Global Mycobacterium avium subsp. paratuberculosis Research Trends: A Network and Bibliometric Analysis

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ABSTRACT

MAP is the causative agent of paratuberculosis and has also been implicated in the etiology of Crohn's Disease in humans. Therefore, the importance of studies on this subject increases as MAP causes many economic losses by causing disease in cattle and is important for public health. The aim of this paper was to map the global scientific landscape related to MAP research. The WOS database was queried for publications bearing the title "Mycobacterium avium subsp. paratuberculosis" during January 2001-December 2021 employing the R bibliometrix program. A total of 1775 articles were reviewed in this bibliometric analysis. Notably, the majority of these articles originated from the USA (n = 536, 30.541%). The year 2013 emerged as the most productive year for publications. In terms of research fields, veterinary science (n = 730, 41.6%) was the leading research area. These studies were conducted by a diverse array of researchers, including veterinarians, physicians, and other experts working to define MAP. The sustained increase in the number of publications on paratuberculosis underscores the ongoing global interest in this factor. The determination of effective control strategies for paratuberculosis is important for the food sector and public health. Therefore, a research collaboration between countries should be established in this regard.

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Introduction

Mycobacterium avium subsp. paratuberculosis (MAP) is a Gram-positive bacterium with a size of 0.5×1.5 microns as short thick rods. MAP is acid-fast, immobile, non-spore-forming, aerobic, non-encapsulated, and an obligate intracellular bacterium. It grows very slowly in media and forms a visible colony in 8-24 weeks [1]. Due to its lipid-rich cell wall, MAP can survive for over a year in cattle feces and soil, approximately 160 days in river waters, 9 months in pool waters, and at least one year at -14°C [2]. MAP is the etiological agent of paratuberculosis (Johne's disease), an infectious disease characterized by chronic gastroenteritis, diarrhea, and emaciation in domestic and wild ruminants [3, 4]. Animals usually contract MAP through the consumption of contaminated feed, water, and colostrum. In infected animals, it progresses with diverse symptoms, such as severe diarrhea, cachexia, rough fur, dry skin, severe anemia, submandibular edema, and a decrease in milk yield [5]. Paratuberculosis has been reported in many countries with a high prevalence [6-8]. There is a hypothesis that MAP, the causative agent of paratuberculosis, may also be involved in Crohn's disease in humans [9]. Crohn's disease is a chronic inflammatory condition affecting the human gastrointestinal tract from the mouth to the anus, and its exact cause remains undetermined [3]. The similarity of the clinical and pathological findings between paratuberculosis in animals and Crohn's disease in humans supports the idea that MAP might be involved in Crohn's disease [10, 11]. Studies have shown the presence of MAP DNA in the intestines of individuals with Crohn's disease, strengthening the notion that MAP could play a role in this disease [12, 13].

It has been suggested that the transmission of MAP from infected animals to humans may occur through the consumption of contaminated meat, meat products, dairy products, and water [14]. Both milk and feces from dairy cows with clinical and subclinical paratuberculosis can lead to foodborne contamination [15]. Studies have reported the presence of MAP in milk, dairy products, meat, meat products, baby foods, and river waters [16-20]. The fact that MAP causes great economic losses in the ruminant/livestock industry worldwide, harming animal welfare, and its role in Chron's disease in humans reveals the importance and seriousness of this bacterium. Recently, there have been increasing reports on the role and importance of MAP in public health [21].

The aim of this study was to investigate the importance of publications in this field and to perform a bibliometric analysis to review relevant trends and clusters. This analysis will provide a better understanding of the direction for future scientific and clinical research.

Result

Document Analysis

In our bibliometric analysis of MAP studies conducted during 2001-2021, we identified 1755 articles, 96.467% of which were published in SCIE-indexed journals, and 3.533% were published in ESCI-indexed journals. English was the predominant language, ac-

Table 1.
Number and rates of articles by languages.

