Original Article

Bibliometric analysis of global rabies research between 1992 -2022

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Abstract
Rabies is a deadly viral infection for which there is still no definitive cure. Many researchers are making publication on this subject. The current study used bibliometric techniques to examine the rabies literature and highlighted current rabies research trends as well as prospective future hotspots for rabies research. In this bibliometric study, all data were retrieved from the Web of Science Science Citation Index-Expanded (SCI-E) database on January 1, 2023, using the selected terms ("rabies virus" [MeSH Terms] OR "rabies virus" [Text Word] OR "rabies" [MeSH Terms] OR "rabies" [Text Word]) in the title field of the search engine. The search was further narrowed by the document type (article), language (English), and year of publication (1992–2022). According to the used search strategy, we reached a total of 5973 articles. The average number of citations per document was 21.3. Over 300 articles per year were published in the years 2020, 2021, 2019, 2018, and 2017. The rabies literature was written by authors from 158 different countries. The main countries with the highest number of articles on rabies were the USA, China, and France. Germany, India, Brazil, England, Japan, and Canada Research collaboration and cooperation between institutions and researchers in developing countries need to be supported by developed countries. The analysis provides information on the overall situation of rabies research worldwide. The analysis also provides a better understanding of the trends in rabies development over the past 30 years, which can serve as a scientific benchmark for subsequent studies.
Keywords: Article, Bibliometric analysis, Rabies, Zoonotic disease

Introduction
Bibliometrics, also known as network analysis, is a relatively new field that emerged as a research front in information science in order to study the development of literature in a field as well as other quantitative aspects of literature (Askar et al., 2021; Onturk et al., 2021; Sachithanantham and Raja, 2015). For many years, the method of network analysis (NA) has been employed in a variety of fields, including the social sciences. Until recently, NA was rarely used in studies of medication use (Askar et al., 2021; Ntürk et al., 2021; Uyar et al., 202). The number of quantitative analyses published on rabies is quite limited (Kabeto et al., 2021; Sachithanantham and Raja, 2015; Takahashi-Omoe and Omoe, 2014).

Rabies is a deadly zoonotic disease that is frequently present throughout the world and affects the central nervous system of all warm-blooded animals. It is brought on by the rabies virus, which is a member of the *Lyssavirus* genus (Lyssa means "madness"), the *Rhabdoviridae* family, and the *Mononegavirales* order. The deadly disease rabies is endemic in developing nations and kills thousands of people every year, with more than 95% of the victims coming from Africa and Asia (Kabeto et al., 2021). The majority of human rabies cases (99%) are caused by infected dogs (often domestic dogs), whose saliva contains the rabies virus that causes the disease. Other wild animals, such as bats, foxes, jackals, mongooses, skunks, and raccoons, cause a small percentage of rabies cases (Ahmad et al., 2021). The development of pre- and post-prophylactic vaccines has reduced the prevalence of rabies worldwide (Briggs DJ, 2012). Despite huge financial investments, rabies is still a serious health issue that goes largely undetected in many nations (Pantha et al., 2020). Since Louis Pasteur and his colleagues developed the first basic nerve tissue vaccines in 1885, rabies vaccines have continuously evolved. Currently, 10 vaccine regimens are recommended by the World Health Organization (WHO) and/or the Advisory Committee on Immunization Practices (ACIP) for pre-exposure and post-exposure prophylaxis in humans. These vaccines are safe and effective for both people and animals. Dog rabies, which accounts for 98% of all human rabies deaths worldwide, must be reduced by the use of rabies vaccines. However, eliminating rabies in the animal species that serve as reservoirs is impossible without an intersectoral strategy involving cooperation between experts in animal and human health (Briggs, 2012). The World Organization for Animal Health (OIE), the Food and Agricultural Organization of the United Nations (FAO), the Global Alliance for Rabies Control (GARC), and the WHO approved a plan in December 2015 to eradicate canine-mediated rabies from humans by the year 2030 (WHO, 2015). The Global Strategic Plan to Finish the Human Deaths from Dog-Mediated Rabies by 2030 has as one of its primary short-term outcomes the development of evidence-based tools and strategies for efficient dog vaccination. Economic analyses show that these canine marionettes should be included in vaccination programs to guarantee the best possible control of rabies in lower-middle-income countries with considerable dog populations (WHO, 2019).

