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Original Article

A global bibliometric analysis of *Salmonella* Typhi over the past 52 years (1970–2022)

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Abstract

Introduction: *Salmonella Typhi* (*S. Typhi),* a bacterial human-restricted pathogen, is an essential systemic health problem of global importance in humans and animals. This study aimed to determine the overall scientific impact of *Salmonella Typhi* (*S. Typhi)* research using bibliometric methods.

Methodology: In this research, a bibliometric analysis was performed on *S. Typhi* using the Web of Science (WoS) database and the Bibliometrix R package. A total of 1,966 articles, published between 1970-2022, were analyzed.

Results: This bibliometric analysis showed that the most productive years in the process were 2012 and 2022. This analysis also showed that Infection and Immunity Journal was the leading journal with a total of 1,332 articles in publications related to *S. Typhi* research, with the USA being the most productive country in *S.* Typhi publications, as well as having the highest co-authorship collaboration. The University System of Maryland ranked first with 110 records when affiliations were analyzed. The United States Department of Health and Human Services was at the top of the Funding Agencies analysis. Analysis of the most cited authors revealed that Parry CM was the first most cited author (n = 90) of *S. Typhi* publications.

Conclusions: This bibliometric analysis showed that the countries with high economic income were dominant in the studies of published articles, affiliations, and funding agencies on *S. Typhi.* Collaboration of researchers from countries with low or middle incomes with *S. Typhi* epidemics and researchers from countries with high economic income will make the fight against these bacteria more effective.

Key words: Bibliometric analysis; publications; *Salmonella* Typhi; salmonellosis; typhoid fever.

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Introduction

Salmonella enterica subspecies *enterica* serovar Typhi or *Salmonella* Typhi bacteria causes typhoid fever which is a systemic infection. This disease is a major cause of morbidity and mortality worldwide [1-3]. *Salmonella* species are facultative anaerobic, intracellular, Gram-negative, flagellated, non-spore-forming bacteria that belong to the group of the *Enterobacteriaceae* family [4]. People with typhoid fever have bacteria in their blood and intestines [5].

According to the World Health Organisation (WHO) data typhoid fever affects an estimated 21.6–26.9 million cases and 216.000 deaths worldwide each year [5,6]. The most common transmission route to humans is through the consumption of contaminated food or water (oral/fecal route) or by direct contact with an infected person [5,7].

Salmonella infections are frequently seen in the bloodstream. The cornerstone of laboratory diagnosis is still a microbiologic culture of blood or bone marrow [7]. Due to the difficulty of separating typhoid fever from other causes of febrile diseases and the lack of laboratory services in several low- and middle-income countries, routine practice for precise diagnosis and adequate antibiotic therapy is difficult [8].

Children in south-central and southeast Asia are particularly at risk of this infection [9]. It appears that typhoid fever has increased in prevalence or that it was previously underappreciated in sub-Saharan African countries [3]. Populations without access to clean water and adequate sanitation are at greater risk. Prolonged fever, restlessness, headache, nausea, stomach pain, and either constipation or diarrhea are some of the symptoms. Some patients may develop a rash. Severe cases could result in fatal complications [5]. Historically, the first-line antibiotic therapies for typhoid fever were ampicillin, trimethoprim-sulfamethoxazole, and chloramphenicol [7]. Antibiotics are a breakthrough in the management of enteric fever. However, a major barrier to its treatment

is the development of antibiotic resistance brought on by the acquisition of resistance. Multi-drug-resistant *Salmonella* strains are selected through the use of antibiotics in people (and domestic animals for non-typhoidal *Salmonella*), posing serious impacts on global public health [10]. Antibiotic resistance has become more widespread as a result of this use and the selection of naturally occurring resistant strains from the environment. As typhoid is human-restricted, overuse in humans would have a much greater effect than that in animals. For many years, vaccines have been used to prevent typhoid, but in December 2017, the WHO prequalified a new typhoid conjugate vaccine that provides longer-lasting immunity [5].

To better understand scientific research and its evolution in a given field, bibliometric studies, which analyse research trends, have received a lot of attention in recent years. The structure and accumulation of scientific knowledge in particular fields can be mapped through such analysis, and it is also possible to evaluate the development of certain disciplines over time [11-16]. The primary objective of this study was to report on global trends in *S.* Typhi research, by analysing bibliometric data from articles in the Web of Science database.

