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A bibliometric analysis of brucellosis research (1991–2022): Research trends and hotspots

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Abstract

Brucellosis is an important, highly contagious, bacterial zoonotic disease that has economic and public health implications. It is caused by various *Brucella* species with a wide host range including livestock, wildlife, other terrestrial animals, and humans. Despite the availability of a huge number of publications on brucellosis, no comprehensive bibliometric analysis discussing research trends has been published. Bibliometric studies are important tools to highlight research trends and outputs of the relevant discipline. The current study aimed to highlight the research trends of published brucellosis data (9,022 articles published 1991–2022) from the Web of Science Core Collection database. The relevant data were obtained for the keywords "*Brucella*", "brucellae", and "brucellosis" and highlight the most research-active countries, institutions, authors, publications, journals, and disciplines. The articles focusing on brucellosis were predominantly published in journals categorized under veterinary sciences, followed by microbiology and infectious diseases. The United States emerged as the leading contributor to brucellosis research articles. The University of Navarra, Spain, and the French National Institute for Agricultural Research (INRA) stood out as the most prolific institutions in this field. The word cluster analysis indicated emerging brucellosis research areas including the development of diagnostic assays, host range (humans, cattle, small ruminants, rodents), and *Brucella* species (*B. abortus, B. melitensis, B. suis* and *B. ovis*). This review indicates the research landscape and future hotspots in brucellosis research that will promote sharing of knowledge and initiate collaborative research under the umbrella of "One Health".

Keywords: research trends, brucellosis, Brucellae, *Brucella,* zoonosis, bibliometric, citation analysis, Web of Science
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Introduction

Brucellosis is a bacterial zoonosis that causes severe economic losses to the livestock industry. It also poses serious public health risks to humans globally. Brucellosis is caused by gram-negative facultative and intracellular bacterium of the genus *Brucella,* which is classified as a category B

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pathogen with bioterrorism potential, as declared by the National Institute of Allergy and Infectious Diseases (NIAID) and the Centre for Disease Control and Prevention (CDC) (Pappas *et al*., 2006a; Doganay & Doganay, 2013; Cetaruk and Ciccone, 2016). Many developed countries have effectively controlled brucellosis in domestic animals, but sporadic cases are being reported in wildlife. However, brucellosis is still endemic in developing countries, particularly in the Middle East and central Asian and African countries (Boschiroli *et al*., 2001).

The genus, *Brucella*, consists of 12 recognised species with six so-called “classical” species, *B. melitensis* (sheep and goats)*, B*. *ovis* (rams), *B. abortus* (bovines), *B. canis* (canines), *B. suis* (pigs), and *B. neotomae* (rodents). Later, *B. microti* and *B. vulpis* were isolated from terrestrial wildlife, *B. ceti* and *B. pinnipedialis* from marine mammals, *B. papionis* from primates, and *B. inopinata* from human breast implants. Brucellae are causing cross-infections in other hosts, especially those in contact with hosts e.g., cohabitation of farm animals. In livestock, brucellosis causes huge economic losses due to reproductive problems e.g., orchitis, stillbirth, weak offspring, repeat breading, infertility or abortion, mastitis, and lameness. Control measures include vaccination, testing, and culling of positive animals (Singh *et al*., 2015). Brucellosis may spread horizontally via reproductive tract discharges and milk from chronically-infected livestock (Nikokar *et al*., 2011) and vertically to newborn calves (Kato *et al*., 2007). Mechanical dissemination may be possible by the consumption or feeding of undisposed placental and foetal material by domestic (dogs and cats) and wild carnivores (Coelho *et al*., 2015; Wareth *et al*., 2017).

Brucellosis also poses a severe public health concern that causes acute febrile illness in humans as a result of *B. melitensis*, *B. abortus,* and *B. suis* (Godfroid, 2017). It is transmitted by direct or indirect contact with infected animal discharges, birth products, and consuming contaminated, unpasteurized dairy products (Palanduz *et al*., 2000). Brucellosis transmission among humans is a rare event but has been reported via sexual intercourse, breastfeeding to infants, bone marrow transplant, and blood transfusion (Lubani *et al*., 1988; Palanduz *et al*., 2000; Arroyo-Carrera *et al*., 2006). In humans, the clinical outcomes are diverse, raising serious concerns among clinicians and scientists regarding both disease pathogenesis and diagnosis. The clinical picture may include intermittent fever, sweating, insomnia, arthritis, infertility, nervous system disorders, and abortion (Megid *et al*., 2010; Saddique *et al*., 2019; Jamil *et al*., 2021).

Usually, brucellosis is diagnosed using serological assays, such as the Rose Bengal plate test (RBPT) and enzyme-linked immunosorbent assay (ELISA) but these assays require the provision of specific equipment that could be challenging in field conditions (El-Diasty *et al*., 2018; Khan *et al*., 2020a). Isolation of brucellae from clinical samples and detection of *Brucella* DNA using molecular assays such as polymerase chain reaction (PCR) is the method of choice for a definitive diagnosis (Khan *et al*., 2019a). Culture is laborious, time consuming, and poses serious health hazards to laboratory personnel (Khan *et al*., 2019b; Khan *et al*., 2020b; Khan *et al*., 2021). In animals, the control of brucellosis is possible through vaccination, then testing and culling of infected animals. There are no vaccines available for human use but the disease is treated using various antimicrobials alone or in combination, such as rifampicin, doxycycline, aminoglycosides, streptomycin, and quinolones for three to four weeks (Ariza *et al*., 2007; Khan *et al*., 2019b).

This bibliometric analysis analysed a total of 10 204 publications associated with brucellosis. The data were harvested from the Science Citation Index Expanded database of the Web of Sciences, the most acknowledged database in bibliometrics. The retrieved data were analysed for country, institution (laboratory), scientific journals, most cited articles, and most productive authors. Based on current analysis, the scientific trends and research hotspots in brucellosis research were identified and described.

Materials and Methods

In this study, data were geared using the Clarivate Analytics Web of Science Core Collection (WSCC), through the online edition of the Science Citation Index Expanded (SCI-EXPANDED) (data updated on 3 August, 2023). The system in question catalogues 9 510 academic journals, encompassing citation references spanning 178 categories within SCI-EXPANDED on the Web of Science platform. The journal's impact factor (IF2022) in the Journal Citation Reports (JCR) was reported on June 28, 2023, and documents published in the year 2022 were sourced from SCI-EXPANDED. *Keywords Plus* is a unique feature in the WSCC, providing additional search terminologies obtained from the article titles cited by authors in their bibliographies and footnotes in the Institute of

Science Information (ISI) (now Clarivate Analytics) database, and substantially augments title word and author keyword indexing (Garfield, 1990). Some articles are irrelevant to the search topic and only rely on *Keyword Plus* (Fu and Ho, 2015). The 'front page' was used as a filter and included the article title, author keywords, and abstract (Wang and Ho, 2011). The "Front page" as a filter in bibliometric research topics published in journals listed in WSCC creates a large difference in bibliometric search (Farooq *et al*., 2022). This can be avoided by using other unrelated publications for bibliometric analysis.

Quotation marks (" ") and the Boolean operator "or" were used, which ensured the appearance of at least one search keyword in the terms of TI (title), AB (abstract), and AK (author keywords) as 'front page' from 1991–2022 (Giannoudis *et al*., 2021). The search keywords were: "*Brucella*", "Brucellae", and "Brucellosis". It is recommended that 'front page': TI, AB, and AK be used as a filter in a bibliometric studies using the Web of Science core Collection when search keywords are single words but not phrases. A total of 10 971 documents were found, including 10 942 documents (99.7% of 10 971 documents) published in SCI-EXPANDED from 1991–2022. This procedure resulted in 10 971 documents, including 9 022 articles with the search keywords on their 'front page' from 1991–2022. The full record in SCI-EXPANDED and the number of citations in each year for each document were checked and downloaded into Excel Microsoft 365 and additional coding was manually performed (Li and Ho, 2008). Functions of Excel Microsoft 365, for example, Count, Concatenate, Filter, Match, look-up, Proper, Rank, Replace, Freeze Panes, Sort, Sum, and Len were applied. The journal impact factors (IF_{2022}) were taken from the Journal Citation Reports (JCR) published in 2022.

The corresponding author in the SCI-EXPANDED database was considered a reprint author but we used the term "corresponding author" in this study as well and the articles containing single authors were considered as both the first and corresponding author simultaneously (Ho, 2012). All corresponding authors, institutes, and countries were considered in multi-corresponding author articles. Articles with corresponding authors in SCI-EXPANDED that had only addresses but no affiliation names were checked out and the addresses were changed to be affiliation names, for example, 19 Rue Rougemont, F-37380 Crotelles, France was changed to Animal Infectiology & Public Health, F-37380 Nouzilly, France; 108-32 Sk 22 D 11 Adnan Suvari Mahalesi Esenyali, Izmir, Turkey was changed to Dr. Behcet Uz Children's Hospital, Department of Infectious Diseases, Izmir, Turkey; and 1 Hollyshaw Terrace, Leeds LS15 7BG, W Yorkshire, England was changed to be University of Leeds, Sch Philosophy, Leeds LS2 9HD, W Yorkshire, UK. The geographic location of the countries was determined as described elsewhere (Usman and Ho, 2020).

Publications were assessed using the following citation indicators:

C_{year}: the number of citations from Web of Science Core Collection in a year (e.g., C_{2022} describes citation count in 2022) (Ho, 2012).

TC_{year}: the total citations from Web of Science Core Collection received from publication year till the end of 2022 (TC_{2022}) (Wang *et al*., 2011; Wang and Ho, 2011).

CPP_{year}: average number of citations per publication ($CPP_{2022} = TC_{2022}/TP$), *TP*: total number of publications (Ho, 2013).

Six publication indicators were applied to evaluate the publication performance of countries and institutions (Hsu and Ho, 2014):

TP: total number of articles

IP: number of single country articles (IP_C) or single institution articles (IP_I)

CP: number of international articles (CP_C) or inter-institutional collaborative articles (CP_I)

FP: number of first author articles

RP: number of corresponding author articles

SP: number of single author articles

Six citation indicators related to the six publication indicators (CPP_{2022}) were also applied to evaluate the publication's impact on countries and institutes (Ho and Mukul, 2021).

