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Quantifying the Global Research Effort on Bioactive Compounds: A Scientometric Analysis (1989-2023)

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Globally, there has been an evolving interest in the research area of bioactive compounds. Bioactive compounds have attracted significant attention because they prevent several chronic diseases. Assessing the current state of global bioactive compounds research activity is essential to identify the research trends in this field. This scientometric analysis aims to identify the trends in the publication of global bioactive compounds over the last 35 years. The study data were extracted from the Web of Science (WoS) Core Collection database to evaluate publications' scientific results from 1989 to 2023. Software bibliometrix R-package Biblioshiny, BibExcel, HistCite, and VOSviewer have been used for analysis and visualization mapping of the data. The study found tremendous publication growth in the field during the last five years, i.e., 2011-2023. The King Saud University of Saudi Arabia has contributed 98 research publications, the highest amongst other institutions, and Brazil topped with 2081 publications. This study has some limitations in that only the data from the Web of Science Core Collection database were selected, so the analyses entirely depended on the quality of the input information imported from the WoS database. These findings suggest a strong momentum in bioactive compound research, emphasizing the need for continued global collaboration and exploring diverse databases to gain a broader understanding of the field's progress.

Keywords: Biblioshiny, Bioactive compounds, Research trends, VOSviewer, Web of science

Introduction

"Bioactive compounds" refers to secondary metabolites extracted from fungi, plants, bacteria, and animals.[1] Bioactive, essential, and non-essential compounds are naturally occurring substances that are a food chain component and have influenced human health.[2] Bioactive compounds are extra nutritional components in foods that can influence metabolic processes and promote good health.[3,4] Fruits, vegetables, nuts, herbs, roots, and spices are highly bioactive, particularly non-starch polysaccharides and polyphenols.[5] The presence of potential therapeutic molecules in the bioactive compounds can treat metabolic disorders, pro-inflammatory states, and oxidative stress while influencing energy intake.[6,7] Bioactive compounds have health-promoting properties like inhibiting enzymes, such as pancreatic lipases in obese patients[8], free radical scavenging, and the ability to prevent cancer cell development.[9] Epidemiological studies specify that consuming foods high in bioactive compounds with antioxidant activity may reduce the risk of several diseases, including Alzheimer's, stroke, cancer, diabetes, heart disease, cataracts, and age-related diseases.[10] Bioactive compounds are gaining popularity in various fields, including geomedicine, the food industry, pharmacology, plant science, agrochemicals, cosmetics, nano bioscience, etc.[11] Several research articles on bioactive compounds have been published in the last three decades, with significant findings. The present used the scientometric method to investigate the published literature on bioactive compounds. Scientometric methods can provide quantitative and qualitative research review approaches for tracking scientific research activities to identify research trends by assessing the authors, countries, institutions, and keywords and projecting future directions for research.[12–15] There is no dearth of literature on scientometrics and bibliometrics studies in various research areas. A brief review of the recent past has shown us the truth. Recently, Ding and Zeng[16] studied the bibliometric analysis ofthe research progress in sulfate-rich wastewater pollution control technology. Moshobane *et al.*[17] identified a bibliometric overview of the International Journal of Tropical Insect Science from 2012 to 2020 using the Web of Science

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database. They revealed that there had been an increase in insect science research collaboration among different countries. In the bibliometric study by Song *et al.*[18] on the bioremediation of petroleum-contaminated soils, the USA and China played a significant role in the field, and Chemosphere was the most preferred journal by the researcher. India needs to become more competitive with global researchers in artificial intelligence research, as revealed in the study by Pandey *et al.*[19] on India's artificial intelligence research productivity. Liao *et al.*[20] studied medical big data (MBD) through visualization analysis of the research published on MBD. China ranked the top in toxicity research on organic ultraviolet filters, followed by the USA, according to the study by Carve *et al.*[21] Again, Wu and Ye[22] conducted a study on a scientometric assessment of ontology research. The 100 most cited lung cancer articles were analyzed by Li *et al.*[23] from the Web of Science database. Chen *et al.*[24] identified the groundwater remediation research from past, present, and future perspectives. Similar studies on scientometric and bibliometrics were also conducted on different research themes by various researchers.[25–31] The scientometric studies covering other subject areas are also expected to continue. To help researchers, uncover and pursue new research paths and expand future research initiatives, the current study is an effort to conduct a thorough evaluation study on research initiatives carried out in the bioactive compounds research publication outputs. Thus, this scientometric analysis will measure publication growth rates, most cited articles, most prolific authors, journals, institutions, keywords analysis, etc., to get a complete bioactive compounds research scenario. For this study, the subsequent research questions have been formulated, and the same has been addressed.

a) What are the publication growth trends and citation patterns of research on bioactive compounds?
b) What are the most cited articles, prolific authors, countries, and institutions on bioactive compounds research?
c) What are the most prolific journals, keywords, and topics?

Methods

Data Collection

This research employs scientometric analysis to examine global publications on bioactive compounds from 1989 to 2023. Data was sourced from the Clarivate Analytics Web of Science Core Collection (WoSCC) database[51], renowned for its extensive scientific content indexing.[32] Utilizing the keyterms bioactive compounds, the title search strategy, i.e., "TITLE = "Bioactive Compounds*," is employed to retrieve the data from the database. Bibliometric indicators such as the h-index and g-index are sourced from the citation database WoSCC. The h-index, introduced by Hirsch in 2005, measures the quantity and impact of a scholar's published work by counting the number of articles (h) that have received at least h citations. The g-index, proposed by Egghe in 2006, emphasizes the quality of publications by giving more weight to highly cited articles.

