arena. Such momentum amplified between 2008 and 2012, with an impressive AGR of 131.06% and a DT of only 0.53 years. From the year 2013 to 2017, the growth rate slowed to 22.49%, resulting in a DT of 3.11 years, reflecting potential saturation of interest. A resurgence manifested from 2018 to 2024, with an AGR of 36.29% and a DT of 1.93 years. The WOS database demonstrated substantial growth, distinctly from 2003 to 2007, with an AGR of 89.20% and a DT of 0.78 years. The period from 2008 to 2012 observed the highest growth rate at 144.74% and a DT of 0.48 years. However, from 2013 to 2017, the AGR dropped to 10.74%, and the DT increased to 6.51 years, insinuating diminishing publication output. The recent timeframe, 2018 to 2024, experienced a revival, with an AGR of 48.51% and a DT of 1.44 years. Both databases indicate a design of initial rapid growth, trailed by a slowdown and a recent resurgence, proposing that while tardigrades research is becoming more established, there are still chances for exploration. The findings accentuate the importance of continued investment and collaboration within the field to stimulate further growth and tackle emerging research queries in tardigrades studies. *Time Series and Exponential Growth:* The fig 2 shows time series and exponential growth analysis of tardigrada research publications from Web of Science (WoS) and SCOPUS databases entre 2004 and 2024. The rapid growth of both

Table 1. Year wise publication Growth, Citation trends and Performance Efficiency Index

Year	Scopus Publications	Scopus Citations	Scopus PEI	Year	WOS Publications	WOS Citations	WOS PEI
2004	14	83	5.93	2004	15	2	0.13
2005	17	104	6.12	2005	24	19	0.79
2006	21	220	10.48	2006	29	120	4.14
2007	36	383	10.64	2007	37	262	7.08
2008	49	447	9.12	2008	37	368	9.95
2009	36	491	13.64	2009	36	442	12.28
2010	36	789	21.92	2010	37	715	19.32
2011	39	911	23.36	2011	36	852	23.67
2012	49	1157	23.61	2012	54	1061	19.65
2013	42	1134	27	2013	49	1132	23.1
2014	37	1479	39.97	2014	47	1393	29.64
2015	54	1273	23.57	2015	39	1261	32.33
2016	69	1524	22.09	2016	50	1432	28.64
2017	65	1744	26.83	2017	73	1784	24.45
2018	44	1812	41.18	2018	61	1792	29.38
2019	75	1984	26.45	2019	68	1929	28.36
2020	95	2554	26.88	2020	74	2298	31.05
2021	82	3129	38.16	2021	98	3184	32.49
2022	91	2896	31.82	2022	80	2761	34.51
2023	82	3061	37.33	2023	89	3182	35.76
2024	82	2703	32.96	2024	101	3116	30.85

Table 2 . Annual growth Rate (5 year block period) and Doubling Time

Database	Period	AGR (%)	DT (Years)	Database	Period	AGR (%)	DT (Years)
Scopus	2004-2007	74.39	0.94	WOS	2004-2007	89.2	0.78
	2008-2012	131.06	0.53		2008-2012	144.7	0.48
	2013-2017	22.49	3.11		2013-2017	10.74	6.51
	2018-2024	36.29	1.93		2018-2024	48.51	1.44

Table 3. Top 10 Most Prolific Authors in Tardigrades Research

Sl No	WOS Database Authors Publications		Sl No.	Scopus Database Authors and Publications	
1	Kaczmarek L	106	1	Kaczmarek, L.	82
2	Michalczyk L	95	2	Rebecchi, L.	73
3	Guidetti R	72	3	Michalczyk, Ł.	69
4	Kristensen RM	44	4	Guidetti, R.	67
5	Bertolani R	42	5	Stec, D.	51
6	Cesari M	39	6	Schill, R.O.	45
7	Gasiorek P	38	7	Zawierucha, K.	41
8	Lisi O	35	8	Bertolani, R.	40
9	Jonsson KI	34	9	Roszkowska, M.	40
10	Jorgensen A	32	10	Nelson, D.R.	39

Table 4. Most Productive Journals in Tardigrades Research (Top Ten Only)

WOS Database Journals	Records	Scopus Database Journals	Records
Zootaxa	111	Zootaxa	92
Zoological Journal of the Linnean Society	59	Zoologischer Anzeiger	44
Zoologischer Anzeiger	45	Journal Of Limnology	43
Journal Of Limnology	43	Zoological Journal of the Linnean Society	42
Integrative And Comparative Biology	41	Polar Biology	31
Polar Biology	35	Plos One	28
Plos One	29	Scientific Reports	26
Scientific Reports	27	Journal of Zoological Systematics and Evolutionary Research	24
Zoological Science	25	Hydrobiologia	20
Hydrobiologia	22	Zoological Science	17