The variability and inconsistent quality of scholarly data may make it difficult for scientists or physicians to review all of the material that is now accessible, despite the fact that many research publications on rabies have been published during the previous few decades. As a result, analyzing the literature on rabies using advanced mathematical methods might offer profound insights into the performance of worldwide research as well as the collaborative architectural structure within the rabies scientific community. The current study used bibliometric techniques to examine the rabies literature and highlighted current rabies research trends as well as prospective future hotspots for rabies research.

Methods
This study is a retrospective bibliometric study.
Sources of Data and Search Strategy
A data pool was established after duplicate articles were eliminated. From the data pool, only the original articles were taken. At the same time, additional analyses of other kinds of publications-including book chapters, meeting abstracts, scientific letters, editorial papers, and corrections were forgone. Unrelated articles were eliminated after manually reviewing the article titles and abstracts.

All data were retrieved from the Web of Science (Wos)' Science Citation Index-Expanded (SCI-E) database (https://webofknowledge.com/) via Çanakkale Onsekiz Mart University Library on January 1, 2023, using the following search terms: ("rabies virus" [MeSH Terms] OR rabies virus [Text Word] OR "rabies"[MeSH Terms] OR rabies [Text Word]) in the title field of search engine. The Wos database is the most popular and commonly used database for the examination of scientific

publications, and it offers comprehensive publishing data. The search was further narrowed by the document type (article), language (English), year of publication (1992-2022), and WoS index (SCI-E).

Data Analysis

Publications were sorted and methodically evaluated by country, journal, year of publication, the field of study, authors, and affiliations. Additionally, a network analysis of the advancement of rabies research was conducted, which involved evaluating the frequency of terms collected from the publications.

For additional evaluation and analysis, the data were transferred into a Microsoft Excel 2019 Sheet. Using the VOSviewer software program version 1.6.18, the network visualization mapping (co-authorship countries, co-occurrence of all keywords, and countries citations) was created (Center for Science and Technology Studies, Leiden University, Netherlands). The number of articles in which two keywords appear together is shown by their co-occurrence. The number of articles with the associated keywords is shown by the size of the circles in the VOSviewer figure. The

strength of the connections between the circles represents how frequently two keywords appear together. The average of the link strengths for the term over all other keywords is the overall link strength.

Results

There were 8430 articles between 1970-2022 in the SCI-E index of the WoS database on rabies according to the search criteria. The first publications were published in the 1970s. Since we only wanted to evaluate the last 30 years in the study, we accepted 1992 as the starting year, and 5973 publications were included in the study. This 5973 publications cited 21.3 per document and produced by 16042 authors. The main features of the articles are summarized in Table 1. Over 300 articles per year were published in the years 2020,2021,2019,2018, and 2017, which are the years with the most publications. Figure 2 shows the distriubition of publications and citations between 1992 -2022. The main features of the top-cited articles on rabies published between 1992 and 2022 are given in Table 2.
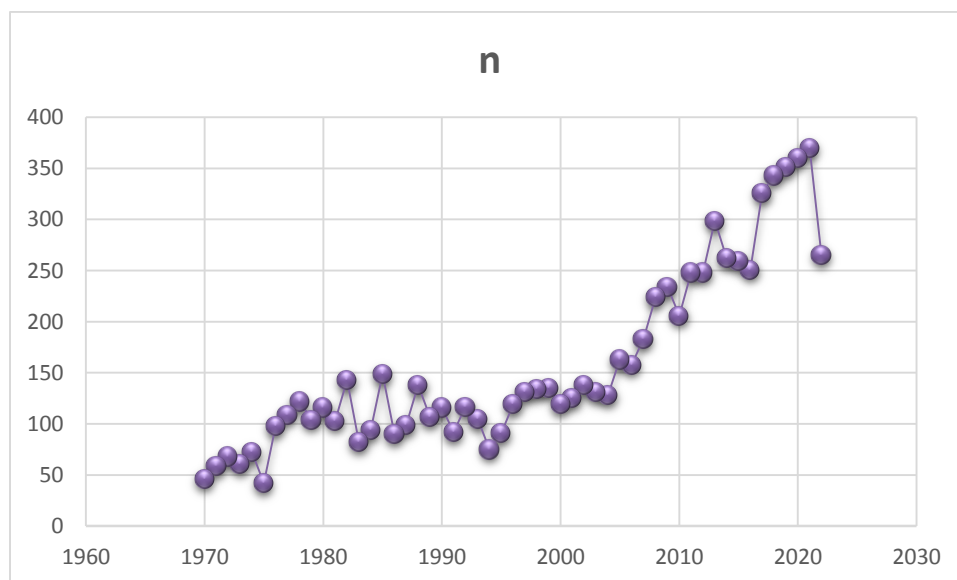

Fig. 1. The documents published since 1970 on rabies.