Exclusion and Inclusion of Data

The initial search from the database generated a total of 8,133 documents. By applying the standard of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart, of which 2,274 document types such as review, proceeding papers, meeting abstracts, editorial material, letters, retracted publications, and corrections were considered inappropriate for further analysis and were excluded (Fig. 1). After applying these exclusion criteria of documents, only the documents that were

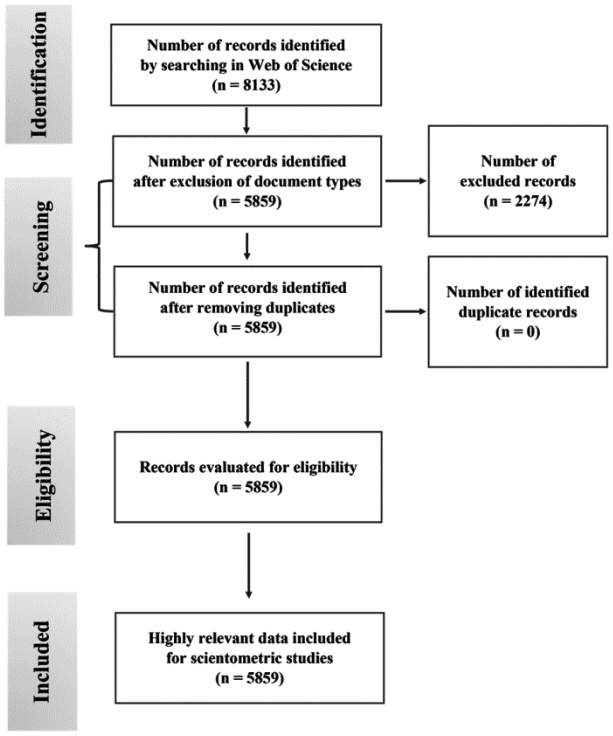

Fig. 1 — PRISMA flowchart showing the data exclusion and inclusion for the study

published in the form of articles, i.e., 5,859 which received 1,36,344 citations during the study period, were considered and included in the analysis. The dataset was extracted from the database in plain text (.txt) format and converted to comma-separated values (.csv) format for further study. The comprehensive approach enables insights into the evolution and trends within bioactive compounds research over the specified timeframe. The data were extracted, and a search was performed on the 13th of September, 2024, using the Web of Science Core Collection database.

Analysis Tool

Several statistical tools and software were employed to analyze the 5,859 retrieved data. Microsoft Excel 2019 (v16.0) facilitated data cleaning and extraction, while bibliometrix R-package Biblioshiny (v4.0.0)[33] was utilized for the same purpose. Moreover, VOSviewer (v1.6.18) was employed for mapping and data visualization[34] alongside HistCite[35] and BibExcel (v2017).[36] Except for Microsoft Excel, these scientometric tools are open-source educational software widely utilized globally for academic and research endeavors.

Results

A comprehensive repository of essential descriptive details pertinent to the study is given in Table 1. Within the confines of this table, 984 journals have contributed to disseminating knowledge through 5,859 research articles dedicated to this subject matter, and 26,072 researchers authored these documents. The authors' keywords used by these authors add up to 12,907. Of the 5,859 articles, only 88 were contributed by a single author, while 5,771 collaborated with others. Another important thing to note is that this study's international co-authorship was 27.15%. This number indicates a strong network of collaboration among researchers in this field. In simpler terms, many scientists work together and share ideas to study bioactive compounds.

Annual Research Growth and Citation Trends

The Table 2 presents a comprehensive outline of the research on bioactive compounds, including the

Table 1 — Main scientometric profile on bioactive compounds research

Description	Results	Description	Results
Timespan	1989 to 2023	Authors	26072
Journals	984	Authors of single-authored documents	83
Documents	5859	Single-authored documents	88
Annual Growth Rate %	14.73	Co-Authors per Documents	5.77
Document Average Age	6.16	International co-authorships %	27.15
Average citations per document	23.27	Keywords Plus (ID)	9982
References	199101	Author's Keywords (DE)	12907

Table 2 — Growth of bioactive compounds literature during 1989–2023

Year	TP	TC	C/P	MeanTC per Year	Year	TP	TC	C/P	MeanTC per Year
1989	7	139	19.86	0.55	2007	45	2602	57.82	3.21
1990	12	341	28.42	0.81	2008	55	2641	48.02	2.82
1991	10	129	12.9	0.38	2009	59	3560	60.34	3.77
1992	8	217	27.12	0.82	2010	81	4579	56.53	3.77
1993	8	156	19.5	0.61	2011	115	7252	63.06	4.5
1994	6	173	28.83	0.93	2012	160	5682	35.51	2.73
1995	7	237	33.86	1.13	2013	164	7260	44.27	3.69
1996	5	368	73.6	2.54	2014	207	6961	33.63	3.06
1997	13	609	46.85	1.67	2015	261	9187	35.2	3.52
1998	9	125	13.89	0.51	2016	310	9188	29.64	3.29
1999	10	174	17.4	0.67	2017	332	8954	26.97	3.37
2000	21	777	37	1.48	2018	426	12499	29.34	4.19
2001	17	596	35.06	1.46	2019	523	12782	24.44	4.07
2002	20	897	44.85	1.95	2020	600	11856	19.76	3.95
2003	16	906	56.62	2.57	2021	734	10482	14.28	3.57
2004	25	1502	60.08	2.86	2022	799	7479	9.36	3.12
2005	21	1303	62.05	3.1	2023	749	2861	3.82	1.91
2006	24	1880	78.33	4.12					