TP-CPP_{2022}: average number of citations per publication (TC_{2022}/TP)

IP-CPP_{2022}: the total TC_{2022} of all single country articles per the number of single-country articles (TC_{2022}/IP_C) or the total TC_{2022} of all single institution's articles per the number of single institutions articles (TC_{2022}/IP_I)

CP-CPP$_{2022}$: the total *TC*$_{2022}$ of all internationally collaborative articles per the number of internationally collaborative articles (*TC*$_{2022}$/*CP*$_{C}$) or the total *TC*$_{2022}$ of all inter-institutional collaborative articles per the number of inter-institutional collaborative articles (*TC*$_{2022}$/*CP*$_{I}$)

FP-CPP$_{2022}$: the total *TC*$_{2022}$ of all first author per the number of first author articles (*TC*$_{2022}$/*FP*)

RP-CPP$_{2022}$: the total *TC*$_{2022}$ of all corresponding-author articles per the number of corresponding-author articles (*TC*$_{2022}$/*RP*)

SP-CPP$_{2022}$: the total *TC*$_{2022}$ of all single-author articles per the number of single author articles (*TC*$_{2022}$/*SP*)

The *Y*-index was used to evaluate the publication performance of authors. The *Y*-index is defined as (Ho, 2012; Hsu & Ho, 2014) *Y*-index (*j*, *h*) where *j* is a constant related to the publication potential, the sum of the first author articles, and the corresponding author articles; and *h* is a constant related to the publication characteristics, polar angle of the proportion of *RP* to *FP*. The greater the value of *j*, the more the first and corresponding author contributes to the articles.

h = π/2, indicates an author that has only published corresponding-author articles, *j* is the number of corresponding author articles; π/2 > *h* > π/4 indicates that an author has more corresponding author articles than first author articles (*FP* > 0); *h* = π/4 indicates that an author has the same number of first and corresponding author articles (*FP* > 0 and *RP* > 0); π/4 < *h* < 0 indicates an author with more first author articles than corresponding author articles (*RP* > 0); *h* = 0, indicates that an author has only published first author articles; *j* is the number of first author articles.

Results and Discussion

In recent years, Ho's group identified the characteristics of document types based on the average number of citations per publication (*CPP*$_{year}$ = *TC*$_{year}$/*TP*) and the average number of authors per publication (*APP* = *AU*/*TP*) as basic information for document types in a research topic (Nájera & Ho, 2017). Using *TC*$_{2022}$ and *CPP*$_{2022}$ is advantageous owing to their invariability and ensured repeatability when compared to the number of citations from the Web of Science Core Collection directly (Ho & Hartley, 2016). A total of 10 942 brucellosis publications in SCI-EXPANDED were found for 16 article types (Table 1). This includes 9 022 articles (82% of 10 942 documents) with an *APP* (average number of authors per publication) of 6.1. The *APP* of brucellosis articles (6.1) was slightly higher than for other medical related topics, for example 6.0 for Q fever (Farooq *et al*., 2022), 5.6 for insomnia (Jallow *et al*., 2020), 5.2 for breast reconstruction (Li *et al*., 2020), 5.0 for keloid (Chong *et al*., 2021), and 4.7 for non-union fractures (Giannoudis *et al*., 2021).

The document type "review" with 611 documents had the greatest *CPP*$_{2022}$ value of 48. The *CPP*$_{2022}$ of the document type "review" was found to be 2.4 times higher than that of medical-related topics, for example, keloid (2.0 times) (Chong *et al*., 2021), insomnia (1.4 times) (Jallow *et al*., 2020), non-union fracture (1.3 times) (Giannoudis *et al*., 2021), and breast reconstruction (0.86 times) (Li *et al*., 2020). However, a higher ratio of citations of reviews and articles can be found in Q fever, i.e., 2.7 times (Farooq *et al*., 2022). In brucellosis research, reviews entitled "The new global map of human brucellosis" (Pappas *et al*., 2006b) and "Legionella and Legionnaires' disease: 25 years of investigation" (Fields *et al*., 2002) were the only classic documents with a *TC*$_{2022}$ of 1,000 or more (Long *et al*., 2014) with a *TC*$_{2022}$ of 1,300 and 1,147, respectively. Publications can be categorized in two types in WSCC, 178 proceedings, papers, and two book chapters were also classified as document type "article". Therefore, cumulative percentages exceed 100% in Table 1 (Usman & Ho, 2020).

A total of 9 022 brucellosis-related articles were published in 16 languages. The most often used language was English with 8 500 articles (94% of 9 022 articles), followed with great distance by Spanish (140 articles), French (94), Portuguese (89), German (75), Turkish (63), Russian (20), and Hungarian (15). Some other languages that were less often used were Italian (8), Polish (7), Chinese (5), Dutch (2), and one article each for Catalan, Korean, Serbo-Croatian, and Slovak languages, respectively. Non-English articles had less citations with a *CPP*$_{2022}$ of 5.3, whereas English articles had a *CPP*$_{2022}$ of 21. Non-English articles had an *APP* of 4.9, whereas English articles had an *APP* of 6.2.

Table 1. Citations and authors according to the document type

Document Type	*TP*	%	*TP**	*AU*	*APP*	TC_{2022}	CPP_{2022}
Article	9,022	82	9,015	54,930	6.1	179,781	20
Review	611	5.6	611	2,693	4.4	29,550	48
Meeting abstract	479	4.4	474	2,262	4.8	96	0.20
Letter	370	3.4	370	1,523	4.1	2518	6.8
Editorial material	204	1.9	195	644	3.3	1578	7.7
Proceedings paper	178	1.6	178	814	4.6	4,940	28
Note	125	1.1	125	460	3.7	3,275	26
Correction	57	0.52	57	375	6.6	29	0.51
News item	56	0.51	9	10	1.1	26	0.46
Book chapter	10	0.091	10	32	3.2	342	34
Addition correction	8	0.073	8	17	2.1	14	1.8
Reprint	5	0.046	4	14	3.5	2	0.40
Retraction	2	0.018	2	4	2.0	0	0
Biographical-item	1	0.0091	1	2	2.0	12	12
Item about an individual	1	0.0091	1	1	1.0	2	2.0
Discussion	1	0.0091	1	4	4.0	0	0

TP: total number of brucellosis publications; *TP**: total number of publications with author information in SCI-EXPANDED; *AU*: number of authors; *APP*: average number of authors per publication; TC_{2022}: total number of citations from Web of Science Core Collection since publication year to December 31, 2022; CPP_{2022}: average number of citations per publication (TC_{2022}/*TP*)

Characteristics of publication outputs

To understand publications in medical research topics, a relationship between the average number of citations per publication (CPP_{year}) and article life was proposed (Chuang *et al*., 2007). The article life with CPP_{2022} for all 9 022 brucellosis articles and the comparison to medical related topics is displayed in Fig. 1. It took *CPP*s three full years to reach a peak. Articles related to brucellosis took three full years to reach a peak CPP_{year} of 2.2. A peak appeared in four and five full years for breast reconstruction of (Li *et al*., 2020) and child sexual abuse (Vega *et al*., 2019) research with CPP_{year} of 3.0 and 4.2, respectively. After the peak, a decrease in CPP_{year} was generally found. However, articles related to non-union of fractures needed a longer citation life (ten full years) to reach the peak with CPP_{year} of 2.4.

The correlation between the annual number of articles (*TP*) and their citations ($CPP_{year} = TC_{year}/TP$) by year (Ho, 2013) was proposed to understand the impact of publication and development trends in medical related topics in SCI-EXPANDED, including dengue (Ho *et al*., 2016; Pouris and Ho, 2016), non-union fracture (Giannoudis *et al*., 2021), keloid (Chong *et al*., 2021), insomnia (Jallow *et al*., 2020), and Q fever (Farooq *et al*., 2022). The 9 022 articles associated with brucellosis were published in SCI-EXPANDED from 1991–2022. The mean value of TC_{2022} was 20 with 908 as the highest for an article. The distribution of the annual number of articles (*TP*) and their CPP_{2022} by year is demonstrated in Figure 2. In 2003, 202 articles had the highest CPP_{2022} of 43. The current study showed a slight increase in published articles from 1991 (155 articles) to 2022 (431 articles). In addition, a peak of annual publications was found in 2021 with 456 articles. Figure 2 further highlights that almost 16 years were taken for *CPP*s to reach a plateau. Brucellosis-related articles had a longer life in comparison to other medical related topics, for example non-union fracture with 14 years (Giannoudis *et al*., 2021), breast reconstruction with 10 years (Li *et al*., 2020), and child sexual abuse with 8 years (Vega *et al*., 2019).

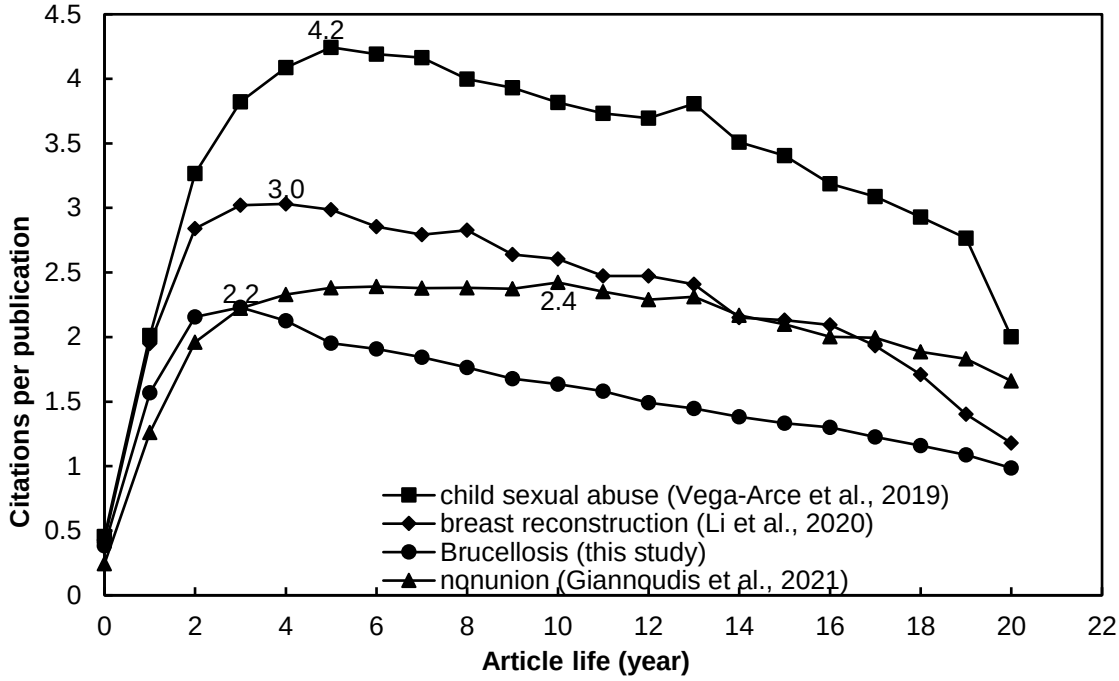

Figure 1. Citations per publication by article life

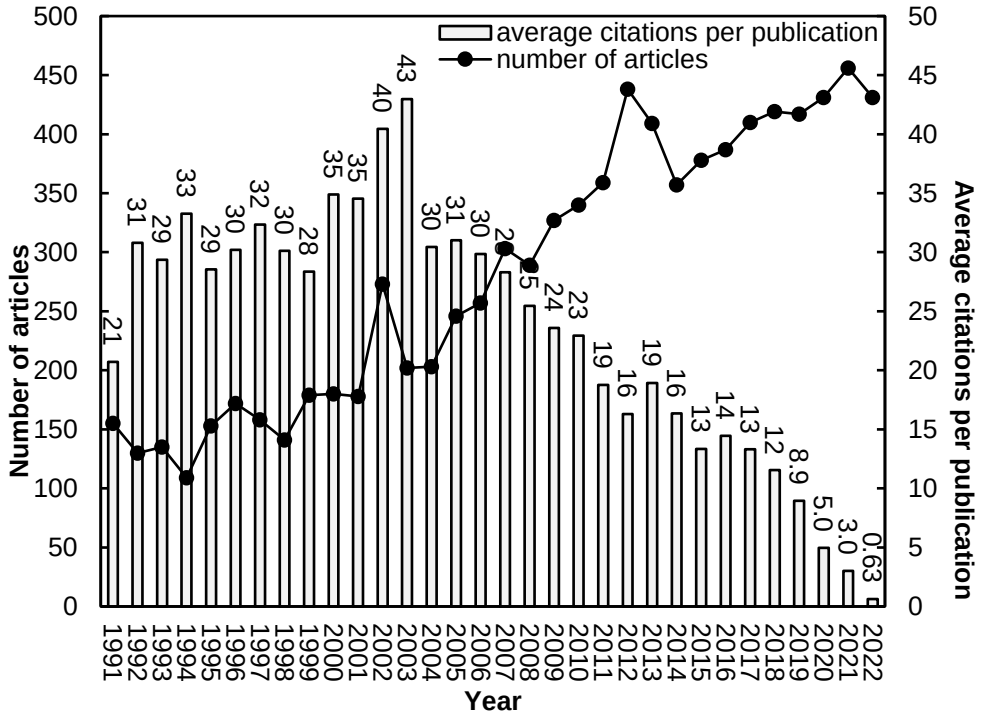

Figure 2. Number of brucellosis articles and average citations per publication by year.