Table 1. The main features of the articles on rabies were published between 1992 and 2022**.**

Description	Results
H index	126
Total citations	127288
Average citations per document	21.31
Authors	7609
Author Appearances	16042
Authors of single-authored documents	69
Authors of multi-authored documents	7540
Single-authored documents	153
Documents per Author	0.316
Authors per Document	3.16
Co-Authors per Documents	6.66
Collaboration Index	3.34

- H index: Hirsch index.
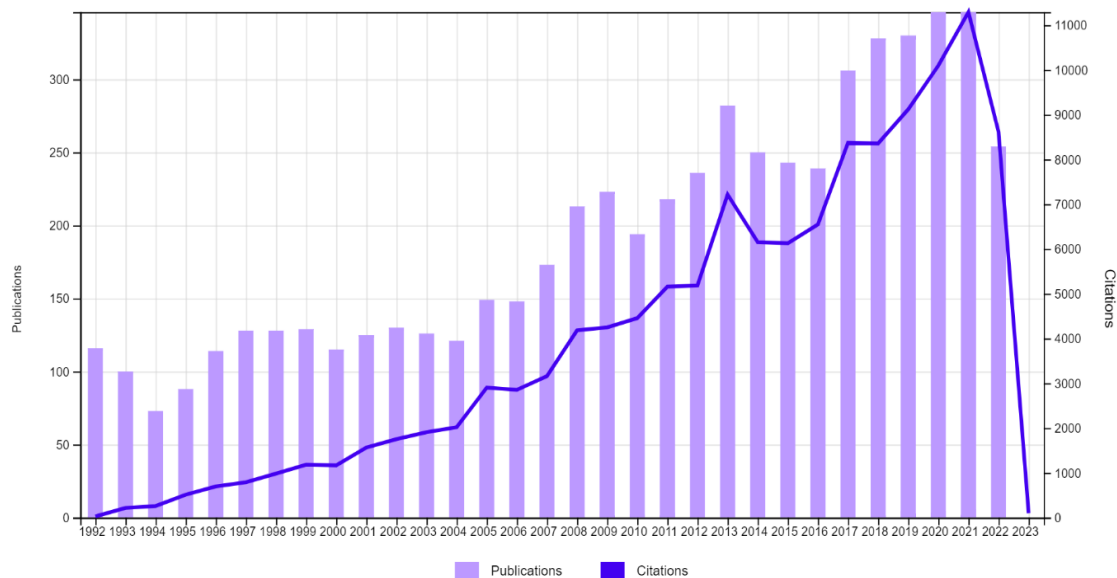
Fig. 2. Annual publications and citations on rabies between 1992 and 2022.

The rabies literature was written by authors from 158 different countries. The top countries with the highest number of articles on rabies were the USA (n = 1609, 26.938%), China (n = 815, 13.645%), France (n = 571, 9.560%), Germany (n = 465, 7.785%), India (n= 440, 7.366%), Brazil (n= 417, 6.981%), England (n= 389, 6.513%), Japan (n = 372, 6.228%), and Canada (n = 303, 5.073%). The global map of the publications is given in Figure 3.

The rabies literature was published by 4886 organizations and institutions. The Pasteur Institute published most of the articles (n = 517). The Centers for Disease Control and Prevention (USA) and Udice-French Research Universities were also mostly publishing under other affiliations (Table 3).