**TP = Total number of publications; TC = Total citations; C/P = Average citations per publication*

number of publications and their citation indices spanning from 1989 to 2023. Over this period, researchers contributed a total of 5,859 articles in this field. The correlation between the quantity of publications and the citation trends during this timeframe is visualized in Fig. 2. Remarkably, there has been a consistent upward trend in publications, as evidenced by the high R^2 value (R^2 = 0.5418), indicating a strong correlation. In 2022, the highest number of articles were published, reaching 799, followed by 2023 with 749 and 2021 with 734. In terms of citations, 2019 received the highest total citations (TC = 12,782), followed by 2018 (TC = 12,499) and 2020 (TC = 11,856). Interestingly,

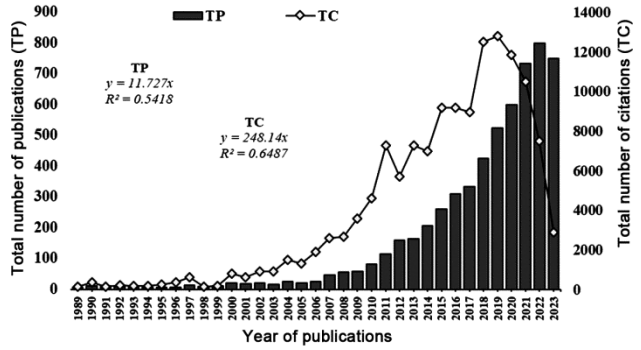

Fig. 2 — Publications growth and citation trends in bioactive compounds (1989–2023)

2006 had the highest average citations per publication (C/P = 78.33), followed closely by 1996 (C/P = 73.6). These findings indicate that the articles published in these years had a strong and significant impact on the bioactive compound research. The findings of the citations have been supported by the R^2 value (R^2 = 0.6487) of total citations (TC), as shown in Fig. 2, showing a strong correlation. The annual growth rate of published research articles is 14.73%, illustrating a substantial increase from just 7 publications in 1989 to 749 in 2023, highlighting the growing recognition of bioactive compounds' potential in medicine, food, and agriculture during the last three decades. The surge in research activity is likely driven by advances in analytical techniques, increased funding for natural product research, and a growing interest in alternative therapeutic approaches. Fig. 2 effectively captures this growth trend, depicting the steady rise in research output on bioactive compounds from 1989 to 2023.

Highly Cited Articles

The most influential research articles on bioactive compounds published between 1989 and 2023 are listed in Table 3. These articles are ranked based on their citation impacts, which include total citations (TC), total citations per year (TCPY), and normalized total citations (NTC). The number of citations for these articles ranges from 337 to 1273. The article

Table 3 — Top 10 highly cited articleson bioactive compounds from 1989–2023

Title	Author(s) & Year	Journal	TC	TCPY	NTC
Bioactive compounds in seaweed: functional food applications and legislation.[37]	Holdt & Kraan (2011)	Journal of Applied Phycology	1273	90.93	20.19
Bioactive compounds and antioxidant capacities of 18 non-traditional tropical fruits from Brazil.[38]	Rufino *et al.* (2010)	Food Chemistry	837	55.80	14.81
Use of principal component analysis (PCA) and hierarchical cluster analysis (HCA) for multivariate association between bioactive compounds and functional properties in foods: A critical perspective.[39]	Granato *et al.* (2018)	Trends in Food Science & Technology	589	84.14	20.07
Bioavailability of bioactive food compounds: a challenging journey to bioefficacy.[40]	Rein *et al.* (2013)	British Journal of Clinical Pharmacology	527	43.92	11.90
Integration of chemical-genetic and genetic interaction data links bioactive compounds to cellular target pathways.[41]	Parsons *et al.* (2004)	Nature Biotechnology	499	23.76	8.31
Exploring the mode-of-action of bioactive compounds by chemical-genetic profiling in yeast.[42]	Parsons *et al.* (2006)	Cell	386	20.32	4.93
Microencapsulation by spray drying of bioactive compounds from cactus pear (*Opuntia ficus-indica*).[43]	Saénz *et al.* (2009)	Food Chemistry	380	23.75	6.30
Determination of the bioactive compounds, antioxidant activity and chemical composition of Brazilian blackberry, red raspberry, strawberry, blueberry and sweet cherry fruits.[44]	de Souza *et al.* (2014)	Food Chemistry	376	34.18	11.18
Porous calcium carbonate microparticles as templates for encapsulation of bioactive compounds.[45]	Sukhorukov *et al.* (2004)	Journal of Materials Chemistry	361	17.19	6.01
Dietary bioactive compounds and their health implications.[46]	Liu (2013)	Journal of Food Science	337	28.08	7.61

TC = Total Citations; TCPY = Total Citation Per Year; NTC = Normalized Total Citations

entitled "Bioactive compounds in seaweed: functional food applications and legislation," authored by Holdt and Kraan[37] and published in 2011 in the *Journal of Applied Phycology* has received the highest number of citations (TC), with a total of 1273. Following closely is the article entitled "Bioactive compounds and antioxidant capacities of 18 non-traditional tropical fruits from Brazil," authored by Rufino *et al.*[38] and published in 2010 in *Food Chemistry*, which received a total of 837 citations.

These highly cited articles are essential because they address core topics in the study of bioactive compounds, particularly their antioxidant properties, bioavailability, chemical-genetic interactions, and encapsulation techniques. Their high citation numbers reflect their foundational contributions, influencing various fields, including food science, biotechnology, and healthcare. For instance, several articles explore the health benefits of bioactive compounds, emphasizing their role in combating oxidative stress, improving functional food design, and even advancing biotechnological applications. Studies like Granato *et al.*[39] indicate its significant impact on the field over time, despite being published more recently compared to other highly cited articles, and Rein *et al.*[40] also highlight the challenges in analyzing bioactive compounds' efficacy and bioavailability, which are critical for translating laboratory research into real-world health benefits. These articles have significantly shaped ongoing research in understanding and applying bioactive compounds, driving innovation in food technology and health sciences.