Methodology

Data collection

A thorough search technique was used to gather data in the online version of the Web of Science (WoS) (Clarivate Analytics, Philadelphia, PA, USA) database's Science Citation Index Expanded (SCI-EXPANDED) which is one of the most comprehensive and experienced bibliographic databases covering multidisciplinary sciences all over the world. Because the WoS database is updated daily, the data collected in a single day was theorised to be most reliable for this analysis. After the data was extracted, they were analysed according to the research questions. Our main research goal was to find insights into *S.* Typhi with the decoupling between research questions. All data were acquired by searching the database for literature concerned with salmonellosis with the consequent parameters: WoS TOPIC of title, abstract, author keywords, and keywords plus. The use of citation signs (“ ”) is obligatory to determine the full searched nomenclature by preventing the lemmatization and synonym characteristics of WoSCC (by default, in the search setting, these properties are ON) [17]. Since it is necessary to use different expressions in this search feature, the Boolean operator was used, which allows at least one term to appear on this subject. There are no time or country restrictions on these searches. The online search was updated on 8 November 2022. The search strategy consisted of combining the Boolean operator "AND" to get the intersection. Specifically, we used the following Boolean search phrase: "*Salmonella* Typhi" OR "*S.* Typhi" OR "*Salmonella enterica* subspecies *enterica* serovar Typhi" of the WoS database. The search was carried out in all available data series for the last 52 years, from 1970 to 2022. It is important to note in the method that KeyWords Plus can obtain additional search terms extracted from the article titles referenced in the WoS database, resulting in a significant increase in title-word and author-keyword indexing [18]. For this reason, this bibliometric analysis was also analysed by KeyWords Plus.

Table 1. Literature data on *S.* Typhi.

Description	Results
Keywords plus (ID)	1645
Author's keywords (DE)	1142
Period	1970-2022
Average citations per documents	23,9
Authors	3938
Author appearances	5352
Authors of single-authored documents	42
Authors of multi-authored documents	3896
Single-authored documents	43
Documents per author	0,254
Authors per document	3,94
Co-authors per documents	5,35
Collaboration index	4,07
H index	94

Data analysis

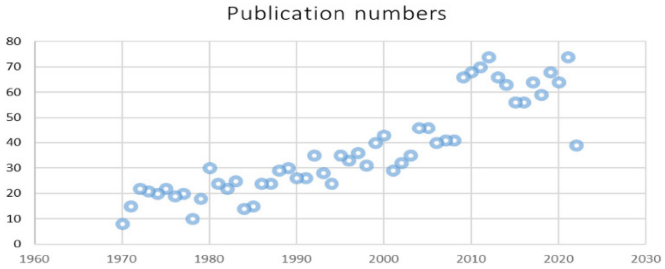
The search was restricted to journal articles. Book reviews, conference papers, letters, erratum-type materials, and editorials were not included. To examine the trends in collaboration and thematic development in the manuscripts, the open-source data visualization tool Biblioshiny (version 2.0) was utilized. Also, a topic dendrogram was composed and situated on the identified research subjects. The topic dendrogram showed the relationship of documents in terms of common vocabulary and the effect of cooperation between countries in terms of publication frequency.

Results

Search findings for S. Typhi

A total of 2,699 documents were extracted from the WoS database. Finally, 1,966 research articles were selected and retrieved for the bibliometric analysis. These publications were written in 13 different languages. English (n = 1792, 91,15%) is the most common language followed by Russian (n = 56, 2.85%), French (n = 55, 2.80%), German (n = 23, 1.17%), Spanish (n = 18, 0.1), Italian (n = 5, 0.25%),

Figure 1. Distribution of Publications by Years.



Chinese (n = 4, 0.20%), Portuguese (n = 4, 0.20%), Czech (n = 2, 0.10%), Hungarian (n = 2, 0.10%), Norwegian (n = 2, 0.10%), Turkish (n = 2, 0.10%), and Japanese (n = 1, 0.5%).

Qualifications of the included literature

For articles related to *S.* tyhpi, the average number of citations per document was 23.9, whereas the average number of authors per document was 3.94. There was a total of 3,938 authors in the 1,966 publications, and the number of single-authored documents was 43. While the collaboration index of the publications was 4.07, the H index was 97 (Table 1).

