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Original Article

Trends in Aflatoxin M_1 Global Research: A Bibliometric Analysis Study

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Abstract

Background: Fungal metabolites known as aflatoxin M_1 (AFM_1) are linked to contaminated milk and milk products. Consuming food contaminated with AFM_1 poses major health risks and may even be fatal.

Methods: The retrieved publications were categorized in this bibliometric study using the Web of Science (WoS) database Jan 1, 1970 to Nov 30, 2022 based on a variety of factors, including the time of publication of articles, citation totals, languages, research areas, countries, affiliations, funding agencies, journals, and keywords analysis to identify any hot and developing subjects. Additionally, VOSviewer software version 1.6.18 provided the bibliometric analysis of the global collaboration network and hot research themes.

Results: Overall, 679 published documents were detected. Food Control was the top-line journal in publications on AFM_1 research with 540 published articles, while the USA was the best productive country in AFM_1 publications as well as the major country with the maximum co-authorship collaboration. This study ensures quantitative and qualitative analyses of the top 25 journals, most cited published articles, most relevant authors and title word occurrences in published documents on AFM_1 publications. Over the past two decades, there has been an enormous rise for research conducted on global AFM_1.

Conclusion: The assessment of the historical state and development trend in AFM_1 scientific research can serve as a roadmap for future research and eventually, serve as a foundation for bettering management practices for territorial decisions, healthcare, and dairy industries.

Keywords: Aflatoxin M_1; Milk; Bibliometric; VOSviewer software; Publications

Introduction

Aflatoxins are mycotoxins produced by different species of the genus *Aspergillus,* particularly *Aspergillus parasiticus* and *Aspergillus flavus* (1-3). Because of their many toxicological effects, aflatoxins are the most studied mycotoxins. They cause various diseases such as toxicity in the acute form and cancer in the chronic form. Therefore, they have properties such as extremely toxic, carcinogenic, teratogenic, and immunosuppressive (2). Aflatoxin B_1(AFB_1) is absorbed in the gastrointestinal tract of ruminants consuming contaminated feed and is metabolized in livers to aflatoxin M_1(AFM_1), secreted with milk and causes contamination of milk and dairy products (1). AFB_1

and AFM_1 were categorized by the International Agency for Research on Cancer (IARC) as Group 1 human carcinogens, with the creation of DNA adducts (4). Recent epidemiological research on cancer patients examined how AFB_1 and AFM_1 exposure affected cancer cells in an effort to confirm the link between toxin exposure and cancer cell growth and invasion (1). Both acute and chronic toxicoses have been linked to AFM_1. Since even trace amounts of this metabolite could have an impact on long-term exposure, the existence of AFM_1 in milk and dairy products is a global concern. Milk contamination can be reduced directly by lowering the AFM1 content in contaminated milk or indirectly by lowering the AFB_1 contamination in dairy animals' feeds (2).

The existence of AFM_1 in milk and dairy products causes an important threat to public health, and researchs have proven that it remains intact or comparatively stable later heat treatment like ultra-high temperature treatment or pasteurization (1, 5). Acute aflatoxin outbreaks have been reported in many countries around the world (6). Therefore, in addition to good agricultural and conservation operations, monitoring, periodic control of AFB1 in ruminant feeds and AFM_1 in milk and dairy products, and the implementation of legal limits are important to keep society's exposure to AFM_1 to a minimum (5).

The development of a given subject among many publications may be identified using bibliometric tools. Owing to the growing significance of AFM_1, it is important to summarize the literature on this topic and highlight their development and trends all over the World (7). Bibliometric analysis is cconvenient for this and is presented in this article. Bibliometrics is quantitative analysis for scientific research based on mathematical methods and computational technology (8). With the help of scientometric methods, the internal relationships in a literature collection can be quantitatively analyzed by combining philology, mathematics, and statistics. Scientometrics and bibliometric studies have been conducted on a variety of health-related issues (9-13). Although the subject of aflatoxins was examined in only one bibliometric analysis study (14), no similar study on AFM_1 was found in the available literature.