Prolific Authors on Bioactive Compounds

In Table 4 the top 10 authors are highlighted who have made significant contributions to the field of bioactive compounds, showcasing their impact through metrics like total citations (TC), h-index, and g-index. Lillian Barros from the Polytechnic Institute of Bragança, Portugal, emerges as a leading figure, with 40 publications and 1996 citations since her entry into the field in 2007. Notably, her extensive research in bioactive compounds has garnered widespread recognition. Mehmet Musa Ozcan from Selçuk University, Turkey, follows closely with 46 publications and 671 citations, while Isabel C.F.R. Ferreira, also from the Polytechnic Institute of Bragança, has 45 publications and an impressive 2077 citations. Lillian Barros and Isabel C.F.R. Ferreira hold the highest h-index values of 23, indicating their sustained influence in the domain. A striking feature of the analysis is Daniel Valero's remarkable average citation per publication (C/P) of 52.95, the highest among the top 10 authors, closely followed by Isabel C.F.R. Ferreira with a C/P of 46.16. This highlights the significant contributions of these researchers; whose work is prolific and highly impactful within the scientific community. The international scope of this research is evident, with authors representing institutions from various countries, further emphasizing the global importance and recognition of bioactive compounds research.

The productivity of the top twenty authors regarding how many articles they have produced each year and how many times they have been cited are shown in Fig. 3. The vertical axis represents each author, while the horizontal axis shows the years. Each blue circle represents a specific author's publications in a given year, with the size of the circle indicating how many articles they published. The transparency of the circles indicates the total number of citations the author's articles received up to that year. The red line marks the author's "active period," from their first publication on bioactive compounds to

Table 4 — Most relevant authors and their citation impact

Authors	Affiliations	TP	TC	C/P	h-index	g-index	PY-Start
Lillian Barros	Polytechnic Institute of Bragança, Portugal	49	1996	40.73	23	44	2007
Mehmet Musa Ozcan	Selçuk University, Turkey	46	671	14.59	14	24	2017
Isabel C.F.R. Ferreira	Polytechnic Institute of Bragança, Portugal	45	2077	46.16	23	45	2007
Nurhan Uslu	Selçuk University, Turkey	33	311	9.42	11	16	2017
Antonio Segura Carretero	University of Granada, Spain	31	1154	37.23	20	31	2012
Kashif Ghafoor	King Saud University, Saudi Arabia	30	719	23.97	13	26	2010
Elfadil E. Babiker	University of Khartoum, Sudan	26	503	19.35	11	22	2018
Burhan Ozturk	Ordu University, Turkey	22	360	16.36	12	18	2012
ShelaGorinstein	Hebrew University of Jerusalem, Israel	21	829	39.48	16	21	2008
Daniel Valero	Miguel Hernández University, Spain	20	1059	52.95	16	20	2008

**TP = Total number of publications; TC = Total citations; C/P = Average citations per publication; PY = Publication Year*

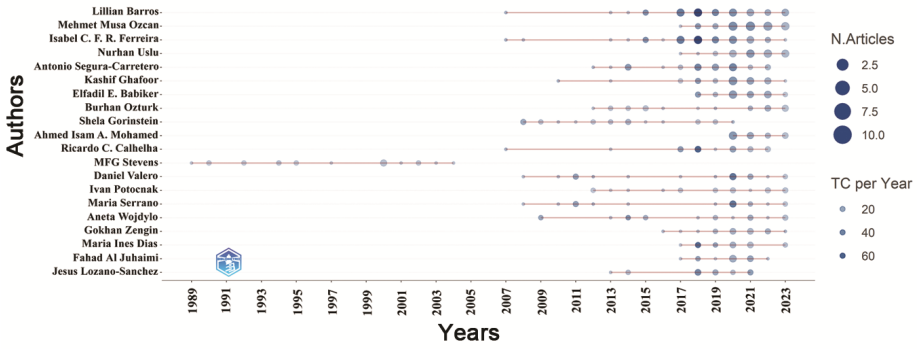

Fig. 3 — Top-Authors' Productivity over the time (1989–2023) *(Source: Biblioshiny)*

Table 5 — Prolific institutions on bioactive compounds

R	Institution	Country	TP	TC	R	Institution	Country	TP	TC
1	King Saud University	Saudi Arabia	98	57	11	University of Vigo	Spain	50	121
2	Spanish National Research Council	Spain	76	102	12	Poznan University of Life Sciences	Poland	43	120
3	University of São Paulo	Brazil	76	221	13	Wrocław University of Environmental and Life Sciences	Poland	42	43
4	Selçuk University	Turkey	73	86	14	Islamic Azad University	Iran	38	418
5	State University of Campinas	Brazil	68	178	15	Universidade Federalde Santa Catarina	Brazil	37	47
6	University of Granada	Spain	62	333	16	Valencia Polytechnic University	Spain	37	431
7	University of Porto	Portugal	62	190	17	University of Zagreb	Croatia	37	59
8	Chinese Academy of Science	China	57	375	18	University of Naples Federico II	Italy	36	369
9	Polytechnic Institute of Bragança	Portugal	52	298	19	University of Valencia	Spain	36	159
10	Universiti Putra Malaysia	Malaysia	50	90	20	State University of Maringá	Brazil	35	107

**R = Rank*; *TP = Total number of publications*

their most recent publication. This visualization helps us understand the output and impact of these authors over time. The figure suggests a surge in most of the authors' productivity since 2007, likely driven by technological advancements, increased research funding, scientific collaboration, an expanding knowledge base, and growing interest in bioactive compounds for their potential applications in medicine, agriculture, and food science.