Table 5. Research Hotspot in tardigrades Research Outputs

Sl No.	Research Areas WOS Database	Record Count	Sl No.	Research Areas in Scopus Database	Record Count
1	Zoology	479	1	Sciences	838
2	Ecology	158	2	Molecular Biology	277
3	Marine Freshwater Biology	102	3	Environmental Science	170
4	Topics	98	4	Earth and Planetary Sciences	90
5	Other Topics	97	5	Multidisciplinary	84
6	Evolutionary Biology	92	6	Medicine	52
7	Biodiversity Conservation	91	7	Physics and Astronomy	45
8	Biology	76	8	Microbiology	38
9	Entomology	45	9	Engineering	33
10	Genetics Heredity	43	10	Chemistry	20

Table 6. Country wise contribution of Tardigrades Research Outputs WoS/Scopus

Sl No.	Countries/Regions WoS Database	Record Count	Sl No.	Countries/Regions Scopus Database	Record Count
1	United States	283	1	United States	273
2	Poland	237	2	Poland	220
3	Italy	169	3	Italy	160
4	Germany	135	4	Germany	146
5	England	105	5	United Kingdom	125
6	Japan	103	6	Japan	115
7	Denmark	98	7	Denmark	91
8	Sweden	62	8	Sweden	61
9	Portugal	33	9	China	39
10	Czech republic	32	10	France	36

Table 7. Collaborative research Institutes in the fired of Tardigrades Research (To 10 Only)

Sl No.	WOS Databse , Tardigrade Research Colloborative institutes	Record Count	Sl No.	SCOPUS Databse , Tardigrade Research Colloborative institutes	Record Count
1	Adam Mickiewicz University	135	1	Adama Mickiewicza w Poznaniu	128
2	Jagiellonian University	118	2	Uniwersytet Jagielloński	99
3	Universita Di Modena E Reggio Emilia	97	3	sità degli Studi di Modena e Reggio	95
4	University Of Copenhagen	90	4	Københavns Universitet	80
5	Keio University	48	5	Statens Naturhistoriske Museum	61
6	Uk Research Innovation Ukri	47	6	Keio University	48
7	University Of Catania	47	7	Universität Stuttgart	43
8	Natural Environment Research Council Nerc	45	8	British Antarctic Survey	43
9	Nerc British Antarctic Survey	43	9	East Tennessee State University	38
10	Polish Academy Of Sciences	37	10	Università degli Studi di Catania	37

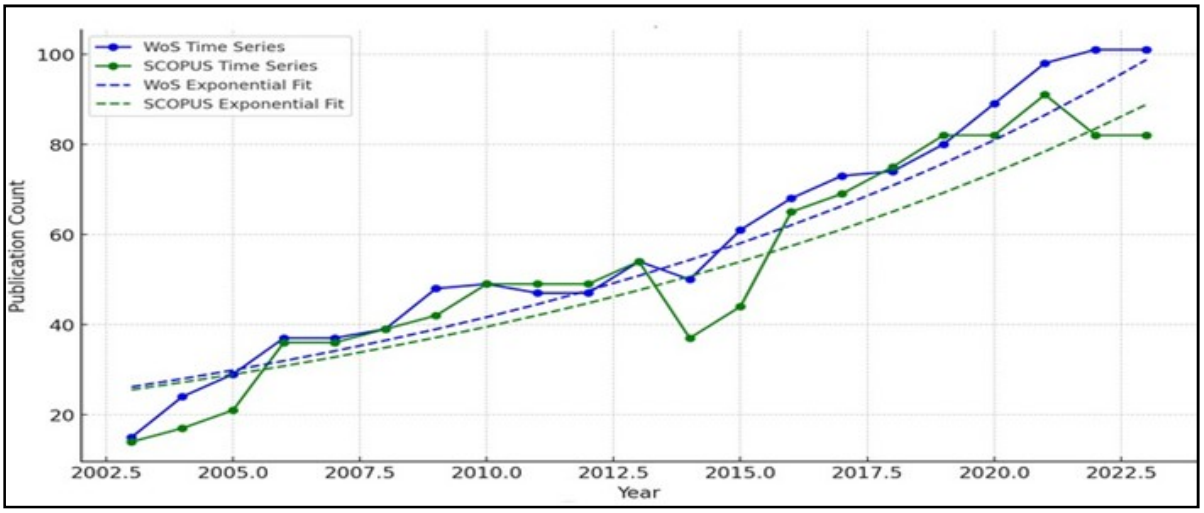

Fig 1. Tardigrades Research publications: WOS and Scopus (2004-2024) Time series and Exponential Growth