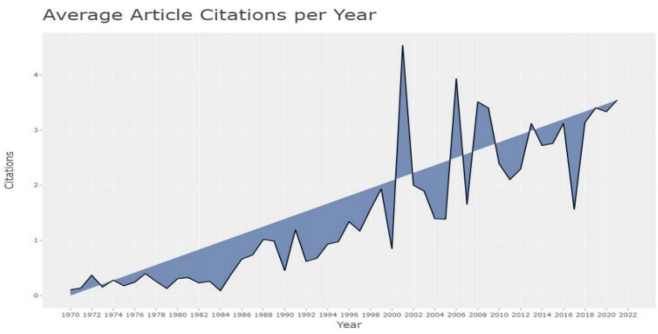
The tendency of publication and citation

The bibliometric analysis showed the number of articles in an increasing trend over time. As shown in Figure 1, the annual amount of publications showed a fluctuating but increasing trend from 1970 to 2022. The number of publications peaked in 2012 and 2022. Figure 2 shows the average article citations, with 2001 being the year with the highest number of citations. The average article citations for all articles appear in this figure.

Table 2. Most cited journals from reference lists.

Sources	Cited Article numbers
Infection and Immunity	1332
Journal of Bacteriology	1155
Journal of Clinical Microbiology	762
Proceedings of the National Academy of Sciences USA	591
Antimicrobial Agents and Chemotherapy	555
The Journal of Infectious Diseases	555
Lancet	539
Molecular Microbiology	474
Nature	434
Clinical Infectious Diseases	420
The New England Journal of Medicine	342
Vaccine	303
Journal of Biological Chemistry	289
Journal of Immunology	264
Nucleic Acids Research	241
Journal of Antimicrobial Chemotherapy	235
Science	224
Bulletin of the World Health Organization	206
Journal of Molecular Biology	201
Plos One	196

Figure 2. Average Citations Per Year.



Publication performances: journals, funding agencies, and countries

Table 2 presents a list of the top 20 most productive *S.* Typhi-related journals. The journal 'Infection and Immunity' was the most productive journal with 1,332 articles. The Journal of Bacteriology was the second with the *S.* Typhi articles it published (1,155 articles), and the Journal of Clinical Microbiology was the third with 762 articles. The list of funding agencies supporting the first 25 *S.* Typhi studies in this analysis period and their percentage share is presented in Table 3. Table 4 lists the top 30 most productive countries in *S.* Typhi research output. Of these, most studies originated from the USA, UK, India or China. The USA was at the top of the list with 414 (21.05%) articles,

Table 3. Funding Agencies.

Funding Agencies	Record Count	% of 1.966
United States Department of Health Human Services	224	11.394
National Institutes of Health	214	10.885
National Institute of Allergy Infectious Diseases	180	9.156
Wellcome Trust	100	5.086
European Commission	76	3.866
National Natural Science Foundation of China	55	2.798
Bill Melinda Gates Foundation	49	2.492
UK Research Innovation	39	1.984
Indian Council of Medical Research Icmr	37	1.882
Medical Research Council UK	30	1.526
Consejo Nacional De Ciencia Y Tecnologia Conacyt	24	1.221
Council of Scientific Industrial Research	21	1.068
Comision Nacional De Investigacion Cientifica Y Tecnologica Conicyt	20	1.017
Fogarty International Center	20	1.017
Biotechnology And Biological Sciences Research Council	19	0.966
Cgiar	19	0.966
United States Public Health Service	19	0.966
Conicyt Fondecyt	18	0.916
Department of Science Technology	18	0.916
National Institute for Health Research	18	0.916
Department of Biotechnology India	17	0.865
National Health and Medical Research Council of Australia	17	0.865
Natural Sciences and Engineering Research Council of Canada	15	0.763
Higher Education Commission of Pakistan	14	0.712
Natural Science Foundation of Jiangsu Province	14	0.712

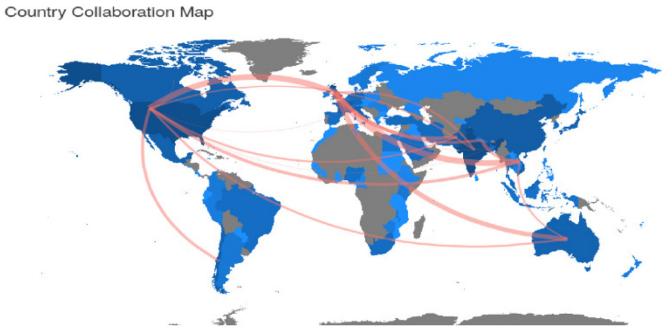
Table 4. Publishing Countries.