Web of Science categories and journals

The JCR indexed 9 510 journals across 178 Web of Science categories in SCI-EXPANDED in 2022. In 2021, to characterize a Web of Science category of a research topic, the CPP_{year} and the *APP* were proposed as basic information (Giannoudis *et al*., 2021). In total, 1 491 journals associated with

134 Web of Science categories in SCI-EXPANDED have published ~9 003 brucellosis-related articles. The top 10 most productive Web of Science categories with *TP*, *APP*, CPP_{2022}, and the number of journals in a category are shown in Table 2. A total of 5 908 articles (66% of 9 003 articles) were published in the top four categories: veterinary sciences (2 497 articles; 28% of 9 003 articles), microbiology (2 081; 23%), infectious diseases (1 492; 17%), and immunology (1 354; 15%). The articles published in the category "immunology" had the greatest CPP_{2022} of 30, whereas articles in "general and internal medicine" had the lowest CPP_{2022} of 8.7. The "multidisciplinary sciences" category articles had the largest *APP* of 8.1, whereas articles in "general and internal medicine" had an *APP* of 5.0.

Table 2. The top 10 productive Web of Science categories in SCI-EXPANDED

Web of Science category	*TP* (%)	No *J*	*APP*	CPP_{2022}
Veterinary sciences	2,497 (28)	143	5.9	15
Microbiology	2,081 (23)	135	6.4	27
Infectious diseases	1,492 (17)	96	6.4	27
Immunology	1,354 (15)	161	6.2	30
Dairy and animal science agriculture	463 (5.1)	62	5.3	9.5
General and internal medicine	444 (4.9)	168	5.0	8.7
Public, environmental and occupational health	427 (4.7)	207	7.0	16
Biochemistry and molecular biology	367 (4.1)	285	6.5	22
Multidisciplinary sciences	340 (3.8)	73	8.1	30
Biotechnology and applied microbiology	335 (3.7)	157	6.0	19

TP: total number of brucellosis articles; *AU*: number of authors; *APP*: average number of authors per publication; No *J*: number of journals in a category; TC_{2022}: the total number of citations from Web of Science Core Collection since publication year to December 31, 2022; CPP_{2022}: average number of citations per publication (TC_{2022}/*TP*)

Figure 3 shows the trend of brucellosis articles in the four main productive Web of Science categories. The four major disciplines are "veterinary sciences" (*TP* = 2 497), "microbiology" (*TP* = 2 081), "infectious diseases" (*TP* = 1 492) and "immunology" (*TP* = 1 354). For the last 32 years, there has been a remarkable rise in publications in the disciplines "veterinary sciences" and "microbiology". However, an increasing trend in publication was recorded in the disciplines "infectious diseases" and "immunology". The highest number of publications was seen in the discipline "veterinary sciences" in 2013.

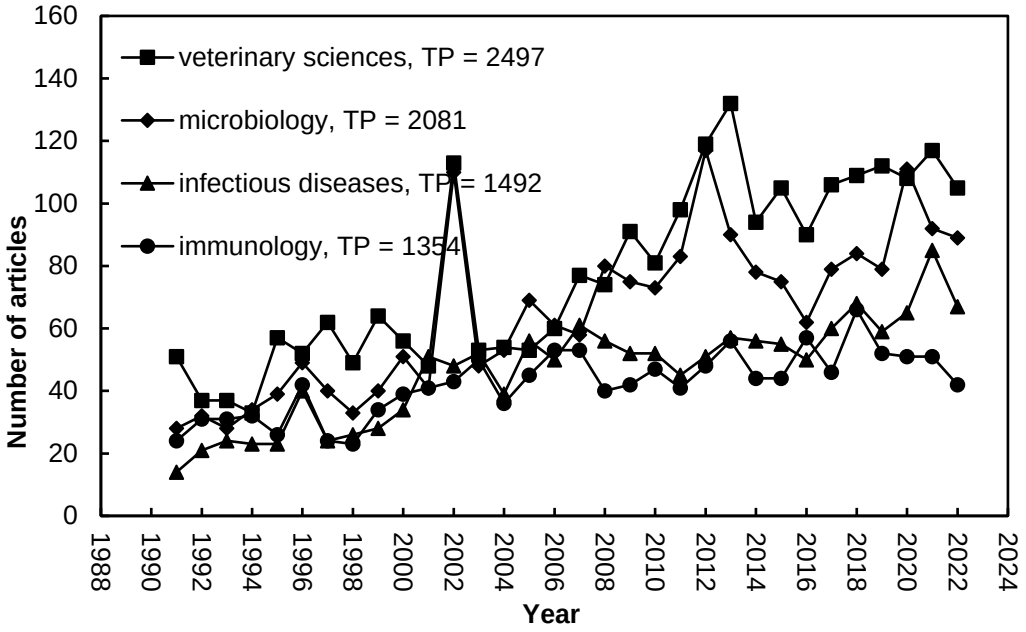

Figure 3. Comparison of the trends in brucellosis articles of the top four Web of Science categories

Table 3 highlights the top 10 most productive journals publishing brucellosis-related research by IF_{2022}, *APP*, and CPP_{2022}. The top four journals are from the category of "veterinary sciences". The *Infection and Immunity* (IF_{2022} = 3.1) published the most articles (294 articles: 3.3% of 9 022 articles). *PLoS One* (IF_{2022} = 3.7) with 195 articles had the highest APP of 8.1, whereas those of the *Indian Journal of Animal Sciences* (IF_{2022} = 0.4) with 97 articles had an APP of 4.5. Articles in the *Journal of Clinical Microbiology* (IF_{2022} = 9.4) with 146 articles had the highest CPP_{2022} of 50, whereas articles in the *Indian Journal of Animal Sciences* had a CPP_{2022} of 2.1. The top five journals had an IF_{2022} greater than 40, i.e., *Lancet* (IF_{2022} = 168.9), *Nature Medicine* (IF_{2022} = 82.9), *Nature* (IF_{2022} = 64.8), *Science* (IF_{2022} = 56.9), and *Lancet Infectious Diseases* (IF_{2022} = 56.3).

Table 3. The top 10 most productive journals publishing brucellosis-related research

Journal	*TP* (%)	IF_{2022}	*APP*	CPP_{2022}	Web of Science category
Infection and Immunity	294 (3.3)	3.1	6.0	49	immunology infectious diseases
Veterinary Microbiology	234 (2.6)	3.3	6.1	32	microbiology veterinary sciences
PLoS One	195 (2.2)	3.7	8.1	25	multidisciplinary sciences
Journal of Wildlife Diseases	163 (1.8)	1.3	6.5	21	veterinary sciences
Journal of Clinical Microbiology	146 (1.6)	9.4	6.6	50	microbiology
Preventive Veterinary Medicine	142 (1.6)	2.6	5.6	24	veterinary sciences
Tropical Animal Health and Production	137 (1.5)	1.7	5.9	13	agriculture, dairy and animal science veterinary sciences
Vaccine	133 (1.5)	5.5	6.3	22	immunology research and experimental medicine
Journal of Bacteriology	122 (1.4)	3.2	6.4	37	microbiology
Indian Journal of Animal Sciences	97 (1.1)	0.40	4.5	2	agriculture, dairy and animal science

TP: total number of Brucellosis articles; %: percentage of articles in all Brucellosis articles; IF_{2022}: journal's impact factor in 2022; *APP*: average number of authors per publication; CPP_{2022}: average number of citations per publication (TC_{2022}/TP)

Publication performances: Countries and institutions

There were 29 articles (0.32% of 9 022 articles) lacking the author's affiliation information in SCI-EXPANDED. A total of 8 993 brucellosis articles were published with author affiliations of 150 countries with a TP-CPP_{2022} of 20, including 6 849 single-country articles (all authors from the same country) (76% of 8 993 articles) by authors associated with 103 countries with an IP_C-CPP_{2022} of 18, and 2 146 international collaborative articles (24%) by authors from 147 countries with a CP_C-CPP_{2022} of 25. The number of citations was increased by international collaborations.

The top 10 most productive countries were assessed based on six publications and related six citation indicators (CPP_{2022}) (Table 4). This data highlighted the dominance of the USA in all publication indicators with a TP of 1 902 articles (21% of 8 993 articles), an IP_C of 1 192 articles (17% of 6 849 single-country articles), a CP_C of 710 articles (33% of 2 146 international collaborative articles), an FP of 1 480 articles (16% of 8 993 first-author articles), an RP of 1 502 articles (17% of 8 954 corresponding-author articles), and an SP of 67 articles (24% of 282 single-author articles). France with TP = 644 articles, CP_C = 375 articles, and RP = 403 articles ranked at the top with a TP-CPP_{2022} of 37, a CP_C-CPP_{2022} of 42, and an RP-CPP_{2022} of 33. The UK with an IP_C of 123 articles, an FP = 222 articles, and an SP = 17 articles ranked top with an IP_C-CPP_{2022} of 37, an FP-CPP_{2022} of 35, and an SP-CPP_{2022} of 73. Furthermore, articles of Iranian, Chinese, and Indian origin had a lower CPP_{2022}.