databases started from 2004 – 2010 with a slow growth, WoS 15 & SCOPUS 14. Interest grew gradually, as evidenced by WoS 50 and SCOPUS 54 publications by 2011. Changes in the database-based publication counts were quite stable between 2011 and 2015 and, since 2016, a trend to war das an upward trend for WoS with 68 and for SCOPUS with 65 publications. The decades had passed but the increase was even steeper in the years since, with numbers of 74 and 75 in WoS and SCOPUS by 2019, respectively. Analysis of the exponential growth indicates a growth rate of 6.64% for WoS (higher than SCOPUS with 6.23%). During the years 2020 until 2024 this trend is even more salient, WoS reached 101 publications while SCOPUS recorded 82, showing an increase in research and interest in tardigrades. The overall increase in publications is highlighted in each annual analysis, further demonstrated by the increasing global interest in this field from 2016 onwards. The similar growth structure implied by both databases shows that while research into Tardigrades is maturing quickly as evidenced by the rapid early growth and subsequent evening out of publications there is still much to learn. These results underline how much growth and progress has been made but also how critical continued investment and collaboration will be to realize the potential of the field and bud off new areas of inquiry. *Most Prolific Authors (Top ten only):* In the authors' contributions analysis of Tardigrades research, Kaczmarek, L. had the highest number of publications (106) in the Web of Science database, which may show that the author plays an important role in this field (ESI 2023). A little bit further down, Michalczyk, L. has made a large contribution too (95 pubs). Guidetti, R. comes next with 72 papers, reinforcing the collaborative nature of the Tardigrades top authors. Together, they show a rich baseline of research in this area, creating a platform for future research activities.

Most Productive Journals in Tardigrades Research (Top Ten Only): In terms of the journals where the records of Tardigrades research are published, Zootaxa is by far the largest contributor with 111 records in Web of Science (WOS) and 92 in Scopus (Fig. 2). Zoological Journal of the Linnean Society (2nd in WOS with 59 records) and Zoologischer Anzeiger (2nd in Scopus 44 records) share the second place just behind Zootaxa. Some other prominent journals are Journal of Limnology (43 records in WOS; 43 in Scopus) and Polar Biology (35 records in WOS; 31 in Scopus). This shows how important these journals are for Tardigrades research, reflecting high research interest in these hardy organisms.

Research Hotspots: The analysis of research areas indicates great Tardigrades literature in both Web of Science (WOS) and Scopus databases. While Zoology tops the list in WOS with 479 records, Environmental Sciences Ecology (158) and Marine and Freshwater Biology (102) follow in a line-up foregrounding their ecological roles. Agricultural and Biological Sciences leads in Scopus with 838 records and Biochemistry, Genetics and Molecular Biology follows (277 records). Environmental Science (170) and Earth and Planetary Sciences (90) are among other notable fields. This diversity indicates the different biological and ecological roles Tardigrades fill.

Country wise contribution of Tardigrades Research Outputs WoS/Scopus: Countries that provide the most contributions to which Tardigrades is the most prominent among the top countries obtained in both the Web of Science (WoS) and Scopus databases. U.S. The United States heads both databases with 283 records in WoS and 273 in Scopus, emphasizing the importance of the U.S. in this field. This is followed by Poland, with 237 records available in WoS and 220 in Scopus, which corroborates the large number of research studies conducted on Tardigrades. In turn, Italy and Germany come up with important contributions with 169 and 135 records in WoS, and 160 and 146 in Scopus records, respectively. England, Japan, Denmark, Sweden and Portugal are among those, with the Czech Republic also contributing to advancing knowledge of Tardigrades. All this data shows a coordinated international research effort in studying the biology and ecology of these hardy species around the world.