Countries/Regions	Record Count	% of 1.966
USA	414	21.058
India	350	17.803
England	224	11.394
Peoples R China	113	5.748
Pakistan	89	4.527
France	84	4.273
Mexico	80	4.069
Canada	72	3.662
Australia	69	3.510
Chile	69	3.510
Vietnam	68	3.459
Malaysia	66	3.357
Japan	64	3.255
Italy	60	3.052
USSR	50	2.543
Germany	45	2.289
Switzerland	43	2.187
South Korea	42	2.136
Bangladesh	40	2.035
Thailand	35	1.780
Netherlands	34	1.729
Spain	30	1.526
Iran	27	1.373
Saudi Arabia	25	1.272
Nepal	24	1.221
South Africa	24	1.221
Israel	22	1.119
Taiwan	22	1.119
Brazil	21	1.068
Turkey	21	1.068

India was second with 350 articles (17.80%), and England was third with 224 (11.39) articles.

Scientific collaboration at the global level is presented in Figure 3, where developed countries have emerged as the most productive countries in cooperation. The width of the connecting lines is a symbol of a higher level of cooperation, and the intensity of the color blue increases with the rate of cooperation. In addition to the USA, India, England, and China are prominent in research density. This ranking is not surprising, with the dominance of these countries likely being explained by their economic development, and substantial financial support for scientific research.

Figure 3. Country Collaboration Map.



Searching key terms

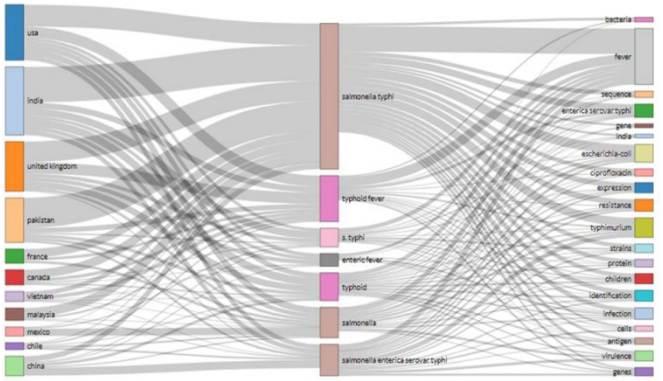
Analysing the distribution of words in articles is very useful for analysing trends in the relevant field of research. These analyses can minimize various limitations on research issues with keywords plus [19]. Therefore, an analysis of publications between 1970 and 2022 was carried out to show gross trends while minimising fluctuations (in article titles, abstracts, keywords, and keywords plus). Their distribution has allowed us to visualize major focuses and trends in *S.* Typhi-related publications over the years. Figure 4 shows the bibliometrics of the WordCloud treatment (Studio R), which includes the top 50 most common keywords. In the figure legend, bigger words appear more in this bibliometric analysis. The minimum number of occurrences for which a keyword is to be set is 20. A total of 1,142 keywords were drawn that crossed the threshold for the network visualization. The most used keyword is "fever".

Network visualization

The three-field plot demonstrated above is a representation of the three units, consisting of countries, keyword plus, and keywords (Figure 5). These were drawn in order, with gray links displaying their

Figure 4. Word Cloud.

Figure 5. Three-Fields Plot (Countries-KeyWords Plus-Keywords).



relationship to each other. The size of each rectangle in each list indicates the number of publications related to that unit. The first unit, on the left, is the countries. Eleven countries were indexed in the three fields plot as having published papers on the topic of *S.* Typhi. The second unit in the middle contains the keywords plus. Most of the countries have merged into the "*Salmonella* Typhi" keyword plus. The third unit contains the keywords that appeared most frequently in the publications. Twenty keywords are listed, and the keyword that appeared most frequently was "fever" as demonstrated by the size of the grey rectangle, which dominated the other rectangles.

In the visualization of the topic dendrogram, the distance between the clusters on the y-axis of the dendrogram is seen (Figure 6). As shown in Table 5 the most cited literature among *S.* Typhi publications was the article titled "Complete genome sequence of a multiple drug-resistant *Salmonella enterica s*erovar Typhi CT18" with 937 citations., Parkhill *et al* (2001) followed by Devi *et al* (2010) and Germanie and Furer (1975).

The thematic map

The thematic map was drawn using the keywords plus, which are constantly included in the titles of the sources cited in the article and not in the title of the article. The thematic map was performed based on a two-dimensional matrix containing two types of metrics: centrality (X-axis indicating the importance of the theme) and density (Y-axis indicating the development of the theme). According to the thematic

Figure 6. Topic Dendrogram.