Table 4. Top 10 most productive countries with six publication and citation indicators

Country	*TP*	*TP*		*IP*$_C$		*CP*$_C$		*FP*		*RP*		*SP*	
		R (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*
USA	1,902	1 (21)	30	1 (17)	30	1 (33)	28	1 (16)	31	1 (17)	31	1 (24)	32
Turkey	834	2 (9.3)	12	2 (12)	12	31 (2.0)	13	2 (9.2)	12	2 (9.2)	12	5 (4.6)	6.7
China	818	3 (9.1)	9.4	3 (10)	8.9	9 (6.3)	12	3 (8.6)	9.1	3 (8.7)	9.1	N/A	N/A
France	644	4 (7.2)	37	8 (3.9)	29	2 (17)	42	6 (4.5)	33	6 (4.5)	33	3 (7.4)	8.3
Spain	577	5 (6.4)	31	6 (4.9)	28	5 (11)	35	5 (4.9)	30	5 (5.0)	29	9 (2.5)	22
India	494	6 (5.5)	9.3	4 (6.2)	8.8	21 (3.4)	12	4 (5.1)	9.0	4 (5.2)	9.1	11 (2.1)	3.3
UK	461	7 (5.1)	32	13 (1.8)	37	3 (16)	30	11 (2.5)	35	11 (2.7)	33	4 (6.0)	73
Brazil	451	8 (5.0)	14	7 (4.8)	11	11 (5.7)	23	7 (4.4)	13	7 (4.4)	13	N/A	N/A
Argentina	444	9 (4.9)	25	9 (3.8)	23	6 (8.6)	29	9 (4.1)	23	9 (4.1)	23	14 (1.4)	66
Iran	392	10 (4.4)	10	5 (5.0)	11	27 (2.4)	9.2	8 (4.2)	10	8 (4.3)	10	27 (0.71)	5.0

TP: total number of brucellosis articles; *TPR* (%): total number of articles and the percentage of total articles; *IP*$_C$*R* (%): rank and percentage of single country articles in all single country articles; *CP*$_C$*R* (%): rank and percentage of international collaborative articles in all international collaborative articles; *FPR* (%): rank and the percentage of first-author articles in all first-author articles; *RPR* (%): rank and the percentage of corresponding-author articles in all corresponding-author articles; *SPR* (%): rank and the percentage of first-author articles in all first-author articles; *TP-CPP*: total TC_{2022} of all articles per the total number of articles (*TP*); *IP*$_C$*-CPP*: total TC_{2022} of all single country articles per the number of single country articles (*IP*$_C$); *CP*$_C$*-CPP*: total TC_{2022} of all international collaborative articles per the number of international collaborative articles (*CP*$_C$); *FP-CPP*: total TC_{2022} of all first author per the number of first-author articles (*FP*); *RP-CPP*: total TC_{2022} of all corresponding-author articles per the number of corresponding-author articles (*RP*); *SP-CPP*: total TC_{2022} of all single author articles per the number of single author articles (*SP*); N/A: not available

Table 5. Top 10 productive institutions with six publication and citation indicators

Institution	*TP*	*TP*		*IP*$_I$		*CP*$_I$		*FP*		*RP*		*SP*	
		R (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*	*R* (%)	*CPP*
UN, Spain	157	1 (1.7)	42	16 (0.59)	32	1 (2.3)	44	2 (1.0)	43	2 (1.0)	40	N/A	N/A
INRA, France	157	1 (1.7)	47	2 (1.3)	33	3 (2.0)	52	6 (0.85)	36	6 (0.82)	35	5 (1.1)	25
UFMG, Brazil	151	3 (1.7)	24	6 (1.0)	23	2 (2.0)	24	1 (1.1)	22	1 (1.2)	22	N/A	N/A
TA&MU, USA	132	4 (1.5)	32	9 (0.89)	47	5 (1.8)	28	4 (0.88)	35	4 (0.9)	35	3 (1.8)	36
UBA, Argentina	131	5 (1.5)	26	10 (0.86)	19	5 (1.8)	28	3 (1.0)	28	3 (0.91)	28	N/A	N/A
USP, Brazil	119	6 (1.3)	18	90 (0.20)	15	4 (1.9)	18	13 (0.56)	20	12 (0.6)	20	N/A	N/A
UCD, USA	111	7 (1.2)	33	26 (0.50)	50	7 (1.6)	30	8 (0.60)	45	10 (0.62)	44	32 (0.35)	2.0
USDA ARS, USA	101	8 (1.1)	45	1 (1.5)	44	20 (1)	45	5 (0.86)	45	5 (0.84)	44	2 (2.5)	46
LSU, USA	95	9 (1.1)	39	23 (0.56)	38	8 (1.3)	39	16 (0.50	35	19 (0.42)	39	32 (0.35)	1.0
VPI&SU, USA	94	10 (1.0)	36	7 (1.0)	43	14 (1.1)	34	11 (0.58)	36	11 (0.61)	34	N/A	N/A

TP: total number of brucellosis articles; *TPR* (%): total number of articles and the percentage of total articles; *IP*$_I$*R* (%): rank and percentage of single institution articles in all single institution articles; *CP*$_I$*R* (%): rank and percentage of international collaborative articles in all international collaborative articles; *FPR* (%): rank and the percentage of first-author articles in all first-author articles; *RPR* (%): rank and the percentage of corresponding-author articles in all corresponding-author articles; *SPR* (%): rank and the percentage of first-author articles in all first-author articles; *TP-CPP*: total TC_{2022} of all articles per the total number of articles (*TP*); *IP*$_C$*-CPP*: total TC_{2022} of all single institution articles per the number of single institution articles (*IP*$_C$); *CP*$_C$*-CPP*: total TC_{2022} of all inter-institutional collaborative articles per the number of inter-institutional articles (*CP*$_C$); *FP-CPP*: total TC_{2022} of all first author per the number of first-author articles (*FP*); *RP-CPP*: total TC_{2022} of all corresponding-author articles per the number of corresponding-author articles (*RP*); *SP-CPP*: total TC_{2022} of all single author articles per the number of single author articles (*SP*); N/A: not available

UN, Spain: University of Navarra, Spain
INRA, France: Institut National de la Recherche Agronomique (INRA), France
UFMG, Brazil: Universidade Federal de Minas Gerais (UFMG), Brazil
TA&MU, USA: Texas Agricultural & Mechanical University, USA
UBA, Argentina: University of Buenos Aires, Argentina
USP, Brazil: University of Sao Paulo, Brazil
UCD, USA: University of California, Davis, USA
USDA ARS, USA: United States Department of Agriculture (USDA), Agricultural Research Service (ARS), USA
LSU, USA: Louisiana State University, USA
VPI&SU, USA: Virginia Polytechnic Institute and State University, USA

Table 6. Top 20 productive authors with 65 articles or more

Author	*TP*		*FP*		*RP*		*SP*		*h*	rank (*j*)
	rank (*TP*)	CPP_{2022}	rank (*FP*)	CPP_{2022}	rank (*RP*)	CPP_{2022}	rank (*SP*)	CPP_{2022}		
A. Cloeckaert	1 (116)	52	2 (27)	46	7 (31)	44	N/A	N/A	0.8921	3 (56)
J.J. Letesson	2 (107)	47	587 (2)	50	19 (21)	54	N/A	N/A	1.476	31 (23)
I. Moriyon	3 (91)	46	N/A	N/A	33 (17)	49	N/A	N/A	$\pi/2$	75 (17)
S. Kim	3 (91)	15	48 (8)	53	1 (59)	11	N/A	N/A	1.436	1 (67)
J. Godfroid	5 (86)	38	10 (12)	80	49 (14)	76	1 (4)	55	0.8622	21 (26)
J.M. Blasco	6 (83)	42	78 (6)	55	59 (12)	47	27 (1)	13	1.107	59 (18)
H. Neubauer	7 (78)	33	N/A	N/A	N/A	N/A	N/A	N/A	0	7747 (0)
H. Zhang	8 (77)	6.5	24 (10)	3.3	12 (26)	5.0	N/A	N/A	1.204	9 (36)
S.C. Olsen	8 (77)	23	1 (30)	17	5 (34)	16	1 (4)	27	0.8478	2 (64)
M.S. Zygmunt	10 (72)	40	24 (10)	27	69 (11)	24	N/A	N/A	0.8851	49 (20)
K. Nielsen	11 (71)	28	2 (27)	33	9 (27)	33	3 (3)	72	$\pi/4$	4 (54)
E. Moreno	12 (70)	61	312 (3)	71	36 (16)	37	27 (1)	42	1.385	53 (19)
N. Sriranganathan	13 (69)	30	1336 (1)	32	26 (18)	15	N/A	N/A	1.515	53 (19)
S.C. Oliveira	13 (69)	34	48 (8)	68	3 (40)	34	N/A	N/A	1.446	5 (45)
X. De Bolle	15 (67)	38	587 (2)	22	12 (26)	30	N/A	N/A	1.494	17 (28)
G.H. Giambartolomei	16 (66)	31	312 (3)	70	43 (15)	42	N/A	N/A	1.373	59 (18)
R.M. Roop	16 (66)	44	78 (6)	29	5 (34)	37	N/A	N/A	1.425	7 (39)
S.M. Boyle	16 (66)	34	N/A	N/A	98 (9)	39	N/A	N/A	$\pi/2$	180 (9)
C.A. Fossati	19 (65)	36	N/A	N/A	1227 (1)	20	N/A	N/A	$\pi/2$	4227 (1)
C.F. Chen	19 (65)	7.0	N/A	N/A	2 (41)	5.0	N/A	N/A	$\pi/2$	6 (41)

TP: total number of brucellosis articles; *FP*: number of first-author articles; *RP*: number of corresponding-author articles; *SP*: number of single author articles; CPP_{2022}: average number of citations per publication (TC_{2022}/TP); *j*: *Y*-index constant related to the publication potential; *h*: *Y*-index constant related to the publication characteristics; N/A: not available

The author's institutional affiliation may be used to identify the origin of the document. Concerning institutions, 3 030 brucellosis articles (34% of 8 993 articles) had single institutional affiliation with an IP_I-CPP_{2022} of 19, whereas 5 963 articles (66%) were institutional collaborations with a CP_I-CPP_{2022} of 20. The institutional collaborations slightly increased the number of citations. The top 10 leading institutions and their associated features are shown in Table 5. The University of Navarra in Spain and the Institut National de la Recherche Agronomique (INRA) in France ranked at the top with a *TP* of 157 articles (1.7% of 8 993 articles). The University of Navarra in Spain also ranked at the top with a CP_I of 139 articles (2.3% of 5 963 inter-institutional collaborative articles). The Universidade Federal de Minas Gerais (UFMG) in Brazil ranked at the top with an *FP* of 102 articles (1.1% of 8 993 first-author articles) and an *RP* of 103 articles (1.2% of 8 861 corresponding-author articles). The United States Department of Agriculture (USDA), and Agricultural Research Service (ARS) in the USA ranked at the top with an IP_I of 44 articles (1.5% of 3 030 single-institution articles). In addition, the King Saud University in Saudi Arabia published 61 articles (rank 26th), including the greatest *SP* of 14 articles (5.0% of 282 single-author articles). The Institut National de la Recherche Agronomique (INRA) in France with a *TP* = 157 articles and a CP_I = 117 articles ranked at the top with a TP-CPP_{2022} of 47 and an CP_I-CPP_{2022} of 52. The University of California, Davis in the USA with an IP_I = 15 articles and an *FP* = 54 articles ranked at the top with an IP_I-CPP_{2022} of 50 and an FP-CPP_{2022} of 45. The USDA ARS in the USA with an *RP* = 74 articles and an *SP* = 7 articles ranked at the top with a RP-CPP_{2022} of 44 and an SP-CPP_{2022} of 46.