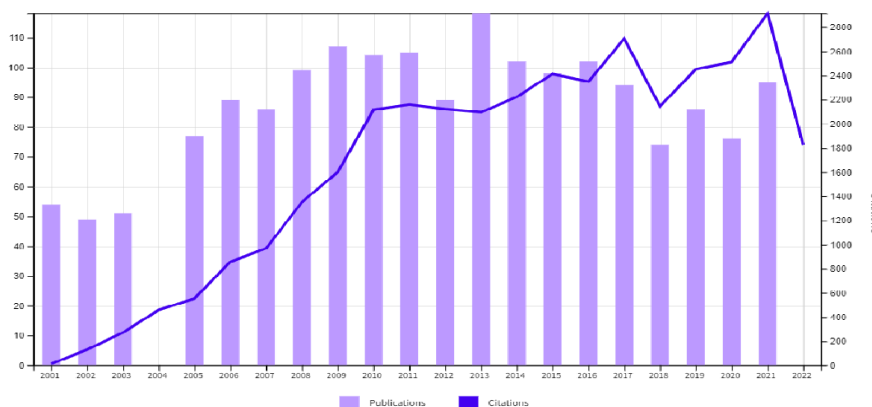| Languages	Record Count	% of 1.755
English	1722	98.120
Spanish	13	0.741
German	10	0.570
Portuguese	5	0.285
Indonesian	2	0.114
Polish	2	0.114
Italian	1	0.057

Figure 1.
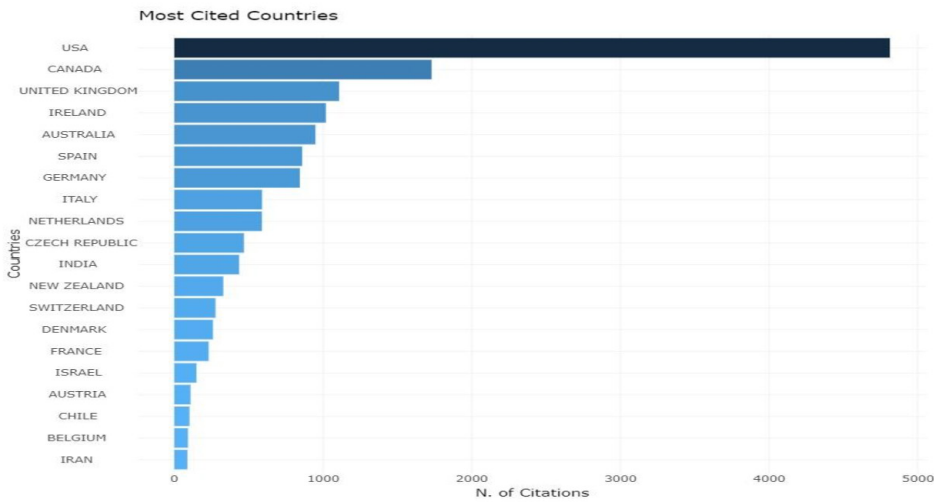Publication and citation frequency of *Mycobacterium avium subsp. paratuberculosis* by year.

Figure 3.
Global article map of Mycobacterium *avium subsp. paratuberculosis*
*4 record(s) (0.228%) do not contain data in the field being analyzed

counting for 95.448% of the papers (Table 1).

Citation Distribution by Year

The analyzed articles amassed a total of 36 237 citations, resulting in an average h-index of 72. Notably, 2013 had the highest number of papers, while 2021 had the highest number of citations (Figure 1). The United States was the most cited country (Figure 2).

Distribution of Publications by Country

The leading countries in terms of MAP-related publications were the USA (n = 536), Canada (n = 167), and Australia (n = 141). MAP-related publications emanated from 75 different countries across the globe (Table 2 and Figure 3).

Most Active Research Areas

The articles were primarily related to the research fields of Veterinary Sciences (n = 730), Microbiology (n = 519), and Immunology (n = 287) (Table 3).

Table 2.
Most productive countries on MAP research.