Materials and Methods

Study design

A descriptive bibliometric study was applied.

Data source

An online search was done in the Science Citation Index-Expanded (SCI-E). Web of Science (WoS), a platform with 1.9 billion citations from more than 171 million records worldwide, was our main data source, as it is a large platform that provides researchers with the necessary information about published articles. Data obtained from the WoS (Clarivate Analytics, Philadelphia, PA, USA) was used for the bibliometric analysis. Data collected on a single day was added to eliminate bias because the WoS database is updated every day. Articles selected as the document type. Using this method, the articles were retrieved from the WoS database.

Publications' duration and searching key terms

Automatic Boolean query refinement method was used in this research (15). Aflatoxin M_1 (Title), AFM_1, Milk (Title), or AFM_1 (Title) were used as search terms to get data from Jan 1, 1970 to Nov 30, 2022.

Data Selection

Results were sorted by literature types. These types of literature were excluded: revisions, books, short communications, congress papers, review articles, and letters. The time of publication of articles, citation totals, languages, research areas, countries, affiliations, funding agencies, journals, keywords, and the authors were analyzed. WoS publications were saved as TXT files and exported to Microsoft Office Excel 2019 (Los Angeles, CA, USA).

Network visualization

Co-citation analysis, co-occurrence analysis, and network analysis were done with VosViewer ver-

sion 1.6.18. and also Biblioshiny, an app version tool of Bibliometrix was used for the analysis (16). The network visualization in the research was created using VOSviewer software version 1.6.18 for Windows. VOSviewer is an easy-to-apply and generally used visualization tool that researchers can use free of charge (17-21). Co-citation analysis, co-occurrence analysis analysis were calculated for each drawn country and total connectivity strength of their country with the others was calculated. Total link strength represents the total strength of a country's researcher links with other countries. The stronger cooperation and attribution between the countries, the color of the countries in the network visualization became the same. In addition, each color in the images represented a different set.

Results

Literature growth

The search engine of the WoS database found 679 documents and 540 articles published in the field of AFM_1 from Jan,1970 to Nov, 2022. The first article was published in 1970 (22,23). Following this, there was little fluctuation in the number of publications as it increased gradually and slowly each year. However, the findings show that the number of yearly publications had gradually increased since 2009, suggesting that during those years, research output had grown steadily (Fig. 1). These articles were cited 13.922 times with a mean of 22,85 citations per document, and a whole H-index of 59 as shown in Fig. 2.