Collaborative research Institutes in the fired of Tardigrades Research (To 10 Only): The overlap of studies specific to Tardigrades conducted by collaborative research institutes analysis reveals a significant overlap between WoS and Scopus database. With 135 papers present in WoS and 128 in Scopus, Adam Mickiewicz University comes first in both databases, indicating the central role of our university in Tardigrades research. In the second place is Jagiellonian University with 118 records in WoS and 99 in Scopus. Other places of note include Universita di Modena e Reggio Emilia and University of Copenhagen, which show a consistent output of research across each platform. International collaborative engagement with the biology and ecology of these resilient organisms. There are 842 (966) Tardigrades research collaboration institutes listed in the WoS (Scopus). It shows a strong International network of scholar where everything in the area of Tardigrades, particularly in the Europe, uses always a sequence of approaches through the various system. This clearly shows us the scientific knowledge that the niche field contains and the necessity for these institutes to work together.

DISCUSSION

The research findings from 2004 to 2024, depicts a consistent global amplification of tardigrade studies, as evidenced by the upward trends in both publication and citation counts in Scopus and Web of Science (WOS). The maxima in 2019 and 2024 together with the increased number of citations in 2020, point to the rising acknowledgment of the employment of tardigrades' extraordinary survival strategies in various fields of science like astrobiology, molecular biology, and stress physiology. Such an incline is in concert with the findings of much wider scientometric studies, for example, Ganguly's (2025) psychology, that also reveal a growing interest in biological resilience. The Publication Efficiency Index (PEI) is a measure that shows the relative influence of research outputs. The highest PEI for Scopus was in 2017 when the most influential publications probably related to cryptobiosis and extremotolerance - the concepts that were notably elucidated in molecular studies by Neves et al. (2021) were made. The peak of PEI for WOS in 2021 signifies continued but more widely spread scholarly interaction. Annual Growth Rate (AGR) and Doubling Time (DT) are the indicators that tell the story of the field's dynamic development. The period of rapid expansion at the beginning, namely from 2004 to 2012, resulted from increased interest in tardigrade survivability in space and biological adaptability, which goes hand in hand with the global interest in astrobiology as reported by Talarico et al. (2022). The period of stabilization came after that, from 2013 to 2017, and the resumption of growth after 2018 was a sign of further integration with genomics, stress physiology, and environmental sciences. The trends over time and exponential growth study both shows that the field has been steadily expanding. The difference is that WOS has a somewhat greater rate of growth than Scopus, which indicates that more and more widely indexed journals are accepting this research. Top contributors such as Kaczmarek and Michalczyk are the main movers and shakers who have substantially influenced the field and their examples are followed by other authors, who similarly influence authorship trends in medicinal plant studies (Chaman Sab et al., 2025) and research data management (Dash et al., 2025). Worldwide cooperation is very clear from the fact that USA, Poland, Italy, and Germany have been the major contributors. This is in harmony with the trends of internationally collaborative projects observed in studies on influenza (Ahmad et al., 2024) and orchids (Goswami et al., 2024). Adam Mickiewicz University is the place that produces the most and it is a clear indication of the power of European research networks. Such a great number of institutions contributing (842 in WOS and 559 in Scopus) is a sign of a strong and broadly scoped interdisciplinary research ecosystem that covers biology, ecology, space science, and biotechnology. The study of the tardigrade has now become a thoroughly scientific field that is mature, very collaborative, and interdisciplinary. It is still being propelled by worldwide interest in the most unusual survival strategies and is going on to infiltrate domains such as stress biology, climate resilience, and astrobiology, whereby tardigrades will be an essential model organism for the next biological and space research.

SUGGETIONS AND LIMITATIONS

This study's limitation is that it depends on a fixed time span (2004 – 2024), which might not consider all research outputs or long-term developments. They could overcome this problem in research by including more databases like PubMed and OpenAlex and lengthening the time frame for their analysis. The use of bibliometric laws alongside scientometric indicators and instruments such as Biblioshiny and VOSviewer would uncover more the directions of research, the networks of collaboration, and the growth of knowledge in the field of Tardigrades Research.

CONCLUSION

This study presents a scientometric analysis of the published literature (publications and citations) associated with tardigrades, a commonly studied group of micro-animals, based on data from Scopus and Web of Science (WOS) databases for the period of 20 years. Results showed not only a rising number of researches, but also a growing perceived importance of their ecological and biological relevance. These variations in publication and citation patterns between the two databases indicate different levels of recognition in the scientific community. While the analyses of particularly authorship and productivity have some limitations only the relative share of the research output by each country is identified, not the total share these general trends suggest that this field requires an ongoing investment.

efforts will be discussed and conclude with the need for further research to address these gaps and for better dissemination of the knowledge we have and how it can be harnessed in different fields of science.

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