Prolific Institutions

Between 1989 and 2023, 3,103 research institutions globally contributed to studying 5,859 bioactive compounds, publishing numerous research articles on the subject. The top 20 most productive institutions, highlighted in Table 5, made significant contributions to the field. King Saud University, Saudi Arabia, is leading the list, with an impressive 98 Total Publications (TP). Close behind are the Spanish National Research Council, Spain, and the University of São Paulo, Brazil, each with 76 publications. Despite not leading in publication volume, Valencia Polytechnic University, Spain, garnered the highest citation count, with 648 citations from 37 publications. Following closely is Islamic Azad University, Iran, with 418 citations from 38 publications. These top-performing institutions represent ten countries: five from Spain, four from Brazil, two each from Poland and Portugal, and one each from China, Croatia, Iran, Italy, Malaysia, Saudi Arabia, and Turkey. The dominance of Spanish and Brazilian institutions in bioactive compound research can be attributed to several factors, including government investment in scientific research, world-class research institutes and universities, and solid international collaborative networks. Furthermore, both countries have a rich tradition of natural product research, supported by their diverse ecosystems, which serve as valuable sources for discovering and studying bioactive compounds.[47,48]

Prolific Countries and Most Cited Countries

The top 10 countries that have been very active in publishing research articles on the research area of

bioactive compounds are presented in Table 6. According to the data, Brazil leads in research publications about bioactive compounds, with 2,081 articles making up 35.52% of the total; followed closely behind are China with 1,879 articles (32.07%), Spain with 1,228 articles (20.96%), India with 1062 articles (18.13%) and Italy with 858 articles (14.64%). The main reasons these countries were actively involved in the bioactive compound were their rapidly growing economies, increased funding for scientific research, large populations of scientists and researchers, and strategic initiatives to boost scientific productivity.

Moreover, these countries have been focusing on biotechnology and pharmaceutical research as part of their economic development strategies, leading to a surge in publications and citations on bioactive compounds. Table 6 also highlights the top 10 countries whose articles have been cited the most. Regarding citations (TC), Brazil's research articles have been cited the most worldwide, with a TC of 16,414 citations, followed by Spain with 15,052 citations and China with 13,635 citations. Regarding average article citations (AAC), the USA ranks the highest with an average of 41.90, followed by Portugal with 35.70 and Spain with 32.80. Fig. 4 illustrates the collaboration network among countries engaged in bioactive chemicals research, with the curved lines denoting the interconnections between nations. The thicker lines signify the intensity of collaboration among the countries. A notable quantity and frequency of collaboration have been recorded between researchers from Spain and Portugal in 61 publications, succeeded by substantial cooperation between Saudi Arabia and Egypt in 57 publications and between Spain and Italy in 49 publications, respectively.

Corresponding Author's Country

The corresponding author's country represents the nation affiliated with a publication's lead or corresponding researcher. The countries contributing the most through their top 10 corresponding authors are presented in Table 7. The results reveal that Brazil is at the forefront with 709 publications, of which616 are

Table 6 — Most prolific country and Most cited countries on bioactive compounds research

	Most Prolific Country					Most Cited Countries		
R	Country	Continent	TP	%	R	Country	TC	AAC
1	Brazil	South America	2081	35.52	1	Brazil	16414	23.20
2	China	Asia	1879	32.07	2	Spain	15052	32.80
3	Spain	Europe	1228	20.96	3	China	13635	19.80
4	India	Asia	1062	18.13	4	Italy	7703	23.90
5	Italy	Europe	858	14.64	5	India	7052	17.40
6	Poland	Europe	674	11.50	6	USA	6707	41.90
7	Mexico	South America	598	10.21	7	Portugal	6132	35.70
8	South Korea	Asia	594	10.14	8	Poland	5299	22.20
9	USA	North America	568	9.69	9	South Korea	3722	17.90
10	Turkey	Asia	517	8.82	10	Turkey	3303	16.70

**TP = Total number of publications; TC = Total Citations; AAC = Average Article Citations*

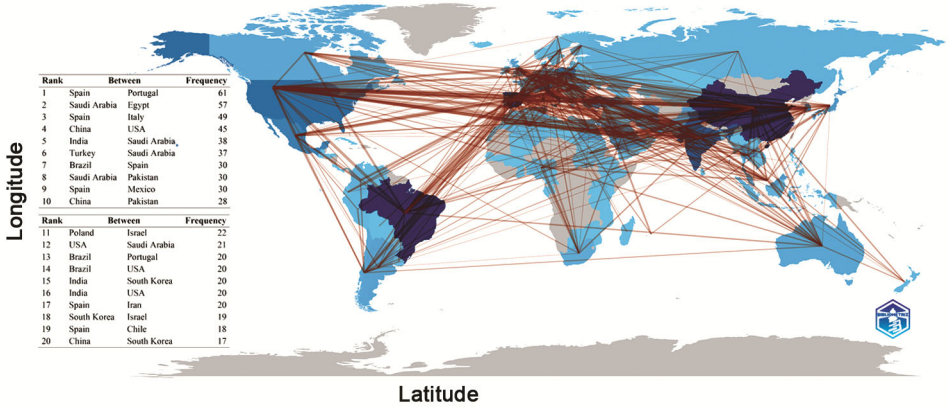

Fig. 4 — Countries scientific collaboration network on bioactive compounds research publications *(Source: Biblioshiny)*

from Single Country Publications (SCP), while 93 are from Multiple Country Publications (MCP), followed by China*(TP = 690; SCP = 559; MCP = 131)*, Spain *(TP = 459; SCP = 315; MCP = 144)*, India *(TP = 406; SCP = 328; MCP = 78)*and Italy*(TP = 322; SCP = 248; MCP = 74)*, respectively. Moreover, Portugal demonstrates a notable trend with high collaborative publications, indicated by an MCP of 40.7%.