Publication performances: Authors

Brucellosis-related articles had an *APP* of 6.1 with a maximum number of 58 authors for a single article. With the available author information of the 9 015 articles, 72% of articles contained 3–8 authors. A total of 1 345 (15% of 9 015 articles), 1 309 (15%), 1 127 (13%), 1 087 (12%), 856 (9.5%), and 723 (8.0%) were written by groups of 5, 4, 6, 3, 7, and 8 authors, respectively. Recently, the publication characteristics for authors have been based on four publication indicators: *TP*, *FP*, *RP*, and *SP*. CPP_{year} as well as *Y*-index parameters were proposed to be added to the basic information of the author on a research topic (Giannoudis *et al*., 2021). The top 20 most productive authors with associated characters are given in Table 6. A. Cloeckaert was the most productive author with 116 articles including 27 first-author articles (ranked 2nd) and 31 corresponding-author articles (ranked 7th). S. Kim with 91 articles had the most corresponding-author articles (59). J. Godfroid with 86 articles had most four single-author articles. In addition, S.C. Olsen with 77 articles also ranked top in both first-author articles and the single author articles. Compared to the 20 most productive authors, E. Moreno with 70 articles (*TP*) and a total of TC_{2022} of 4,290 had the highest CPP_{2022} of 61 (4 290/70) for the total articles in Brucellosis research. J. Godfroid with a *TP* of 86, an *FP* of 12, and an *RP* of 14 articles, had the highest CPP_{2022} of 80 and 76 for the first-author articles and the corresponding-author articles, respectively. K. Nielsen with a *TP* of 71 and *SP* of 3 articles, had the highest CPP_{2022} of 77 for the single-author articles. Only nine of the top 20 authors, including S. Kim, S.C. Olsen, A. Cloeckaert, K. Nielsen, S.C. Oliveira, C.F. Chen, R.M. Roop, H. Zhang, and X. De Bolle were found to be the top 20 publication potential authors as evaluated by *Y*-index. The top 20 most potential authors are evaluated based on the *Y*-index, which relies solely on the number of articles contributed as first and corresponding author (the most important authors in an article).

The 8 683 brucellosis articles (96% of 9 022 articles) with the information of both first and corresponding authors were investigated based on the *Y*-index. In total, 28 105 authors contributed to 8 683 brucellosis articles, with 20 359 authors (72% of 28 105 authors) having no first and no corresponding-author article with a *Y*-index (0, 0). Furthermore, 1 796 (6.4%) authors only published as corresponding authors with $h = \pi/2$, whereas 397 (1.4%) authors published more corresponding-author articles with $\pi/2 > h > \pi/4$ ($FP > 0$). Additionally, 2 810 (10%) authors had published the same number of first author and corresponding-author articles with $h = \pi/4$ ($FP > 0$ and $RP > 0$); 274 (1.0%) authors published more first-author articles with $\pi/4 > h > 0$ ($RP > 0$); and 2 469 (8.8%) authors published only first-author articles with $h = 0$.

The distribution of the *Y*-index (*j*, *h*) in polar coordinates of the leading 20 authors with *j* of 27 or more is indicated in Figure 4, with each point in the coordinate *Y*-index (*j*, *h*) symbolizing single or multiple authors. S. Kim with *Y*-index (67, 1.436) had the greatest publication performance, followed by S.C. Olsen (64, 0.8478). However, Kim had a lower CPP_{2022} (Table 6). P.C. Baldi (39, 1.457) and R.M. Roop (39, 1.425) had the same *j* of 39. The authors are located on the same curve ($j = 39$), demonstrating similar publication potential with contrasting characteristics of publications (Figure 4) (Ho and Hartley, 2016b). Baldi had a higher ratio of corresponding author to first-author articles with an *h* of

1.457, followed by Roop with an *h* of 1.425. Z.L. Chen (27, π/2) and M. Watarai (27, 1.347) were also located on the same curve (*j* = 27). Chen published only 27 corresponding-author articles with an *h* of π/2, whereas Watarai had an *h* of 1.347. Similarly, R. Shome (30, 0.8520), R. Adone (30, 0.7854), Q.M. Wu (28, 1.534), and X. De Bolle (28, 1.494) were positioned on the same curve (*j* = 30 and 28) with similar publication potential but varying publication features. K. Nielsen (54, π/4) and R. Adone (30, π/4) on the diagonal line (*h* = π/4), and C.F. Chen (41, π/2) and Z.L. Chen (27, π/2) on the y-axis (*h* = π/2) demonstrated similar publication characteristics with varying publication potential. Nielsen had a higher publication potential with a *j* of 54 than Adone (*j* = 30). C.F. Chen had a higher publication potential, with a *j* of 41 than Z.L. Chen (*j* = 27).

The position of the graph, along the curve or line of origin, shows various author publication potential or characteristics. However, potential bias in authorship analysis may arise due to the same name of authors or different names of the same authors used over time (Chiu & Ho, 2007).

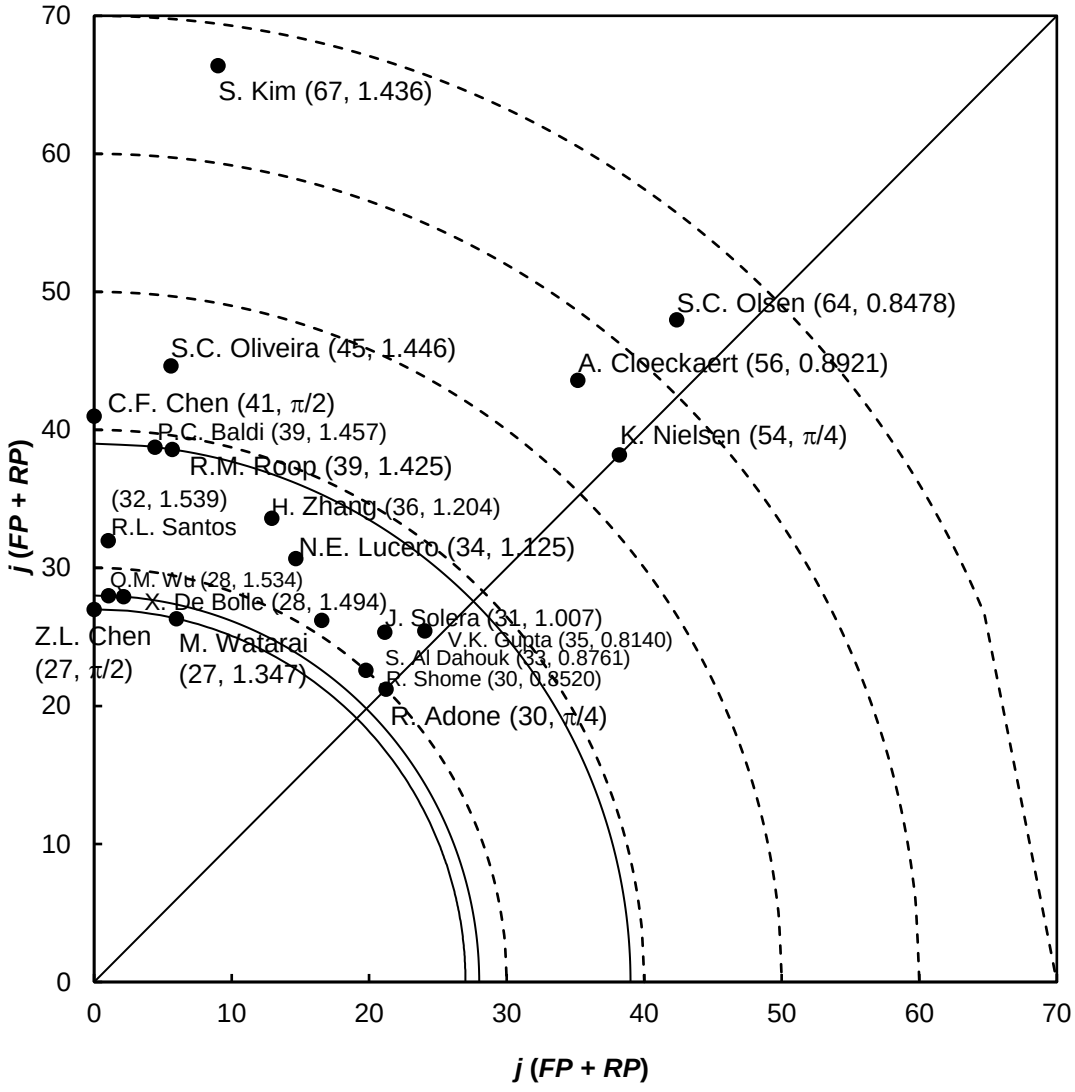

Figure 4. Top 20 authors with *Y*-index (*j* ≥ 27)

Citation histories of the ten most frequently-cited articles

Wang & Ho reported that the total number of citations from the WSCC since publication year to the end of the year 2022 (TC_{2022}) could be applied to improve bibliometric study by addressing the bias directly using the database (Wang & Ho, 2011). The most cited articles with associated features are shown in Table 7; citation history over time of the most cited articles is presented in Fig. 5.

Table 7. Top 10 most frequently-cited articles

Rank (TC_{2022})	Rank (C_{2022})	Title	Reference
1 (908)	8 (37)	Brucellosis: An overview	Corbel (1997)
2 (838)	2 (244)	The European Union summary report on trends and sources of zoonoses, zoonotic agents, and food-borne outbreaks in 2017	[Anonymous] (2018)
3 (787)	5 (74)	The European Union summary report on trends and sources of zoonoses, zoonotic agents, and food-borne outbreaks in 2016	[Anonymous] (2017)
4 (779)	1 (278)	The European Union One Health 2018 Zoonoses Report	[Anonymous] (2019)
5 (566)	110 (10)	Phagosomes are competent organelles for antigen cross-presentation	Houde *et al*. (2003)
6 (552)	51 (14)	An overview of human brucellosis	Young (1995)
7 (522)	29 (17)	Carbonic anhydrase inhibitors	Supuran (2010)
8 (431)	110 (10)	The genome sequence of the facultative intracellular pathogen, *Brucella melitensis*	Delvecchio *et al*. (2002)
9 (420)	42 (15)	*Brucella* evades macrophage killing via VirB-dependent sustained interactions with the endoplasmic reticulum	Celli *et al*. (2003)
10 (418)	141 (9)	Complete genome sequence of *Caulobacter crescentus*	Nierman *et al*. (2001)

TC_{2022}: total number of citations from Web of Science Core Collection since publication year to the end of 2022; C_{2022}: number of citations of an article in 2022 only