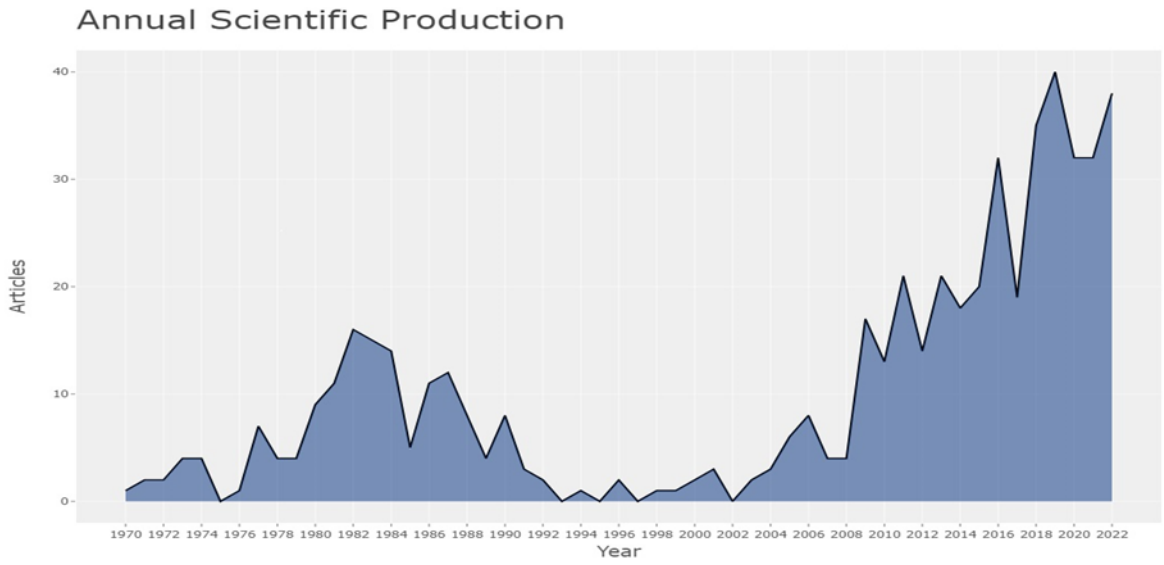

Fig.1: Number of the articles per year on AFM_1 Research (1970–2022)

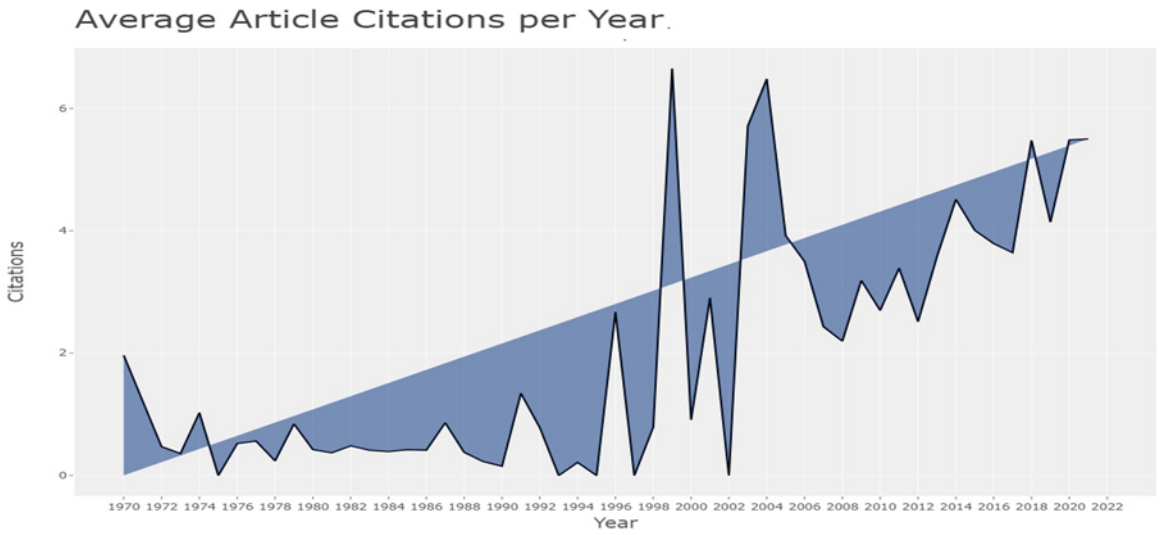

Fig. 2: Number of the citations per year on AFM_1 Research (1970–2022)

Languages, research areas, countries, affiliations, funding agencies, and journals

92.407% of the published literature was in English and the research area of the majority (47.037%) of the publications was Food Science Technology ((Table 1). 17.778% of the publications were studied in the USA (Table 2). Other high-contributory countries are respectively; China (11,481%), Iran (10,370), Italy (9,259%) and Turkey (7,222%) (Table 2). Ministry of Agriculture Rural Affairs was the most active institution producing published documents on AFM_1 research (4,630), followed by Chinese Academy of Agricultural Sciences (4.444%) and Institute of Animal Science of CAAS (4,259%) (Table 3). The institution that provided the most funding for AFM1 research was the National Natural Science Foundation of China. The National Institutes of Health USA was the second-ranked funding agency, and the United States Department of Health Human Services was the third-ranking funding agency. Food Control (12,222%) ranked first in the list of journals with the most publications, followed by Journal of the Association of Official Analytical Chemists (6,667%).