This trend is likely influenced by access to international funding and a history of engaging with global research networks. Such collaborative efforts emphasize the importance of cross-border cooperation, enabling researchers to share resources, access diverse funding, and contribute to broader academic knowledge. Understanding these trends helps recognize the varying priorities and strategies across nations in scientific research and also underlines the need to foster collaborations between national and international institutions to drive academic progress globally. SCP stands for research publications published by authors from the same country, whereas MCP stands for research publications that authors from other countries produced.

Most Prolific Journal

Between 1989 and 2023, 5,859 research articles on bioactive compounds were published in 984 scientific journals. The top 20 most productive journals in this field are listed in Table 8. Collectively, these 20 journals have published 1971 articles, which have garnered a total of 54,275 citations. Among these

Table 7 — Corresponding author's country on bioactive compounds

Country	TP	TP%	Single Country Publications (SCP)	Multiple Country Publications (MCP)	MCP %
Brazil	709	12.1	616	93	13.1
China	690	11.8	559	131	19
Spain	459	7.8	315	144	31.4
India	406	6.9	328	78	19.2
Italy	322	5.5	248	74	23
Poland	239	4.1	203	36	15.1
South Korea	208	3.6	154	54	26
Turkey	198	3.4	174	24	12.1
Mexico	187	3.2	148	39	20.9
Portugal	172	2.9	102	70	40.7

**TP = Total number of publications*

Table 8 — Most prolific journals on bioactive compounds

Journal	TP	TC	C/P	h-index	PY-Start	IF
Food Chemistry	254	15206	59.87	67	2006	8.5
Molecules	240	4092	17.05	32	2010	4.2
Foods	164	2416	14.73	25	2016	4.7
LWT-Food Science and Technology	134	4076	30.42	38	2006	6.0
Food Research International	116	5629	48.53	42	2010	7.0
Journal of Food Processing and Preservation	113	1244	11.01	18	2009	2.0
Journal of Food Measurement and Characterization	85	1062	12.49	20	2016	2.9
Journal of Food Science and Technology-Mysore	84	2111	25.13	27	2012	2.6
Industrial Crops and Products	83	2591	31.22	30	2012	5.6
Journal of Agricultural and Food Chemistry	80	4356	54.45	41	2000	5.7
Antioxidants	80	1254	15.68	22	2018	6.0
Journal of the Science of Food and Agriculture	79	2781	35.20	30	2002	3.3
Plants-Basel	75	939	12.52	16	2019	4.0
International Journal of Food Science and Technology	70	1180	16.86	21	2008	2.6
Food Science and Technology	59	764	12.95	16	2013	1.8
Applied Sciences-Basel	58	743	12.81	15	2017	2.5
Food Bioscience	55	839	15.25	15	2015	4.8
Natural Product Research	51	626	12.27	14	2007	1.9
Journal of Supercritical Fluids	46	1169	25.41	23	2007	3.4
Scientia Horticulturae	45	1197	26.60	22	2010	3.9

**TP = Total number of publications; TC = Total citations, C/P = Average citations per publication*; *IF = Impact factor*

Table 9 — Top 20 most representative Author keywords and KeyWords Plus

Authors Keyword	Occurrences	TLS	Keywords Plus	Occurrences	TLS
Bioactive compounds	923	482	Antioxidant activity	1032	1630
Antioxidant activity	704	629	Phenolic-compounds	965	1779
Phenolic compounds	500	476	Quality	494	743
Antioxidant	304	174	Capacity	464	840
Polyphenols	295	279	Polyphenols	451	923
Antioxidant capacity	254	233	Antioxidant	406	375
Antioxidants	240	190	Flavonoids	348	563
Carotenoids	230	334	Extracts	345	512
Flavonoids	215	281	Anthocyanins	332	709
Phenolics	203	267	Acid	328	471
Anthocyanins	187	257	In-vitro	318	427
Fatty acids	115	150	Antioxidant capacity	304	451
Extraction	108	99	Optimization	296	573
Vitamin c	106	139	Chemical-composition	293	489
Antimicrobial activity	103	99	Extraction	288	491
Ascorbic acid	101	152	Identification	282	414
Hplc	100	97	Fruit	267	482
Molecular docking	81	21	Carotenoids	247	436
Cytotoxicity	75	45	Stability	211	362
Tocopherols	70	102	Growth	208	198

**TLS = Total link strengths*

journals, "Food Chemistry" has the highest number of publications with a TP of 254, TC of 15206, and an h-index of 67, which started publications on bioactive compounds research in 2006. However, the journal "Food Chemistry" began its first volume of publications in other research areas and topics since1976. Following closely are "Molecules" with a TP of 240, TC of 4,092, and an h-index of 25, and "Foods" with 164 articles, TC of 2,416, and an h-index of 25. The "Food Research International" journal received the second-highest citations, with a TC of 5,629. In terms of impact factor (IF) for the year 2024, "Food Chemistry" held the highest position with an IF of 8.5, followed by "Food Research International" with 7.0. These journals represent the core of bioactive compound research, influencing developments in food science, chemistry, and technology. Their consistent output and the high citation metrics affirm their vital role in advancing knowledge in the field.