Countries/Regions	Record Count	% of 1.755
USA	536	30.541
Canada	167	9.516
Australia	141	8.034
Germany	133	7.578
India	127	7.236
Italy	116	6.610
Spain	84	4.786
Netherlands	79	4.501
England	67	3.818
New Zealand	55	3.134
Czech Republic	53	3.020
North Ireland	51	2.906
Scotland	45	2.564
France	44	2.507
Ireland	39	2.222
South Korea	39	2.222
Egypt	37	2.108
Iran	37	2.108
Chile	35	1.994
Argentina	34	1.937
Brazil	31	1.766
Japan	31	1.766
Denmark	29	1.652
Norway	23	1.311
Greece	22	1.254

Table 3.
Research areas of the publications on MAP

Research Areas	Record Count	% of 1.755
Veterinary Sciences	730	41.595
Microbiology	519	29.573
Immunology	287	16.353
Agriculture	226	12.877
Food Science Technology	169	9.630
Biotechnology Applied Microbiology	158	9.003
Infectious Diseases	134	7.635
Science Technology Other Topics	81	4.615
Biochemistry Molecular Biology	79	4.501
Gastroenterology Hepatology	55	3.134
Research Experimental Medicine	38	2.165
Genetics Heredity	28	1.595
Cell Biology	22	1.254
Public Environmental Occupational Health	15	0.855
Zoology	15	0.855
Neurosciences Neurology	14	0.798
Pathology	14	0.798
Life Sciences Biomedicine Other Topics	12	0.684
Chemistry	10	0.570
Reproductive Biology	8	0.456
General Internal Medicine	6	0.342
Engineering	5	0.285
Environmental Sciences Ecology	4	0.228
Mathematical Computational Biology	4	0.228
Pharmacology Pharmacy	4	0.228

*Showing 25 out of 53 entries, 5 record(s) (0.285%) do not contain data in the field being analyzed.

Most Prolific Affiliations

The organization with the most extensive research output on MAP, contributing 168 articles, was the United States Department of Agriculture (USDA) (Table 4).

Most Prolific Journals

The Journal of Dairy Science stood out as the journal with the highest number of MAP-related papers, with a total of 102 publications on this subject (Table 5).

Keyword Occurrence

Our bibliometric analysis highlighted the most frequently used keywords depicted in Figure 4. Keywords are integral to bibliometric analysis, aiding in the identification of primary topics and themes within a specific research area. Search engine algorithms rely on keywords to detect relevant literature. In our keyword visualization analysis, colors indicate preferred keywords, with red representing particularly popular ones. Keywords displayed in larger font sizes had a higher frequency of occurrence in the articles (Figure 2).

Bibliographic Coupling Between Countries

In the network visualization of bibliographic coupling between countries, the size of the bubbles was directly proportional to the volume of research conducted by each country. The width of the lines connecting countries indicates the strength of their coupling, while the line colors signify the cluster to which each country has been assigned. For this research, we considered a

Figure 4.
Keyword visualization map of articles containing *Mycobacterium avium subsp.* paratuberculosis at least 5 times
*** Colors demonstrate preferred keywords, especially red show popular keywords.. Keywords represented with larger circle size or font size had a relatively higher occurrence in the articles.

Table 4.
List of the top affiliations.

Affiliations	Record Count	% of 1.755
United States Department of Agriculture USDA	168	9.573
University of Wisconsin System	88	5.014
University of Wisconsin Madison	87	4.957
University of Sydney	84	4.786
Indian Council of Agricultural Research Icar	81	4.615
University of Minnesota System	76	4.330
University of Minnesota Twin Cities	76	4.330
University of Sassari	58	3.305
Cornell University	53	3.020
Czech Veterinary Research Institute	53	3.020
Iowa State University	53	3.020
Icar Central Institute for Research on Goats	51	2.906
University of Guelph	48	2.735
University of Pennsylvania	48	2.735
University of Calgary	46	2.621
Queens University Belfast	45	2.564
Icar Indian Veterinary Research Institute	39	2.222
Utrecht University	39	2.222
Egyptian Knowledge Bank Ekb	37	2.108
University of Veterinary Medicine Hannover Foundation	36	2.051
Justus Liebig University Giessen	35	1.994
Universidad Austral De Chile	35	1.994
Agresearch New Zealand	34	1.937
Inrae	33	1.880
Friedrich Loeffler Institute	31	1.766

*Showing 25 out of 1.201 entries, 753 record(s) (42.906%) do not contain data in the field being analyzed.