**Table 2.** The main features of the top-cited articles on rabies were published between 1992 and 2022.

Authors	Source Title	Publication Year	DOI	Total Citations	Average per Year
Yoshie et al	NATURE	2004	10.1038/nature03119	1798	89.9
Knobel et al	BULLETIN OF THE WORLD HEALTH ORGANIZATION	2005		862	45.37
Hampson et al	PLOS NEGLECTED TROPICAL DISEASES	2015	10.1371/journal.pntd.0003709	841	93.44
Martinis et al	PHYSICAL REVIEW LETTERS	2002	10.1103/PhysRevLett.89.117901	831	37.77
Brune et al	PHYSICAL REVIEW LETTERS	1996	10.1103/PhysRevLett.76.1800	804	28.71
Stievater et al	PHYSICAL REVIEW LETTERS	2001	10.1103/PhysRevLett.87.133603	584	25.39
Braak	PHYSICAL REVIEW LETTERS	2011	10.1103/PhysRevLett.107.100401	534	41.08
Schnell et al	EMBO JOURNAL	1994	10.1002/j.1460-2075.1994.tb06739.x	508	16.93
WHO	WHO EXPERT CONSULTATION ON RABIES	2005		472	24.84
Wickersham et al	NATURE METHODS	2007	10.1038/NMETH999	433	25.47
Kamada et al	PHYSICAL REVIEW LETTERS	2001	10.1103/PhysRevLett.87.246401	430	18.7
Ahmed et al	JOURNAL OF MATHEMATICAL ANALYSIS AND APPLICATIONS	2007	10.1016/j.jmaa.2006.01.087	426	25.06
Schlather et al	NANO LETTERS	2013	10.1021/nl4014887	398	36.18
Xiang, et al	VIROLOGY	1994	10.1006/viro.1994.1105	353	11.77
Willoughby et al	NEW ENGLAND JOURNAL OF MEDICINE	2005	10.1056/NEJMoa050382	351	18.47
Mazarakis et al	HUMAN MOLECULAR GENETICS	2001	10.1093/hmg/10.19.2109	332	14.43
Vijay et al	NATURE	2012	10.1038/nature11505	330	27.5
Boca et al	PHYSICAL REVIEW LETTERS	2004	10.1103/PhysRevLett.93.233603	321	16.05
Vasa et al	NATURE PHOTONICS	2013	10.1038/NPHOTON.2012.340	319	29
Cliquet et al	JOURNAL OF IMMUNOLOGICAL METHODS	1998	10.1016/S0022-1759(97)00212-3	319	12.27
Alberer et al	LANCET	2017	10.1016/S0140-6736(17)31665-3	317	45.29
Hampson et al	PLOS BIOLOGY	2009	10.1371/journal.pbio.1000053	309	20.6
Santhosh et al	NATURE COMMUNICATIONS	2016	10.1038/ncomms11823	308	38.5
Streicker et al	SCIENCE	2010	10.1126/science.1188836	305	21.79
Zibold et al	PHYSICAL REVIEW LETTERS	2010	10.1103/PhysRevLett.105.204101	283	20.21

The analysis of funding sources revealed that the top 10 funders are from China, the USA, European countries, and Japan (Table 4). There were 118 countries with a minimum of five articles among 186 publishing countries. The co-authorship analysis between 118 countries is given in Figure 4. There were 7226 keywords, with 451 appearing more than five times. The majority of the keywords are summarized in Table 5. There were 16 clusters and 4473 links, and the total link strength was 10737. Figure 5 depicts the keyword analysis of the articles on rabies. The keywords most frequently used were "rabies" (859 times), "rabies virus" (250 times), and "vaccination" (113 times) (Table 5).