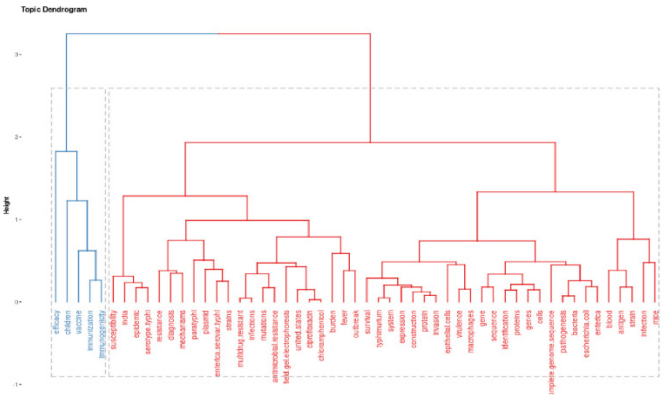
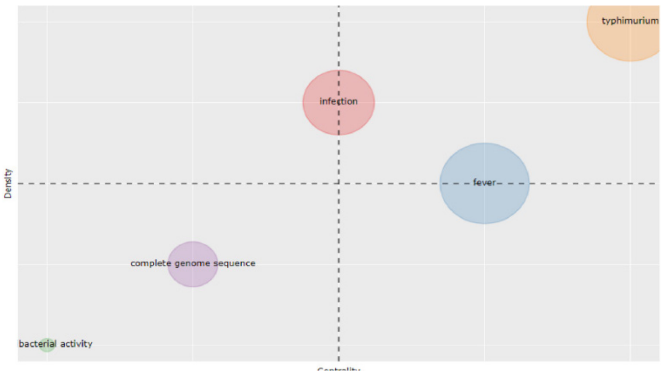


Table 5. Top Ten Most-Cited References on *S.* Typhi.

No	Author	Title	Source title	Doi	Year	Citation
1.	Parkhill J *et. al.*	Complete genome sequence of a multiple drug-resistant *Salmonella enterica* serovar Typhi CT18	Nature	10.1038/35101607	2001	937
2.	Devi K *et. al.*	Eugenol (an essential oil of clove) acts as an antibacterial agent against Salmonella typhi by disrupting the cellular membrane	Journal Of Ethnopharmacology	10.1016/j.jep.2010.04.025	2010	468
3.	Germanie R and Furer E	Isolation And Characterization of Gal-E Mutant Ty 21a of *Salmonella*-Typhi - Candidate Strain for a Live, Oral Typhoid Vaccine	Journal Of Infectious Diseases	10.1093/infdis/131.5.553	1975	428
4.	Langridge Gemma C *et. al.*	Simultaneous assay of every *Salmonella* Typhi gene using one million transposon mutants	Genome Research	10.1101/gr.097097.109	2009	396
5.	Holt Kathryn E *et. al.*	High-throughput sequencing provides insights into genome variation and evolution in *Salmonella* Typhi	Nature Genetics	10.1038/ng.195	2008	390
6.	Klemm, Elizabeth J *et. al.*	Emergence of an Extensively Drug-Resistant Salmonella enterica Serovar Typhi Clone Harboring a Promiscuous Plasmid Encoding Resistance to Fluoroquinolones and Third-Generation Cephalosporins	mBio	10.1128/mBio.00105-18	2018	340
7.	Lin FYC *et. al.*	The efficacy of a *Salmonella* Typhi Vi conjugate vaccine in two-to-five-year-old children	New England Journal of Medicine	10.1056/NEJM200104263441701	2001	325
8.	Achary IL *et. al.*	Prevention of Typhoid-Fever in Nepal with The Vı Capsular Polysaccharide of *Salmonella*-Typhi - A Preliminary-Report	New England Journal of Medicine	10.1056/NEJM198710293171801	1987	305
9.	McClelland M *et. al.*	Comparison of genome degradation in Paratyphi A and Typhi, human-restricted serovars of Salmonella enterica that cause typhoid	Nature Genetics	10.1038/ng1470	2004	297
10.	Wong Vanessa K *et. al.*	Comparison of genome degradation in Paratyphi A and Typhi, human-restricted serovars of *Salmonella enterica t*hat cause typhoid	Nature Genetics	10.1038/ng.3281	2015	280

map, it included five words representing themes (fever, infection, *typhimurium*, complete genome sequence, bacterial activity). In the thematic map, the size of the bubbles is proportional to the number of times the term occurs. Density order and centrality order are shown in Figure 7. The top right quarter of the graph shows higher intensity and the bottom left quarter shows lower intensity.