Keywords Analysis

To track the latest trends in research, researchers utilize statistical keyword analysis to measure the progress of the field and how it pushes the boundaries forward.[49,50] This analysis focuses on two types of keywords: Author keywords and KeyWords Plus. Firstly, there are 12,907 author keywords among the data, of which 762 are significant for analysis. A comprehensive overview of the most prevalent author keywords in bioactive compounds research is presented in Table 9 and Fig. 5(a). The study reveals that the top three author keywords— "bioactive compounds," "antioxidant activity," and "phenolic compounds"—are of paramount importance, occurring with frequencies of 923, 704, and 500 times, respectively. This underscores the significant attention and emphasis on these key concepts by researchers and scholars. Moreover, examining emerging research areas within bioactive compounds unveils additional insights. Keywords such as "antioxidants," "polyphenols," and "carotenoids" are observed to be gaining prominence, with frequencies of 304, 295, and 230 times, respectively. These findings highlight the evolving landscape of scientific inquiry as researchers explore these specific compounds' potential health benefits and applications.

Similarly, an in-depth analysis of 9,982 sets of KeyWords Plus in Fig. 5(b) reveals further valuable insights into the prevailing research themes and trends. Among these sets, 1,219 keywords meet the significance threshold, providing additional granularity to our understanding of the research landscape. Notably, "antioxidant activity" emerges as the most prevalent keyword, occurring 1032 times,

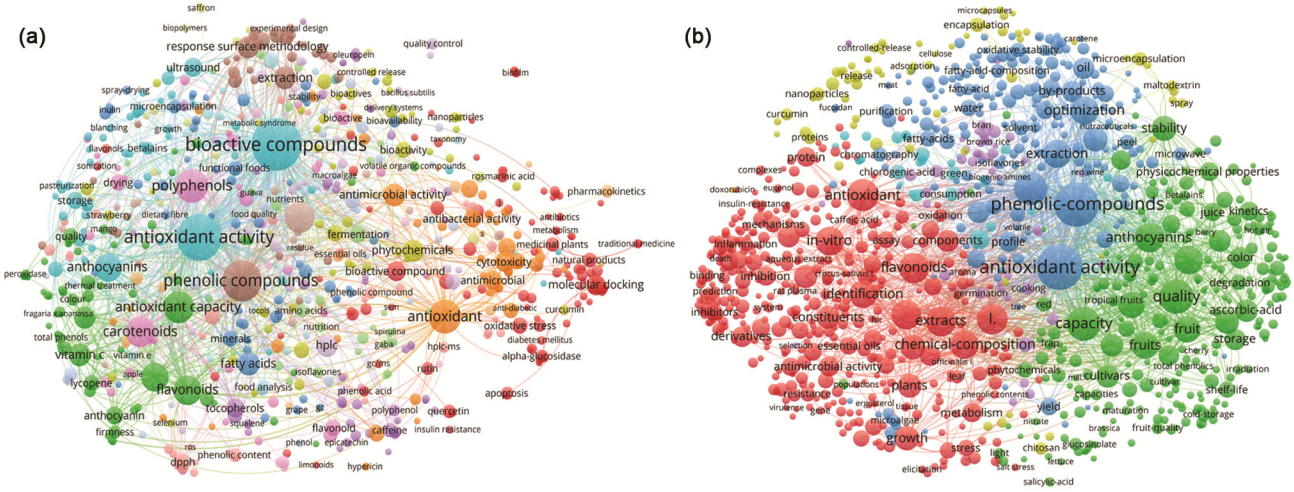

Fig. 5 — (a) Author's keywords, and (b) KeyWords Plusin Bioactive compounds research *(Source: VOSviewer)*

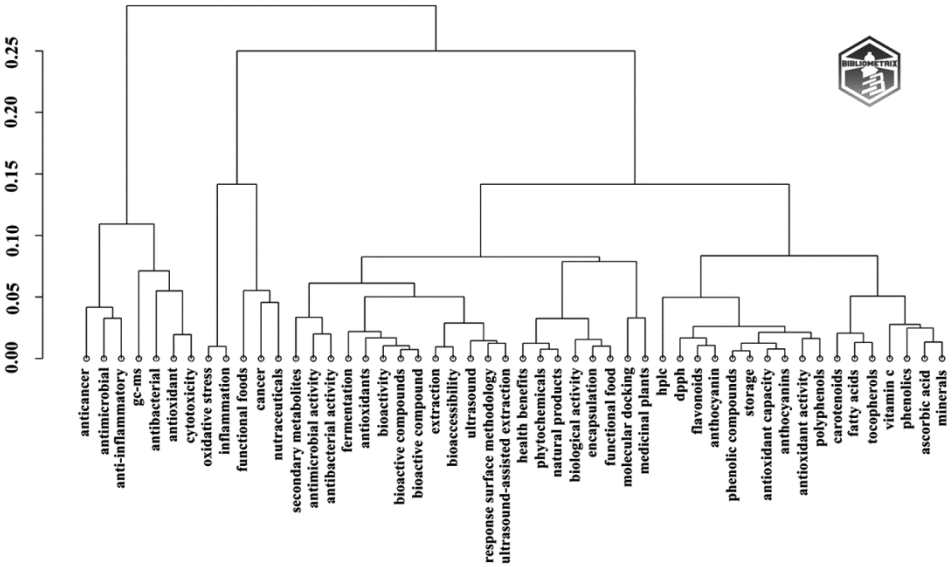

Fig. 6 — Topic dendrogram on bioactive compounds *(Source: Biblioshiny)*

followed closely by "phenolic-compounds" (965) and "quality" (494). This explains the predominant focus on antioxidant properties and phenolic compounds. Overall, this comprehensive analysis sheds light on the prominent themes and topics driving current research in bioactive compounds. These findings offer valuable insights for researchers, policymakers, and industry stakeholders, facilitating informed decision-making and strategic planning in pursuing advancements in this important field of study.