There were 7 clusters and 3596 links, and the total link strength was 82732. Figure 6 depicts the citation analysis between countries. The "*Vaccine*" journal was the leading journal on rabies research (n = 316, 5.290%), followed by "Physical Review A" (n = 219, 3.666%) and "PLOS Neglected Tropical Diseases" (n = 202, 3.382%) journals.
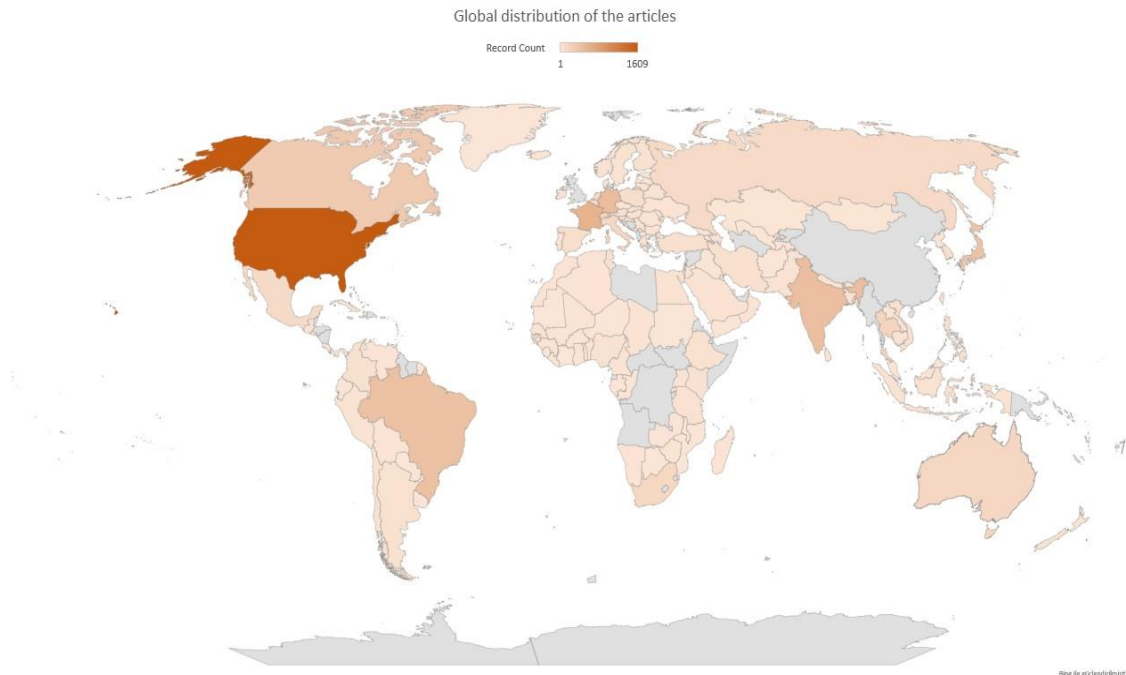
Fig. 3. Global distribution map of publications.

Table 3. Top organizations and institutions were conducting rabies research between 1992 and 2022.

Organizations/institutes	Number	%
The Pasteur Institute	517	8.656
Centers for Disease Control and Prevention (CDC)	446	7.467
Udice - French Research Universities	191	3.198
The National Center for Scientific Research	177	2.963
Thomas Jefferson University	155	2.595
WHO	145	2.428
The United States Department of Agriculture	130	2.176
The University System of Georgia	118	1.976
The University of Pretoria	110	1.842
The University of São Paulo	109	1.825
The University of Georgia	109	1.825
Chinese Academy of Sciences	103	1.724

* *WHO: World Health Organization*

Table 4. Top 10 funding agencies on rabies research between 1992 -2022.

Funding Agencies	Number	%
National Natural Science Foundation of China	457	7.651
United States Department of Health & Human Services	330	5.525
National Institutes of Health USA	297	4.972
European Commission	194	3.248
Nih National Institute of Allergy Infectious Diseases	186	3.114
Ministry of Education Culture Sports Science And Technology Japan	126	2.109
National Science Foundation	112	1.875
Wellcome Trust	100	1.674
The United Kingdom Research Innovation	99	1.657
Japan Society for the Promotion of Science	94	1.574