Discussion

The results of bibliometric analysis in the field of diseases have increasingly captured the attention of scientists in recent years [22, 23]. Bibliometric analysis provides a scientific map of various diseases. In the realm of health sciences, it evaluates how a particular disease has evolved over the years and how the inclination to research that disease has shifted, employing a variety of indicators. Bibliometric analysis serves as an analytical method unveiling the broader intellectual landscape surrounding the disease while helping to identify particularly influential articles [23, 24].

In our bibliometric analysis of MAP studies spanning from 2001 to 2021, we discovered 1775 articles, 96.467% and 3.533% of which were published in SCIE-indexed and ESCI-indexed journals, respectively. These papers collectively received 36 237 citations, resulting in an average h-index of 72. While the year 2013 had the highest number of articles, 2021 saw the highest number of citations. A steady increase in the number of citations persisted until 2017; however, in recent years (2018-2020), the average number of citations has decreased. This phenomenon might be attributed to older publications being cited more frequently than newly published articles within that year [25].

Our findings revealed that a substantial portion of MAP publications originated from the United States, accounting for 30.541 articles. This is hardly surprising, as the USA, similar to the case of tuberculosis, allocates more resources to research and development related to paratuberculosis than most other countries [26]. In terms of the sheer number of publications, Canada ranks second with 9516 articles, while Australia se-
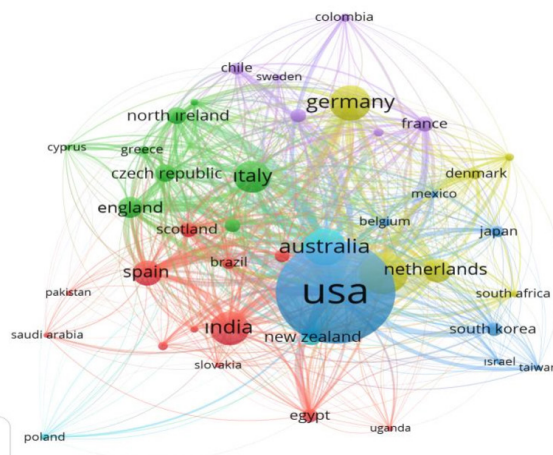

Figure 5.
Countries with at least 5 publications and 5 citations are shown on the map. *Collaboration is shown with lines linking nations. Stronger cooperation is indicated by thicker lines. Countries with a bigger circle or text size had a higher level of international cooperation.

cures the third position with 8349 articles. The presence of these countries in the top three may signify the widespread prevalence of this factor within their regions. Germany, as the fourth most productive country, with 7578 publications, can be linked to its substantial research funding initiatives. India, an Asian nation, also occupies a prominent position in the top five for productivity in MAP research. An overarching examination of the worldwide distribution of publications by country underscores the necessity for the development and implementation of global strategies to combat paratuberculosis.

Reviewing the leading journals based on the number of published articles, we find that the Journal of Dairy Science, ranked first, with an impact factor of 4.225. It is worth noting that the official publication of the American Dairy Science Association is not only indexed in WOS but is also included in various databases, such as Agricola, Biological Abstracts, Biological and Agriculture Index, BIOSIS Database, CABI Abstracts, Current Contents, Elsevier Bibliographic Databases, PubMed, and Scopus. When examining the most cited publications, the article titled 'The Complete Genome Sequence of MAP' by Li L. et al. published in 2005, has garnered 353 citations.

In our co-citation analysis among countries, an interesting trend emerges; the countries ranking in the top ten for article publication, including the USA, Australia, Germany, India, Netherlands, Italy, and Spain, are also prominent in joint citation analysis for MAP.

The keywords "paratuberculosis" and "Johne's disease" were the most frequently encountered in our bibliometric analysis of the number of publications, which aligns

Table 5.