Topic Dendrogram

The dendrogram in Fig. 6 represents a hierarchical clustering of keywords related to bioactive compounds. This dendrogram organizes these keywords into clusters based on their co-occurrence in scientific literature showing how specific research topics within bioactive compounds are closely related. At the core of this figure, we can observe that keywords like "anticancer," "antimicrobial," and "antioxidant" are grouped closely together, suggesting a strong interconnection between these research areas. This indicates that studies on bioactive compounds often explore these themes simultaneously, reflecting their typical application in health-related fields, particularly in combating diseases. Similarly, terms like "secondary metabolites" and "functional foods" form another cluster, highlighting their importance in

nutritional science and bioactive compounds' role in functional foods that provide health benefits beyond essential nutrition.

The dendrogram's vertical axis (scaled from 0.00 to 0.25) represents a measure of distance or dissimilarity between topics—the smaller the distance, the more closely related the topics are. Terms more frequently used together in the literature appear on lower branches of the tree, meaning they are more closely related, while those on higher branches are more distantly connected. For example, "phenolic compounds," "antioxidant capacity," and "flavonoids" appear together, reflecting the central role of phenolics and flavonoids in studies focused on antioxidant properties. This hierarchical arrangement shows how different themes in bioactive compound research are interrelated and provides insight into how specific topics evolve and diverge. The clustering reveals broad trends in the field and more niche areas of study, offering a visual representation of the intellectual structure of bioactive compound research.

Limitations and Future Direction

This study presents several limitations that should be acknowledged. First, the analysis was limited to articles indexed in the Web of Science (WoS) Core Collection database. This selection may have excluded relevant literature from other databases, potentially impacting the comprehensiveness of the findings. Besides, the manual process of reviewing and analyzing these articles proved to be time-consuming and complex. Future research could benefit from utilizing automated methods, such as text-mining techniques, to streamline data extraction and enhance accuracy. A significant challenge in this study was extracting data for citation relationship analysis. The complexities in accurately identifying and mapping citation relationships between articles posed limitations regarding data consistency and reliability. The manual extraction process could introduce biases or omissions, which could affect the quality of the citation network analysis. Employing more advanced computational tools in future studies could improve the precision and scalability of such analyses. Furthermore, the WoS database is continuously updated, meaning that the data used in this research may not reflect the most current citation relationships and emerging trends. While this study offers valuable insights, the evolving nature of the database underscores the need for future work to incorporate updated datasets.

Discussion

This study represents the first comprehensive scientometric analysis of global bioactive compounds research, as far as the author's best knowledge. By examining 5,859 research articles published between 1989 and 2023 and indexed in the Web of Science Core Collection, the study offers significant insights into the growth and focus of this research domain. The data reveals a steady increase in publications, with an average annual growth rate of 14.73%, peaking in 2022 with 799 articles. This growth signals the increasing global attention and investment in the study of bioactive compounds, driven by their importance in the food, health, and pharmaceutical industries. The implications of these findings are particularly relevant for developing regions like the Global South and BRICS countries. Nations such as Brazil, China, and India have emerged as significant contributors to bioactive compounds research, underscoring the growing research capacity and scientific collaboration within these regions. For instance, Brazil's high citation rate reflects its influence in this field, particularly in the context of its biodiversity and natural resources, which are rich sources of bioactive compounds. This trend is crucial for developing nations where bioactive compounds can be harnessed for economic growth, healthcare, and sustainable development.

The involvement of institutions from BRICS countries, notably the University of São Paulo and prominent Chinese universities, also signals these nations' increasing role in shaping the future of bioactive compounds research. Moreover, the prominence of institutions like the University of São Paulo and collaborations with global research networks highlight the importance of building research infrastructure in emerging economies. China's research infrastructure and investment in biotechnology have enabled it to play a crucial role in advancing the global understanding of bioactive compounds, which could serve as a model for other BRICS nations seeking to strengthen their scientific capacity. The findings suggest that countries in the Global South can influence bioactive compounds research to address public health challenges, develop value-added products, and strengthen their position in global scientific discourse. The collaboration between

developed and developing countries, mainly through international co-authorship and journal publications such as *Food Chemistry* and *Molecules*, demonstrates the potential for shared knowledge and resources. This trend not only boosts scientific capacity but also aids in addressing regional challenges such as malnutrition and non-communicable diseases. This study underscores the importance of fostering bioactive compounds research in developing nations, as it has far-reaching implications for health, food security, and economic growth, particularly in regions with rich biodiversity and traditional knowledge systems.

Conclusions

By analyzing research publications on bioactive compounds from 1989 to 2023 using the WoS database, this study sheds light on the growing interest and advancements in this area over the past three decades. The increasing attention from the scientific community is encouraging, yet more focused efforts are needed to explore the diverse applications of bioactive compounds. This analysis is critical for evaluating the current research landscape, identifying gaps, and guiding future efforts. There is a growing emphasis on diversifying the sources of bioactive compounds and improving their synthesis or extraction methods. Countries like Brazil, China, Spain, and India have significantly contributed to the depth and direction of research in this field. The analysis of authors, institutions, and countries involved provides valuable insights into the dynamics of bioactive compound research. However, to ensure the sustainability and effectiveness of this research, more attention and focus are needed. This concerted effort towards expanding our understanding and utilization of bioactive compounds holds promising prospects for enhancing human health and well-being.

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