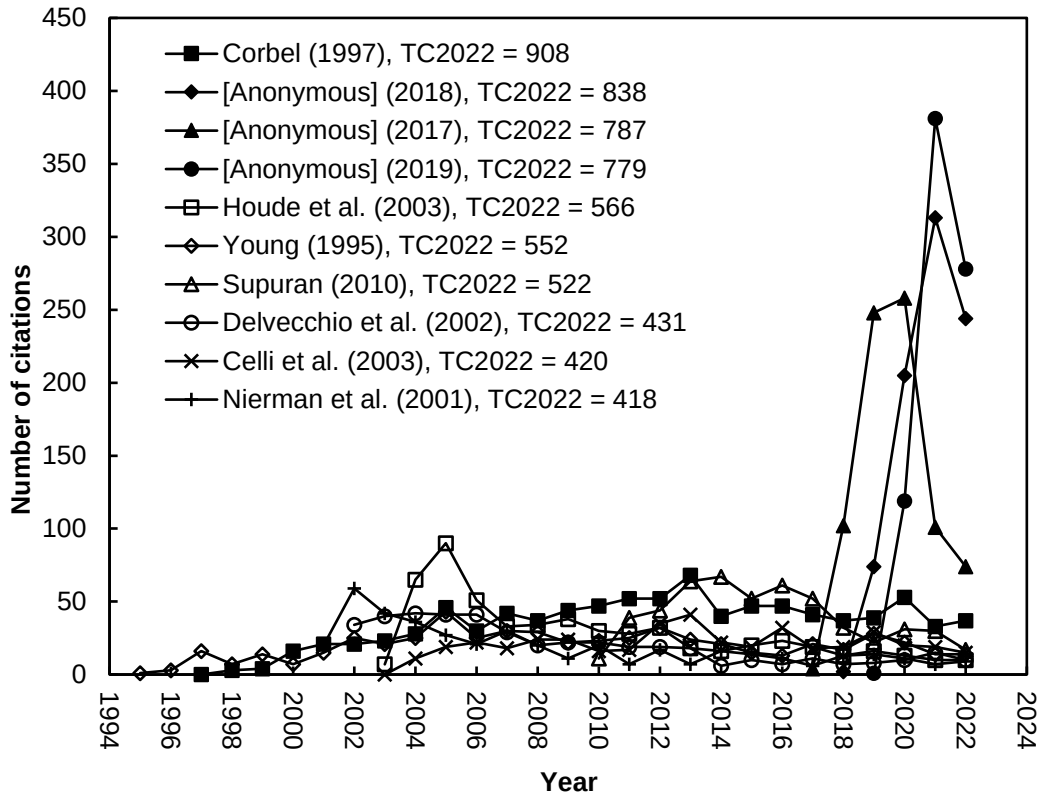

Figure 5. The citation histories of the top ten most-frequently cited brucellosis articles
Only three of the top ten most often cited articles were also ranked in the top ten of C_{2022}.
1. The European Union One Health 2018 Zoonoses Report (EFSA, 2019)
C_{2022} = 278 (rank 1st), TC_{2022} = 779 (rank 4th)

This report published by the European Food Safety Authority (EFSA) and The European Center for Disease Prevention and Control highlights the important food-borne, bacterial, zoonotic diseases in the EU. Brucellosis remained in the top 8 List A diseases that must be notified immediately, needing continuous disease surveillance. Human outbreaks were primarily linked to the consumption of cheese. However, the trend of brucellosis endemicity in animals is on a steady decline. Greece reported an almost 10 times higher number of *Brucella* infections in animals when compared to the EU average. Similarly, Greece and Italy reported more than half of the human brucellosis cases reported in the EU.

2. The European Union summary report on trends and sources of zoonoses, zoonotic agents, and food-borne outbreaks in 2017 (EFSA, 2018)

C_{2022} = 244 (rank 2nd), TC_{2022} = 838 (rank 2nd)

Although *Brucella*-associated foodborne illnesses have become a rare event in the EU, Italy and Germany reported human brucellosis cases. In Italy, brucellosis is strongly associated with the consumption of unpasteurized milk. The source of infection, e.g., the consumed food responsible for disease, remained unknown in Germany. The report highlights the importance of the transmission from animals to humans via direct contact, which remains the major source of infection in humans. In comparison to the report of the previous year, the number of *Brucella* cases in humans continued to decrease. Overall, the EU reported 378 cases, of which only 30% were diagnosed to the species level of causative agent. Of these, *B. melitensis* remained the major cause of human brucellosis, followed by *B. abortus* and *B. suis*. In Greece, Italy, Portugal, and Spain, brucellosis in humans was usually acquired through contact with domesticated sheep, cattle, and goat herds.

3. The European Union summary report on trends and sources of zoonoses, zoonotic agents, and food-borne outbreaks in 2016 (EFSA, 2017)

C_{2022} = 74 (rank 5th), TC_{2022} = 787 (rank 3rd)

The report highlights that Greece, Italy, and Portugal reported the most *Brucella* infections in the EU. Brucellosis was endemic in these countries and human infections were associated with the consumption of raw dairy products or direct contact with infected animals. These countries reported little monitoring data from raw products in particular, which were the major source of food-borne human brucellosis. The majority of reported human cases in 2016 had unknown travel history to endemic countries, mainly Iraq, Syria, Somalia, and Turkey. Overall, the number of human infections continued to decline over the years, whereas the share of cases of unknown travel history continued to increase. The data showed a continuous decline in *Brucella* infections with every passing year from 2012–2015. However, in 2016, this trend was reversed, and the EU reported a 35.2% higher number of cases in comparison to last year, mainly due to a rise in *Brucella* infections in Italy.

Research foci

The title, abstract, author keywords, and *Keywords Plus* of an article provide important information regarding conducted research. The analysis of word distribution is useful for evaluating research focus and related developmental trends in the field of specific research. This analysing tool can mitigate shortcomings, such as the incomplete meaning of individual words in titles and abstracts, the small sample size of author keywords, and the indirect relationship between *Keywords Plus* and research topics (Farooq *et al*., 2022). This pertinent analysis during the research period provides rough research trends using title, abstract, author keywords, and words in *Keywords Plus* (Zhang *et al*., 2010). Table 8 reports the most commonly-used author keywords for brucellosis-related research and their distribution trends over the last 32 years (1991–1998, 1999–2006, 2007–2014, and 2015–2022). The most frequently-used words by authors also indicate that the major focus areas of researchers as “cattle” (most often-investigated host), “serology” (demonstrating a focus on screening of serum samples), “zoonosis”, “laboratory diagnosis” (PCR, ELISA), clinical manifestations such as “abortion”, “*Brucella* species” (*B. abortus*, *B. melitensis*, *B. canis*), and “epidemiology”.

Table 8. The top 20 most commonly-used author keywords for brucellosis-related research and their distribution over the last 32 years (1991–1998, 1999–2006, 2007–2014, and 2015–2022)

Author keywords	*TP*	91–22 *R* (%)	91–98 *R* (%)	99–06 *R* (%)	07–14 *R* (%)	15–22 *R* (%)
Brucellosis	2 203	1 (35)	1 (27)	1 (34)	1 (40)	1 (33)
Brucella	994	2 (16)	2 (11)	2 (13)	2 (17)	2 (17)
Brucella abortus	608	3 (10)	2 (11)	3 (12)	3 (9.5)	3 (8.9)
Brucella melitensis	441	4 (7.0)	4 (6.5)	4 (7.1)	4 (6.1)	4 (7.8)
Cattle	256	5 (4.1)	7 (5.0)	7 (3.7)	5 (4.7)	6 (3.6)
Serology	255	6 (4.1)	5 (6.3)	5 (5.3)	6 (4.2)	9 (3.2)
Seroprevalence	191	7 (3.0)	31 (1.1)	26 (1.4)	8 (3.7)	7 (3.5)
Zoonosis	190	8 (3.0)	60 (0.65)	32 (1.1)	10 (3.0)	5 (4.1)
Epidemiology	185	9 (2.9)	9 (3.5)	10 (2.7)	9 (3.2)	12 (2.7)
PCR	179	10 (2.9)	109 (0.43)	19 (1.9)	7 (3.7)	10 (3.0)
Vaccine	177	11 (2.8)	13 (2.2)	8 (3.4)	14 (2.6)	11 (2.9)
Sheep	168	12 (2.7)	10 (2.6)	6 (4.9)	16 (2.5)	16 (2.0)
Diagnosis	157	13 (2.5)	15 (1.7)	8 (3.4)	12 (2.9)	15 (2.1)
Risk factors	153	14 (2.4)	N/A	72 (0.62)	13 (2.7)	8 (3.3)
ELISA	150	15 (2.4)	6 (5.6)	14 (2.4)	18 (2.3)	17 (1.9)
Abortion	137	16 (2.2)	22 (1.5)	13 (2.5)	19 (2.2)	13 (2.2)
Prevalence	136	17 (2.2)	42 (0.87)	28 (1.2)	11 (2.9)	14 (2.2)
Zoonoses	127	18 (2.0)	22 (1.5)	23 (1.6)	14 (2.6)	18 (1.9)
Brucella canis	114	19 (1.8)	109 (0.43)	24 (1.5)	17 (2.4)	20 (1.7)
Bovine brucellosis	108	20 (1.7)	10 (2.6)	43 (0.93)	23 (1.7)	18 (1.9)

TP: total number of brucellosis articles containing the keywords; *R*: rank; %: percentage in each period

To highlight the potential research hotspots, the word “cluster analysis” was also performed. Trend analysis concerning the causative agent showed *B. abortus* (*TP* = 2 817 articles) remained the focus, followed by *B. melitensis* (*TP* = 1 941 articles), *B. suis* (*TP* = 648 articles), *B. ovis* (*TP* = 513 articles), *B. canis* (*TP* = 355 articles), *B. ceti* (*TP* = 90 articles), *B. microti* (*TP* = 59 articles), and *B. pinnipedialis* (*TP* = 52 articles) (Fig. 6). The data suggest the greater interest of the scientific community towards *B. abortus* and *B. melitensis,* which also reflects their greater zoonotic potential, demonstrating the serious risk to human health. Humans mainly contract infections from domestic animals infected with *B. abortus* (cattle) and *B. melitensis* (sheep and goats). Human infections are also caused by *B. suis* (pigs) but other brucellae rarely cause infection in humans. Timely and accurate identification of the species causing the disease is important for appropriate therapy and the use of control strategies.

We investigated the research trends for “diagnosis”. Overall, most publications used the keyword “culture” (*TP* = 1 586 articles), followed by “RBPT” (*TP* = 1 296 articles), “PCR” (*TP* = 1 257 articles), “ELISA” (*TP* = 1 157 articles), complement fixation test “CFT” (*TP* = 419 articles), simultaneous amplification and testing “SAT” (*TP* = 268 articles), and multiple-locus variable number tandem-repeat analysis “MLVA” (*TP* = 106 articles) (Fig. 7). Definitive diagnosis of brucellosis can be achieved by culture isolation and nucleic acid-based molecular identification. However, culture is tedious, time-consuming, and poses serious risks to laboratory personnel and the associated environment. Therefore, bacterial culture requires specific biosafety measures (BSL-3). Serological assays are more practical and are used for routine monitoring and diagnosis of brucellosis, particularly in resource-limited locations. However, the choice of the serological test to be used depends upon the epidemiology of the disease in a particular region, the cost of the test, and the sensitivity and specificity of the test. Serological assays such as RBPT, CFT, SAT, or ELISA are used for screening and/or confirmation. RBPT is a highly-sensitive, cost-effective test that can be performed under field conditions for screening

of brucellosis in resource-poor, endemic countries. However, due to its low specificity, this test needs confirmatory tests with high specificity such as ELISA. Thus, RBPT is not recommended for screening in disease-free countries. Instead, assays with high sensitivity and specificity, such as ELISA or CFT, should be used. Additionally, culture-independent molecular diagnostic assays such as PCR [either conventional or quantitative (real-time)] and a multi-locus variable number of tandem repeat assays (MLVA) are being used to characterize and genotype *Brucella* isolates. PCR is considered a safe and reliable molecular method for the confirmation. MLVA remains the method of choice for genotyping in resource-poor settings and is helpful in characterising the origin of an outbreak and may also help in the development of better prophylaxis. Next Generation Sequencing (NGS) and bioinformatic pipelines will replace MLVA shortly in most developed countries.