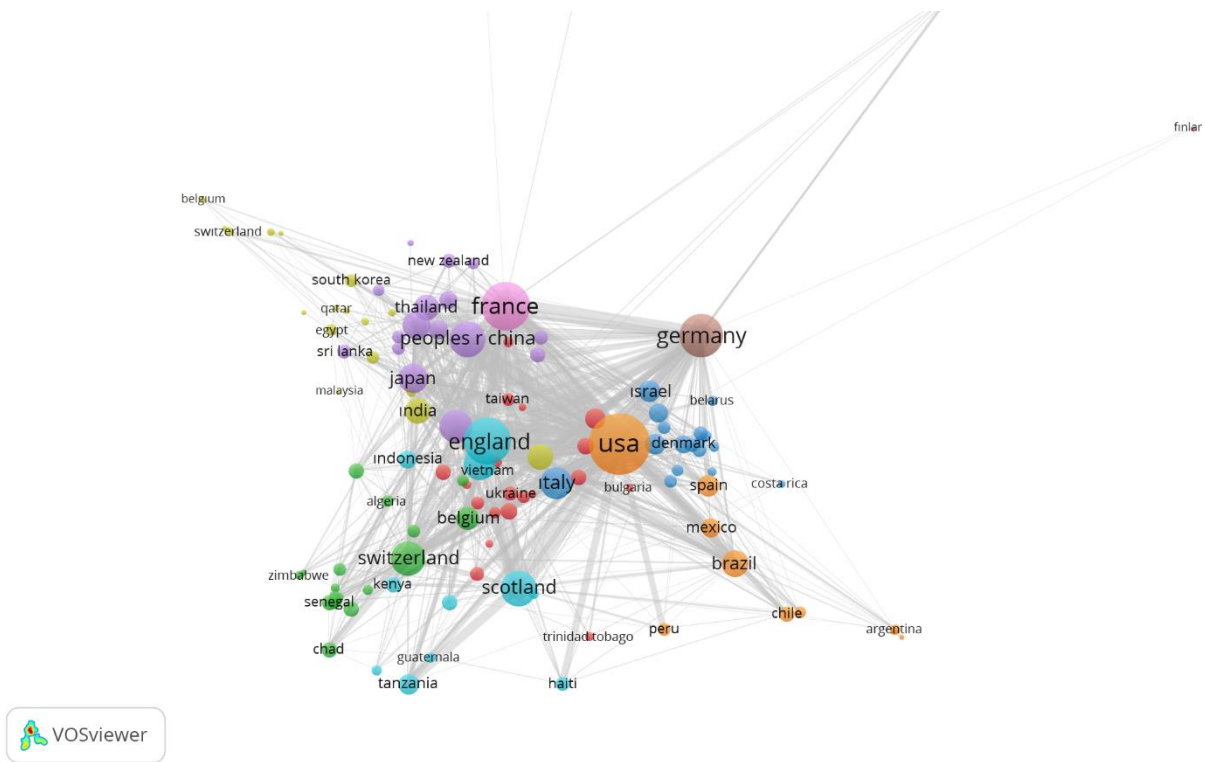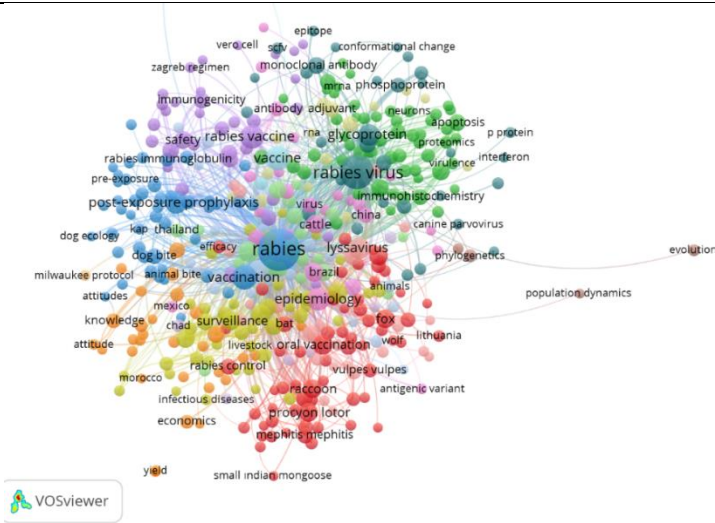*10 out of 2867 funding agencies; 3175 record(s) (53.156%) do not include data.

Fig. 4. The co-authorship analysis between 118 countries.

Fig. 5. Keyword analysis

Table 5. Mostly occurred keywords

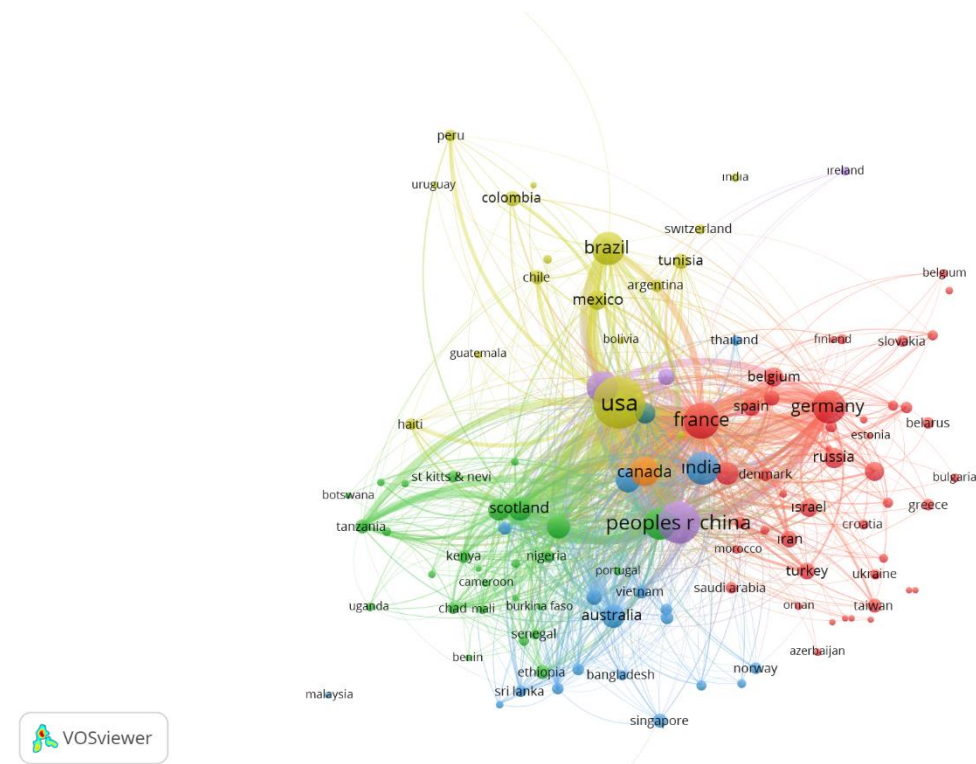| Keywords	Frequency
Rabies	859
Rabies virus	250
Vaccination	113
Post-exposure prophylaxis	111
Vaccine	105
Rabies vaccine	98
Epidemiology	83
İmmunogenicity	51
Dog	50
Zoonosis	47