Figure 7. Thematic Map.



Discussion

The results of bibliometric analyses have attracted the attention of scientists in recent years, as they gather a lot of data [20]. Due to its method of assessing the research trend of a particular subject area with various bibliometric indicators, this analysis is used in many different fields of science, including medicine and health sciences. This study focused on global research trends and findings on *S.* Typhi, a human-restricted food-borne disease. In our bibliometric analysis of *S.* Typhi research over the past 52 years (1970–2022), we have observed a steady increase in the number of articles, similar to another bibliometric analysis of the resistome of *S.* Typhi [21]. Average citations have been declining in recent years (between 2014 and 2022), probably because previous publications are cited more often than newly published articles [22].

Journals are important tools for announcing research to other scientists in the relevant field. The prestige of a journal is also its effect on the transmission of the research it publishes to the relevant segment of society [23,24]. If we look at the best journals according to the number of articles they have published, we see that impact factors do not play a role in the ranking. This analysis accepts the view that the impact factor of article publications does not necessarily reflect the quality of the articles [22, 24].

Cases from *S.* Typhi remain a serious disease, causing a large and widespread health burden, with an estimated 21.6–26.9 million cases and 216,000 deaths worldwide each year [20,25]. Our data show that most *S.* Typhi publications come from the USA; it has been reported that the USA spends more on research than any other country [26]. The number of research funds secured by the top five productive countries was directly proportional to the number of articles they published. While in the USA, approximately 350 culture-confirmed cases are reported to the CDC every year, it was reported in a review published in 2018 that the number of outbreaks reported in the European continent was 28, while outbreaks number was 155 in the Asian continent and 46 outbreaks in Africa [9]. It is estimated that more than 38,000 cases of salmonellosis are seen each year in England, which had the third highest research output [21,27]. Additionally, among the top 5 most cited authors, 3 were from the United Kingdom, one from India, and one from Switzerland. However, Switzerland was 17th on the list of the most productive countries. It is not surprising that a researcher from Switzerland is the fifth most cited author, as reforms since 2000 have strengthened regulations in the field of epidemic control and harmonized human resources regulations in the country [28]. The budget allocated by countries to diseases that burden their economies is the most important factor in promoting research [29]. The results of this bibliometric analysis show that most of the funding agencies are from the USA. It indicates the need for large-scale cross-national studies with a budget focusing on prophylactic studies on *S.* Typhi.

A total of 1,645 keywords were determined by keyword analysis that appeared together in VOSviewer. In the keyword plus analysis, the most frequent keywords were "fever" and "typhimurium". The fact that *S.* Typhi causes typhoid fever in humans may have caused these keywords to be the most frequently used. When WordCloud is examined, keywords such as "resistance", "ciprofloxacin", "antimicrobial resistance", and "multidrug resistance" are present due to antibiotic resistance in this bacterial strain.

Topic dendrograms show the most commonly used topics, their relationship to other topics, and their classification in different colors [30]. In this analysis, the related words appear in the red and blue clusters of the topic dendrogram. In the red cluster, we see a greater number of different interrelated terms. This indicates that many *S.* Typhi literatures are closely linked to the words given in this cluster. In addition, most of the subjects are gathered under a single cluster due to the frequent relationship between them. In the dendrogram, we also see that the themes in the blue

classification have little in common with those in the red classification. Each color is divided into many subgroups and many subjects are included in one group. In short, if we divide the subjects into two clusters in the *S.* Typhi document; the first is the topics studied on *S.* Typhi (red cluster), and the second is the topics related to immunity (blue cluster). The dendrogram describes the dominance of the first group of topics in the world. Articles reporting that the bacterium is still active all over the world support the red cluster density of the dendrogram [1,2,4,5,8,9,20,25,31,32].

Conclusions

This bibliometric analysis includes the most used keywords in *S.* Typhi research to date, the leading countries, the most cited authors, the most cited journals, the highest contributing funding institutions, and the qualitative and quantitative evaluations of global collaboration scenarios, alongside much more data in all dimensions. USA researchers and funding agencies dominated the published *S.* Typhi studies, followed by India. This result highlighted the importance of collaborating with researchers from low- and middle-income countries and researchers from more productive and high-income countries. Acting globally to fight against human-restricted pathogens will provide more effective results.

Conflict of interests: No conflict of interests is declared.

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Conflict of interests

No conflict of interests is declared.

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