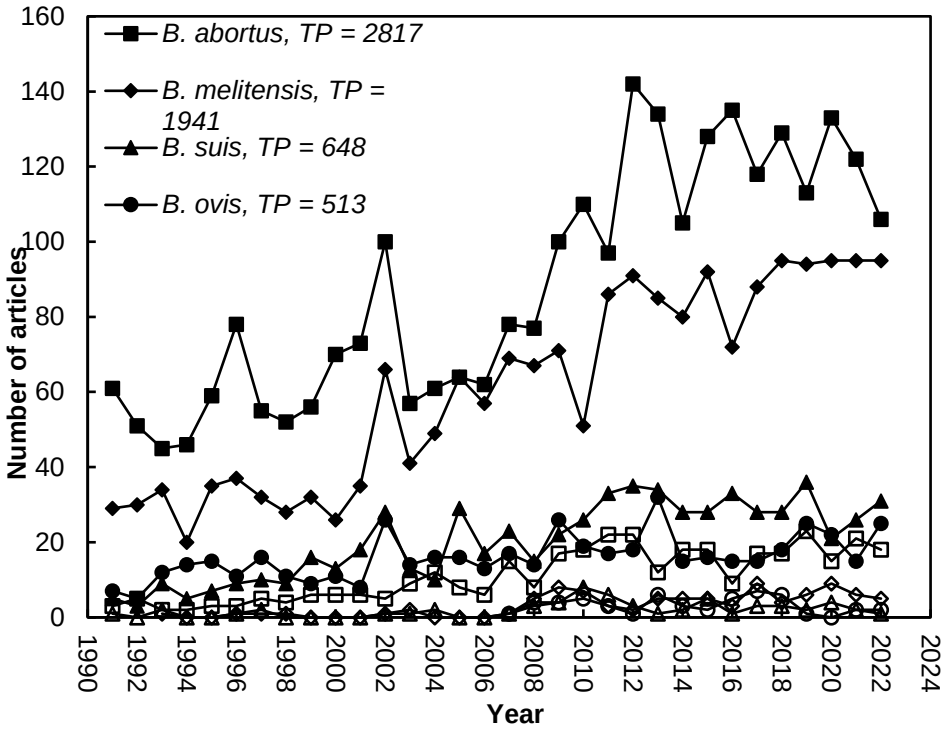

Figure 6. Research trends related to *Brucella* species

Effective control of infectious diseases, particularly zoonotic pathogens, requires knowledge of their hosts. Brucellae have a wide host range, including domesticated animals and wild aquatic and terrestrial animals. Hence, brucellosis is mainly a disease of domesticated animals. However, it can be maintained in wildlife, which can then be the source of re-emerging infections in humans and livestock. In the current study, the keywords related to “host range” are summarized in Fig. 8 and “human” was most-often used keyword (*TP* = 2 837 articles), followed by “cattle” (*TP* = 1 985 articles), “rodents” (*TP* = 1 336 articles), “sheep” (*TP* = 906 articles), “goat” (*TP* = 665 articles), “pigs” (*TP* = 368 articles), “dogs” (*TP* = 345 articles), “wildlife” (*TP* = 303 articles), and “buffalo” (*TP* = 266 articles).

The effective control of disease usually depends on circulating pathogens and their host range. Besides the six classical *Brucella* species infecting cattle, sheep & goats, swine, and humans, in recent years new brucellae have been discovered causing infections in marine and terrestrial animals. This analysis depicts that the predominantly-discussed hosts for brucellae are cattle, rodents, and small ruminants (sheep & goats). Rodents (3rd most discussed keyword) are mainly used as an experimental model to understand the pathophysiology and host–pathogen interaction of *Brucella* species. However, rodents are not the primary source of human brucellosis, which is mainly linked to domesticated animals, such as cattle, sheep, and goats (Jamil *et al*., 2021). Usually, humans contract the infection by direct contact with infected animals or through the consumption of contaminated raw dairy or meat products.

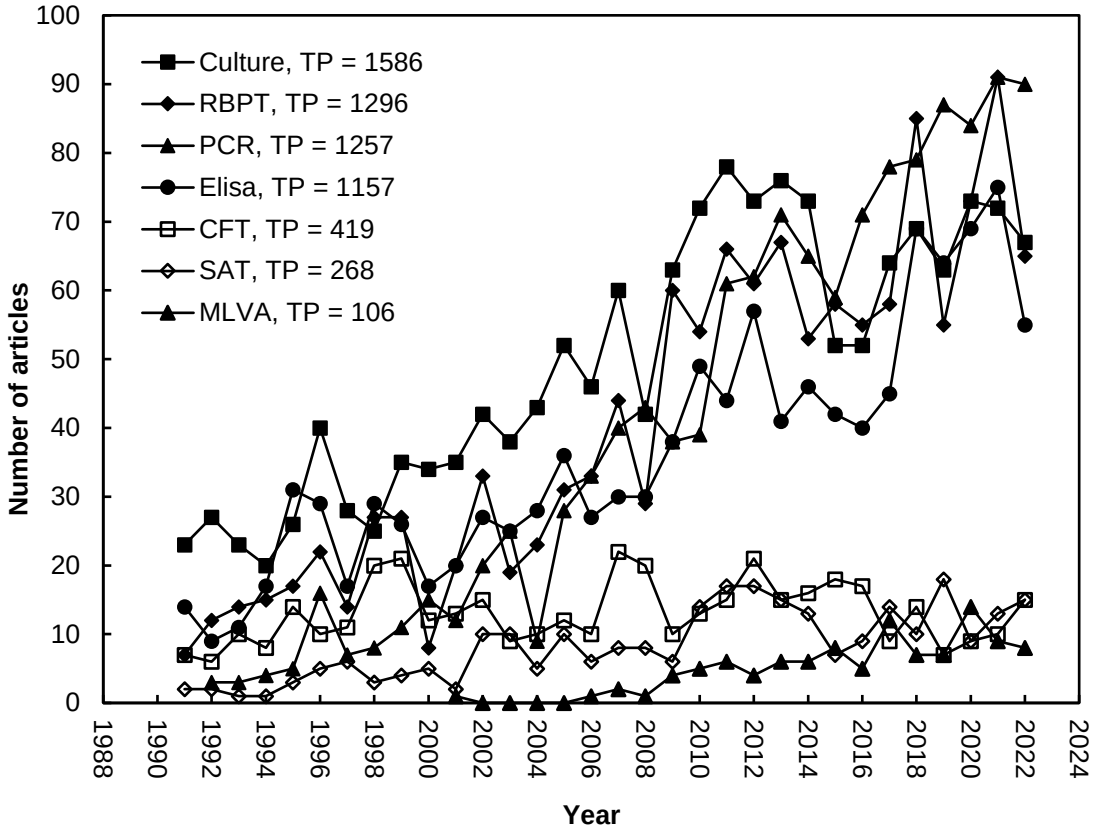

Figure 7. Research trends related to diagnostic techniques in brucellosis

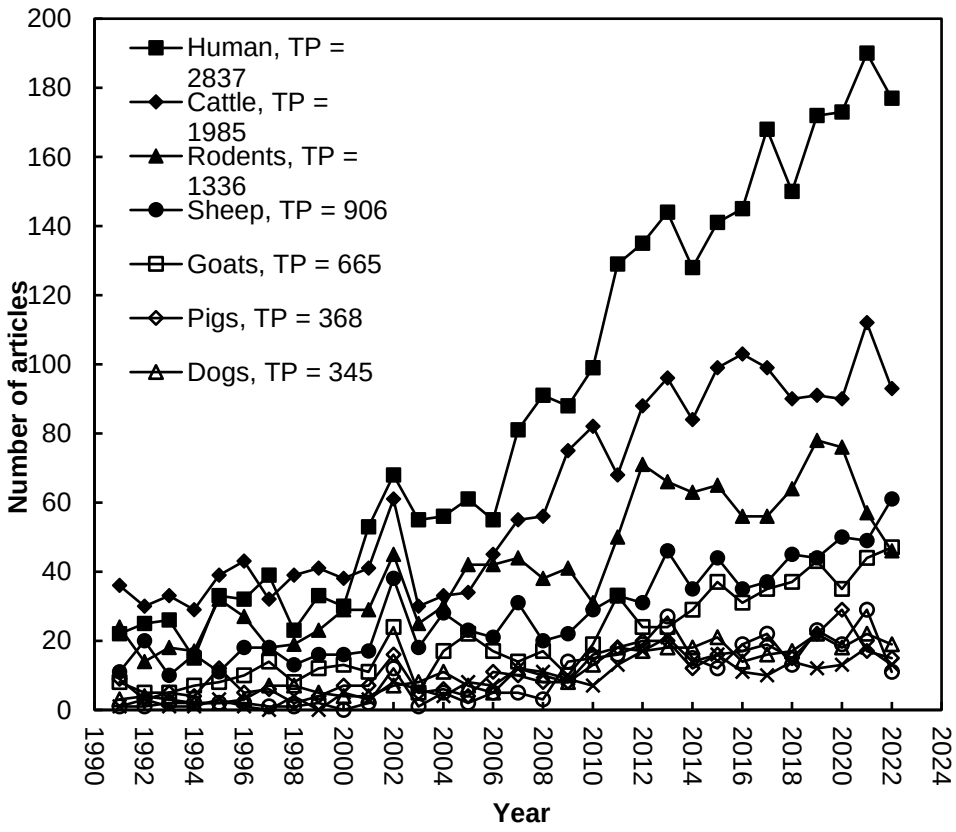

Figure 8. Research trends to “HOST” in brucellosis research

Conclusion

The current study highlights the research trends and important developments in the field of brucellosis research. It provides insights on the most influential authors, institutes, countries, publications, and epidemiological aspects of brucellosis. Furthermore, data on *Brucella* species, host range, and most widely-used diagnostic tests applied in brucellosis research over the last three decades are provided. This analysis will be helpful for the researchers who intend to pursue their careers in brucellosis research in choosing the trending discipline, country, or institute. Furthermore, it will help the relevant researchers to collaborate. We further highlighted the list of journals publishing most articles in this discipline, for the use by the relevant researchers. Additionally, the zoonotic nature of the disease with its wide host range of domestic to wildlife stresses the need for collaboration of physicians, veterinarians, and environmentalists under the umbrella of “One Health” to ensure better global health.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper

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Author Contributions

Data curation, M. F, A. U. K and Y. S. H; Methodology, Y. S. H, M. F and A. U. K. ; Writing – original draft, M. F and A. U. K. and H. E-A.; Writing – review & editing, A. U. K., F. M., H. N., I. K. and H. E-A.

References

Ariza, J., Bosilkovski, M., Cascio, A., Colmenero, J.D., Corbel, M.J., Falagas, M.E., Memish, Z.A., Roushan, M.R., Rubinstein, E., Sipsas, N.V., Solera, J., Young, E.J., Pappas, G., 2007. Perspectives for the treatment of brucellosis in the 21st century: The Ioannina recommendations. PLoS Med. 4.