Fig. 6. The citation analysis between countries.

Table 6. The top 25 journals that publish the most rabies literature between 1992- 2022.

Journals	Number	%
VACCINE	316	5.290
PHYSICAL REVIEW A	219	3.666
PLOS NEGLECTED TROPICAL DISEASES	202	3.382
JOURNAL OF VIROLOGY	142	2.377
JOURNAL OF WILDLIFE DISEASES	140	2.344
PHYSICAL REVIEW B	113	1.892
PHYSICAL REVIEW LETTERS	99	1.657
VIRUS RESEARCH	98	1.641
PLOS ONE	86	1.440
ARCHIVES OF VIROLOGY	84	1.406
JOURNAL OF VIROLOGICAL METHODS	77	1.289
ZOONOSES AND PUBLIC HEALTH	74	1.239
EMERGING INFECTIOUS DISEASES	71	1.189
PREVENTIVE VETERINARY MEDICINE	64	1.071
EPIDEMIOLOGY AND INFECTION	63	1.055
VIRUSES BASEL	63	1.055
JOURNAL OF GENERAL VIROLOGY	61	1.021
JOURNAL OF PHYSICS A MATHEMATICAL AND THEORETICAL	60	1.005
SCIENTIFIC REPORTS	53	0.887
MICROBIOLOGY AND IMMUNOLOGY	51	0.854
REVUE SCIENTIFIQUE ET TECHNIQUE OFFICE INTERNATIONAL DES EPIZOOTIES	49	0.820
JAVMA JOURNAL OF THE AMERICAN VETERINARY MEDICAL ASSOCIATION	48	0.804
JOURNAL OF THE AMERICAN VETERINARY MEDICAL ASSOCIATION	47	0.787
HUMAN VACCINES IMMUNOTHERAPEUTICS	45	0.753
ONDERSTEPOORT JOURNAL OF VETERINARY RESEARCH	45	0.753

Showing 25 out of 1.013 entries

Discussion

It has been stated that bibliometrics and visualization are crucial tools for assessing scientific research and are the crucial means to identify infectious disease epidemics (Ogunsakin et al., 2022). This comment is accurate given the current state of affairs, in which healthcare professionals are exchanging large volumes of information (Ogunsakin et al., 2022). Similar to this, bibliometrics is typically employed in a variety of disciplines to evaluate scientific research both statistically and qualitatively (Alkan and Evlice, 2022; Ekici et al., 2022; Ogunsakin et al., 2022). Our study used bibliometrics and visualization techniques to assess rabies-related publications and citations, countries, and authors' influence. To the best of our knowledge, this is the second bibliometric study on rabies research after the previous study (Sachithanantham and Raja,

2015), in which 5973 published articles were accessed and analyzed.