List of journals that published the greatest number of articles on MAP

Journals	Record Count	% of 1.755
Journal of Dairy Science	102	5.812
Veterinary Microbiology	94	5.356
Veterinary Immunology and Immunopathology	74	4.217
Plos One	58	3.305
Applied and Environmental Microbiology	57	3.248
Preventive Veterinary Medicine	52	2.963
Journal of Clinical Microbiology	42	2.393
Journal of Veterinary Diagnostic Investigation	38	2.165
Infection and Immunity	37	2.108
Clinical and Vaccine Immunology	32	1.823
Veterinary Research	26	1.481
Journal of Microbiological Methods	22	1.254
Vaccine	22	1.254
Small Ruminant Research	21	1.197
Tropical Animal Health and Production	21	1.197
Journal of Wildlife Diseases	19	1.083
American Journal of Veterinary Research	18	1.026
Canadian Veterinary Journal Revue Veterinaire Canadienne	18	1.026
International Journal of Food Microbiology	18	1.026
Veterinary Record	18	1.026
BMC Microbiology	17	0.969
BMC Veterinary Research	17	0.969
Gut Pathogens	17	0.969
Journal of Applied Microbiology	17	0.969
Research in Veterinary Science	17	0.969

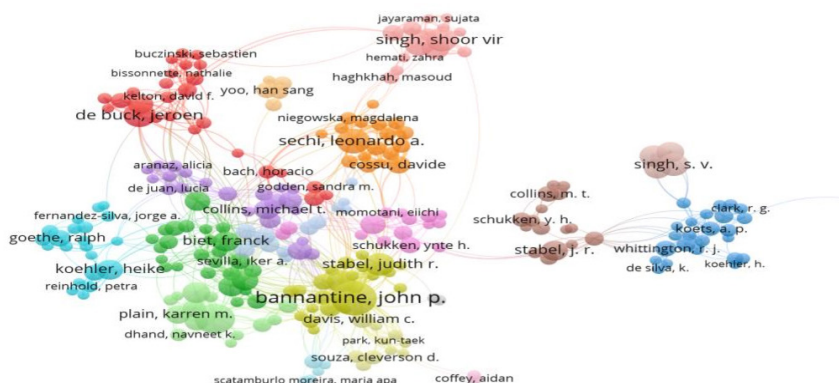*Showing 25 out of 329 entries

Figure 6.

Authors with at least 10 publications and 100 citations are shown on the map. **Citations are shown by lines linking authors. Authors with a greater circle size or font size had a higher number of citations.

with previous research confirming these data [27]. The fact that the agent is pathogenic for both animals and humans makes these keywords the most commonly used.

The varying budgets between countries and universities influence the number of research projects funded. The role of financial institutions in advancing science and research is crucial [28]. The results of the present research showed that the USA ranks in the top three financial institutions contributing to MAP research, which is consistent with other studies [29].

Analyzing the institutions where research published during 2001-2021 was conducted, the United States Department of Agriculture, the University of Wisconsin System, and the University of Wisconsin Madison emerged as the top three funders of paratuberculosis research. The significance of these data is expected to increase over time, encouraging funders to be more diligent in using official fund names [30]. In line with the mentioned argument, a book by Kazda et al. (2009) documented the prevalence of mycobacteria and their impact on the health of animals and humans, highlighting financial losses in ruminants due to MAP, food, and environmental contamination [31].

The majority of publications were in English (98.12%), and other languages included Spanish (0.74%), German (0.57%), Portuguese (0.28%), Indonesian (0.11%), Polish (0.11%), and Italian (0.05%). These findings in our bibliometric analysis align with a previous study [27]. The prevalence of English in publications can be attributed to the widespread acceptance of English in the scientific community and the fact that many publishers primarily accept articles in English, increasing the international accessibility of research findings.