Arroyo-Carrera, I., Lopez Rodriguez, M.J., Sapina, A.M., Lopez Lafuente, A., Sacristan, A.R., 2006. Probable transmission of brucellosis by breast milk. J Trop Pediat. 52, 380–381.

Boschiroli, M.L., Foulongne, V., O'Callaghan, D., 2001. Brucellosis: A worldwide zoonosis. Curr Opin Microbiol. 4, 58–64.

Cetaruk, E.W., Ciccone, T.J. 2016. Brucella Species (Brucellosis) Attack, In: Ciottone's Disaster Medicine. Elsevier. pp. 713–715.

Chiu, W.-T., Ho, Y.-S., 2007. Bibliometric analysis of tsunami research. Scientometrics. 73, 3–17.

Chong, Y., Long, X., Ho, Y.S., 2021. Scientific landscape and trend analysis of keloid research: A 30-year bibliometric review. Ann Transl Med. 9, 945.

Chuang, K.-Y., Huang, Y.-L., Ho, Y.-S., 2007. A bibliometric and citation analysis of stroke-related research in Taiwan. Scientometrics 72, 201–212.

Coelho, A., Díez, J., Coelho, A., 2015. Risk factors for *Brucella* spp. in domestic and wild animals, In: Updates on Brucellosis. InTech.

Doganay, G.D., Doganay, M., 2013. Brucella as a potential agent of bioterrorism. Recent patents on anti-infective drug discovery. 8, 27–33.

EFSA, 2017. The European Union summary report on trends and sources of zoonoses, zoonotic agents, and food-borne outbreaks in 2016. EFSA Journal 15.

EFSA, 2018. The European Union summary report on trends and sources of zoonoses, zoonotic agents, and food-borne outbreaks in 2017. EFSA Journal 16, e05500.

EFSA, 2019. The European Union One Health 2018 zoonoses report. EFSA Journal 17, e05926.

El-Diasty, M., Wareth, G., Melzer, F., Mustafa, S., Sprague, L.D., Neubauer, H., 2018. Isolation of *Brucella abortus* and *Brucella melitensis* from seronegative cows is a serious impediment in brucellosis control. Vet Sci. 5, 4.

Farooq, M., Khan, A.U., El-Adawy, H., Mertens-Scholz, K., Khan, I., Neubauer, H., Ho, Y.-S., 2022. Research trends and hotspots of Q Fever research: A bibliometric analysis 1990–2019. BioMed Res Int. 2022, 9324471.

Fields, B.S., Benson, R.F., Besser, R.E., 2002. Legionella and Legionnaires' disease: 25 years of investigation. Clin Microbiol Rev. 15, 506–526.

Fu, H.-Z., Ho, Y.-S., 2015. Top cited articles in thermodynamic research. J Eng Thermophys 24, 68–85.

Garfield, E., 1990. KeyWords Plus: 1S1's Breakthrough Retrieval Method. Part 1. Expanding Your Searching Power on Current Contents on Diskette. Curr Contents. 13, 295.
Giannoudis, P.V., Chloros, G.D., Ho, Y.-S., 2021. A historical review and bibliometric analysis of research on fracture nonunion in the last three decades. Int Orthop. 45, 1663–1676.
Godfroid, J., 2017. Brucellosis in livestock and wildlife: Zoonotic diseases without pandemic potential in need of innovative one health approaches. Arch Pub Health = Archives belges de sante publique 75, 34.
Ho, Y.-S., 2012. Top-cited Articles in chemical engineering in Science Citation Index Expanded: A bibliometric analysis. Chin J Chem Eng. 20, 478–488.
Ho, Y.-S., 2013. The top-cited research works in the Science Citation Index Expanded. Scientometrics. 94, 1297–1312.
Ho, Y.-S., Mukul, S.A., 2021. Publication performance and trends in mangrove forests: A bibliometric analysis. Sustainability 13, 12532.
Ho, Y.-S., Siu, E., Chuang, K.-Y., 2016. A bibliometric analysis of dengue-related publications in the Science Citation Index Expanded. Future Virol. 11, 631–648.
Ho, Y.S., Hartley, J., 2016. Classic articles in Psychology in the Science Citation Index Expanded: A bibliometric analysis. Br J Psych. 107, 768–780.
Hsu, Y.H., Ho, Y.S., 2014. Highly cited articles in health care sciences and services field in Science Citation Index Expanded. A bibliometric analysis for 1958–2012. Methods Inf Med. 53, 446–458.
Jallow, A., Wang, M.-H., Ho, Y.-S., 2020. Global research trends and publications of insomnia: A bibliometric analysis. COLLNET J Scientomet 14, 349–367.
Jamil, T., Khan, A.U., Saqib, M., Hussain, M.H., Melzer, F., Rehman, A., Shabbir, M.Z., Khan, M.A., Ali, S., Shahzad, A., Khan, I., Iqbal, M., Ullah, Q., Ahmad, W., Mansoor, M.K., Neubauer, H., Schwarz, S., 2021. Animal and Human Brucellosis in Pakistan. Frontiers Pub Health. 9, 660508.
Kato, Y., Masuda, G., Itoda, I., Imamura, A., Ajisawa, A., Negishi, M., 2007. Brucellosis in a returned traveler and his wife: Probable person-to-person transmission of *Brucella melitensis*. J Travel Med. 14, 343–345.
Khan, A.U., Melzer, F., El-Soally, S., Elschner, M.C., Mohamed, S.A., Sayed Ahmed, M.A., Roesler, U., Neubauer, H., El-Adawy, H., 2019a. Serological and molecular identification of *Brucella* spp. in pigs from Cairo and Giza governorates, Egypt. Pathogens (Basel, Switzerland) 8.
Khan, A.U., Melzer, F., Hendam, A., Sayour, A.E., Khan, I., Elschner, M.C., Younus, M., Ehtisham-Ul-Haque, S., Waheed, U., Farooq, M., Ali, S., Neubauer, H., El-Adawy, H., 2020a. Seroprevalence and molecular identification of Brucella spp. in bovines in Pakistan-investigating association with risk factors using machine learning. Front Vet Sci. 7, 594498.
Khan, A.U., Melzer, F., Sayour, A.E., Shell, W.S., Linde, J., Abdel-Glil, M., El-Soally, S., Elschner, M.C., Sayour, H.E.M., Ramadan, E.S., Mohamed, S.A., Hendam, A., Ismail, R.I., Farahat, L.F., Roesler, U., Neubauer, H., El-Adawy, H., 2021. Whole-genome sequencing for tracing the genetic diversity of *Brucella abortus* and *Brucella melitensis* Isolated from livestock in Egypt. Pathogens (Basel, Switzerland) 10.
Khan, A.U., Sayour, A.E., Melzer, F., El-Soally, S., Elschner, M.C., Shell, W.S., Moawad, A.A., Mohamed, S.A., Hendam, A., Roesler, U., Neubauer, H., El-Adawy, H., 2020b. Seroprevalence and molecular identification of *Brucella* spp. in camels in Egypt. Microorganisms 8.
Khan, A.U., Shell, W.S., Melzer, F., Sayour, A.E., Ramadan, E.S., Elschner, M.C., Moawad, A.A., Roesler, U., Neubauer, H., El-Adawy, H., 2019b. Identification, genotyping and antimicrobial susceptibility testing of *Brucella* spp. isolated from livestock in Egypt. Microorganisms 7.
Li, Y., Wang, X., Thomsen, J.B., Nahabedian, M.Y., Ishii, N., Rozen, W.M., Long, X., Ho, Y.S., 2020. Research trends and performances of breast reconstruction: A bibliometric analysis. Ann Trans Med. 8, 1529.
Li, Z., Ho, Y.-S., 2008. Use of citation per publication as an indicator to evaluate contingent valuation research. Scientometrics 75, 97–110.
Long, X., Huang, J.-Z., Ho, Y.-S., 2014. A historical review of classic articles in surgery field. Am. J. Surg. 208, 841–849.
Lubani, M., Sharda, D., Helin, I., 1988. Probable transmission of brucellosis from breast milk to a newborn. Trop Geogr Med. 40, 151–152.
Megid, J., Mathias, L.A., Robles, C., 2010. Clinical manifestations of brucellosis in domestic animals and humans. The Open Vet Sci J. 119–126.

Monge Nájera, J., Ho, Y.-S., 2017. El Salvador publications in the Science Citation Index Expanded: Subjects, authorship, collaboration and citation patterns. Revista de Biologia Tropical 65, 1428–1436.
Nikokar, I., Hosseinpour, M., Asmar, M., Pirmohbatei, S., Hakeimei, F., Razavei, M.T., 2011. Seroprevalence of Brucellosis among high risk individuals in Guilan, Iran. Res J Med Sci. 16, 1366–1371.
Palanduz, A., Palanduz, S., Guler, K., Guler, N., 2000. Brucellosis in a mother and her young infant: Probable transmission by breast milk. Int J Inf Disease. 4, 55–56.
Pappas, G., Panagopoulou, P., Christou, L., Akritidis, N., 2006a. Brucella as a biological weapon. Cell Mol Life Sci. 63, 2229–2236.
Pappas, G., Papadimitriou, P., Akritidis, N., Christou, L., Tsianos, E., 2006b. The new global map of human brucellosis. Lancet Infect Dis. 6, 91–99.
Pouris, A., Ho, Y.-S., 2016. A bibliometric analysis of research on Ebola in Science Citation Index Expanded. S. Afr. J. Sci. 112.
Saddique, A., Ali, S., Akhter, S., Khan, I., Neubauer, H., Melzer, F., Khan, A.U., Azam, A., El-Adawy, H., 2019. Acute febrile illness caused by *Brucella abortus* infection in humans in Pakistan. Int J Env Res Pub Health. 16.
Singh, B.B., Dhand, N.K., Gill, J.P., 2015. Economic losses occurring due to brucellosis in Indian livestock populations. Prev Vet Med. 119, 211–215.
Usman, M., Ho, Y.-S., 2020. A bibliometric study of the Fenton oxidation for soil and water remediation. J Env Mgmt. 270, 110886.
Vega, M., Salas, G., Núñez-Ulloa, G., Pinto Cortez, C., Fernandez, I., Ho, Y.-S., 2019. Research performance and trends in child sexual abuse research: A Science Citation Index Expanded-based analysis. Scientometrics 121.
Wang, M.-H., Fu, H.-Z., Ho, Y.-S., 2011. Comparison of universities' scientific performance using bibliometric indicators. Malays J Libr Inf Sci. 16, 1–19.
Wang, M.-H., Ho, Y.-S., 2011. Research articles and publication trends in environmental sciences from 1998 to 2009. Arch Env Sci. 5, 1–10.
Wareth, G., Melzer, F., El-Diasty, M., Schmoock, G., Elbauomy, E., Abdel-Hamid, N., Sayour, A., Neubauer, H., 2017. Isolation of *Brucella abortus* from a dog and a cat confirms their biological role in re-emergence and dissemination of bovine brucellosis on dairy farms. Transbound. Emerg. Dis. 64, e27–e30.
Zhang, G., Xie, S., Ho, Y.-S., 2010. A bibliometric analysis of world volatile organic compounds research trends. Scientometrics 83, 477–492.