Most cases of rabies are found in Asia and Africa. It has been reported that 99% of all human rabies cases are caused by dogs, which are the main source of transmission of rabies. Both in dogs and humans, rabies is a disease that is preventable by vaccination (Ahmad et al., 2021; Kabeto et al., 2021). One of the key short-term outcomes of the Global Strategic Plan to End Human Deaths from Canine Rabies by 2030 is to ensure the development of effective and evidence-based strategies for canine vaccination. In low- and middle-income countries with large dog populations, dog vaccination campaigns are recommended to ensure the best possible control of rabies. However, this population segment is divided regarding the most effective evidence-based vaccination strategies (Anderson et al., 2019;

Arega et al., 2020). However, one of the major vaccination challenges in low- and middle-income countries, where this disease is prevalent, is the withdrawal of exposed individuals in the middle of the vaccination schedule; as a result, they continue to be at high risk of contracting the rabies virus (Ashwath et al., 2014). The research presented here is the first bibliometric analysis of rabies to identify recent trends in research and publication between 1992 and 2022. A critical assessment of funding requests and potential research trends may be beneficial for the academic community, governmental agencies, researchers, policymakers, and donors. According to our results, the top countries with the highest number of articles on rabies were the USA and other developed countries. This might be the case as a result of increased financing for research and the sensitivity of a government's issue. While year-by-year publication trends have been inconsistent over the past three decades, the years with the most publications were 2020, 2021, 2019, 2018, and 2017. In addition, although the number of publications is irregular, both the number of publications and citations have been on an increasing trend, especially in the last 10 years. Also, the funding sources clearly indicate that the top 10 funding agencies were from China, the USA, European countries, and Japan. It can be due to the sensitive nature of the topic in global or financing accessibility in the research field to further the work leading to publications. There were very few publications and funding sponsorships from developing countries other than India and other countries where the disease is endemic. African countries did not appear in the top-productive countries where the disease is endemic.

The Pasteur Institute, one of the institutions dedicated to eradicating rabies, published 8.656% of all publications, followed by the Centers for Disease Control and Prevention (CDC), which provided 7.467% of the total. This can be because corporations and institutions are concentrating on and giving particular research issues top importance. As rabies is a global public health issue that is highly valued by both the WHO and the CDC, these organizations have also published a significant number of papers on rabies.

In addition, the analysis of the journals with the highest number of publications on rabies can be a reference for those working on this subject in the selection of journals. The most cited articles can also provide ideas to the researchers of this subject in their studies.

The VOSViewer software is used to build a bibliometric map of the associations between countries based on co-authorship (Figure 4, Figure 6). The leading authors are from the United States (n=1609, 26.938%), China (n=815, 13.645%), France (n=571, 9.560%), Germany (n=465,7.785%), India (n=440,7.366%), Brazil (n=417,6.981%), England (n=389, 6.513%), Japan (n=372, 6.228%), and Canada (n=303, 5.073%). The minimum and maximum number of documents per nation are specified at five and twenty-five, respectively. We used "authors" as the unit of analysis for analyzing bibliographic coupling, which refers to how likely it is for authors to cite other works that are comparable to their own. The number of authors who met the threshold was 7609 after one was selected as the minimum number of documents for each author. When "countries" were used as the unit of analysis for citation analysis, 118 countries met the criteria of having at least five documents from one country. Additionally, the Vosviewer map's display of the clusters with related research interests demonstrated the rabies research. The USA, England, Germany, France, and other European nations make up the biggest node. The co-occurrence analysis of "author keywords" showed that of the 7226 keywords, 451 appeared more than five times. The keywords most frequently used were "rabies" (859 times), "rabies virus" (250 times), and "vaccination" (113 times).

Limitations

This study has several limitations, including the following: only two search terms were used, and

the documents were refined by year, document type, and language based on studies that were not included in the final analysis. The data were retrieved from a single database (the WoS database) and the SCIE index. Additionally, only articles were examined. Additionally, despite their rarity, publications in other languages that might be helpful in addressing this topic were undervalued in this research. However, despite these limitations, this study is a welcome contribution to the literature as the incidence of zoonoses, including rabies, is increasing as a result of changing climatic conditions and greater interference with natural ecosystems, and humans are in more direct contact with animals. It is also important because it reflects the last 30 years of rabies studies and emphasizes the need to support studies in low-income countries and countries where rabies cases are endemic.

Conclusions

This study may benefit academics, researchers, and clinicians by offering pertinent bibliographic data that will be important for predicting future research trends. Research collaboration and cooperation between institutions and researchers in developing countries need to be strengthened with developed countries. The highest number of studies was produced in the USA, China, France, Germany, India, Brazil, England, Japan, and Canada. The studies from highly endemic countries were limited.

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Ethics approval

Not applicable.

Conflict of interest statement

The authors declare no conflicts of interest.

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