The current study, conducted by veterinarians, physicians, and food researchers, aims to define MAP. It presents up-to-date data and sheds light on the boundaries and trends in paratuberculosis research from the past to the present. The continuous increase in the number of publications addressing paratuberculosis signifies that this factor remains a topic of active research worldwide. Given the importance of determining effective control strategies for paratuberculosis in both the food industry and public health, it is crucial to foster research collaborations between countries. This bibliometric analysis provides a substantial period within the scientific literature for assessing paratuberculosis, offering diverse data for future research endeavors.

In conclusion, this study provides up-to-date data on MAP, providing important information about the frontiers and trends in MAP research from past to present were presented. The steady rise in the number of publications on paratuberculosis reflects the continued global interest in this factor. Establishing effective control strategies for paratuberculosis is vital for the food industry and veterinary medicine as well as public health, highlighting the need for international research collaborations. This bibliometric analysis provides an important timeframe in the scientific literature for evaluating paratuberculosis and provides diverse data for future research in veterinary and human medicine.

Limitations

In this study, we examined the current status and prospects of MAP research through bibliometric analysis. However, there are several limitations to this analysis. Firstly, the scope of this bibliometric analysis was limited to publications published and indexed in the WOS database, potentially overlooking reports from other databases. Despite these limitations, the study provided valuable insights into MAP trends and identified areas with information gaps.

Secondly, considering that some authors may have multiple names or variations in name spellings, standardizing author names and terms based on VOSviewer results may not be entirely accurate. This could potentially lead to inaccurate results for certain authors. Despite these drawbacks, this article offers a foundational overview of MAP research.

Materials and Methods

Data Collection

Ethics approval was not required for this study as no human or animal participants were included. To retrieve Mycobacterium avium subsp. paratuberculosis publications, the WOS database (Clarivate PA, USA) was used. To evaluate the impact of scientific research effectively, the h-index was introduced as an alternative to traditional bibliometric indicators. Data for this research were sourced from the WOS database as of November 28, 2022. Information from WOS, including publication titles, authors' names, publication years, research countries, affiliated organizations, journal names, keywords, abstracts, and citation data for each record, was saved as TXT files and imported into Microsoft Office Excel 2019 (Los Angeles, USA). The research materials were accessed through Çanakkale Onsekiz Mart University's online library and digital resources.

Comprehensive Overview of the WOS Database

The WOS database was used to determine the research location or country, the type of study, authorship, and the number of citations. Only studies published during 2001-2021 were considered within the designated time frame. As the publication process for 2023 investigations has not been completed yet, those belonging to 2022 and 2023 were not included in the study. English was the selected search language, and h-index was employed as an indicator of publication impact.

Search Strategy

The search terms (keywords) for this study were "Mycobacterium avium paratuberculosis" (Title) OR "Mycobacterium avium subspecies paratuberculosis" (Title) and Article (Document Types) OR Science Citation Index Expanded (SCI-EXPANDED) OR Emerging Sources Citation Index (ESCI) (WOS Index) and 2001-2021 (Publication Years). The selected timeframe was 2001-2021, allowing us to observe bibliometric developments over the last two decades. This research exclusively included research articles, while letters, reviews, editorials, and other types of articles were excluded. The WOS publications saved as TXT files were imported into Microsoft Office Excel 2019 alongside document categories, publication years, author names, journals, affiliations, keywords, group authors, and citations.

Network Analysis

In this bibliometric study, VOSviewer (version 1.6.10, Leiden University, The Netherlands) was employed for data importation and also to reveal future trends, collaboration networks, and significant findings. In addition, authorship, links, keywords, citations, and thematic words were collected and reviewed using this software. This tool allowed for the analysis of keywords, co-occurrences, citations, co-authorships, and co-citations.

Authors' Contributions

M.E.A. and S.K.A. conceived and planned the experiments. S.A. carried out the analysis. M.E.A., S.K.A. and S.A. contributed to the interpretation of the results. M.E.A. took the lead in writing the manuscript. All authors provided critical feedback for nalysis and manuscript.

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Competing Interests

The authors declare that there is no conflict of interest.

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Online supplemental material

Supplementary Figure 1. A Three-field Plot (Sankey diagram) of country, keyword, and cited journals for the ten most researched topics.
Supplementary Figure 2. Trend topic

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