Table 1: Research Areas on AFM_1 Research

Research Areas	*Record Count*	*% of 540*
Food Science Technology	254	47.037
Chemistry	159	29.444
Toxicology	90	16.667
Veterinary Sciences	37	6.852
Agriculture	35	6.481
Biotechnology Applied Microbiology	31	5.741
Biochemistry Molecular Biology	24	4.444
Pharmacology Pharmacy	22	4.074
Environmental Sciences Ecology	21	3.889
Nutrition Dietetics	21	3.889

Showing 10 out of 38 entries 1 record(s) (0.185%) do not contain data in the field being analyzed.

Table 2: Countries with at Least Ten Publications on AFM_1 Research

Countries/Regions	*Record Count*	*% of 540*
USA	96	17.778
China	62	11.481
Iran	56	10.370
Italy	50	9.259
Turkey	39	7.222
India	28	5.185
Fed Rep Germany	16	2.963
Pakistan	16	2.963
Serbia	16	2.963
Egypt	13	2.407
Greece	13	2.407
France	12	2.222
Netherlands	12	2.222
Spain	12	2.222

Those with at least 10 record counts are shown

Table 3: Affiliations on AFM_1 Researchs

Affiliations	*Record Count*	*% of 540*
Ministry of Agriculture Rural Affairs	25	4.630
Chinese Academy of Agricultural Sciences	24	4.444
Institute of Animal Science CAAS	23	4.259
University of Wisconsin Madison	21	3.889
University of Wisconsin System	21	3.889
United States Department of Agriculture	18	3.333
Islamic Azad University	17	3.148
Egyptian Knowledge Bank	12	2.222
University of Novi Sad	9	1.667
Croatian Veterinary Institute Zagreb	8	1.481
Technical University of Munich	8	1.481
University of California System	8	1.481
University of Tehran	8	1.481
Indian Council of Agricultural Research	7	1.296
University of Bologna	7	1.296

Showing 15 out of 616 entries 7 record(s) (1.296%) do not contain data in the field being analysed

Network visualization

The minimum number of documents for a country was set at three. Forty-seven out of 88 countries crossed the threshold drawn as shown Supplementary Fig. S1. According to the publications, the USA led the way in terms of published studies, while China was the most influential country in terms of total link strength (Fig. 3). The citation network visualization map among countries with at least one publication is shown in Fig. 4.

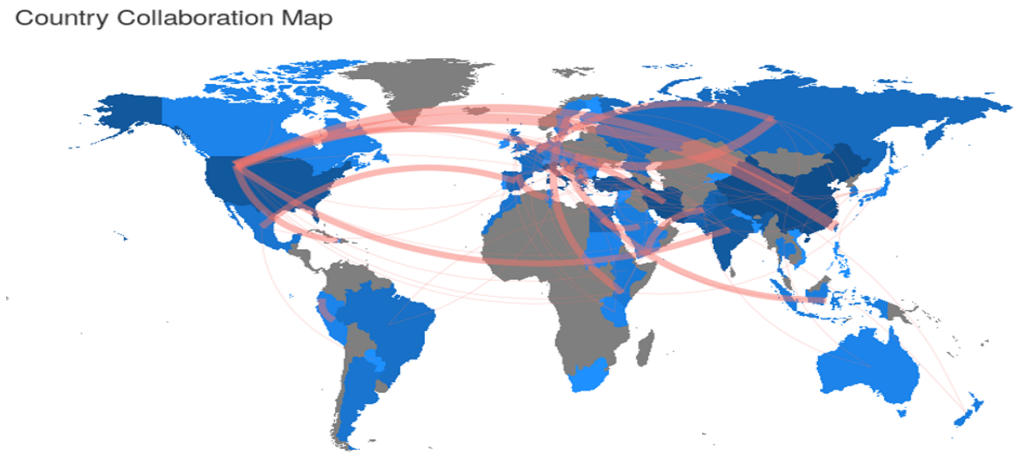

Fig. S1: International collaboration network map.

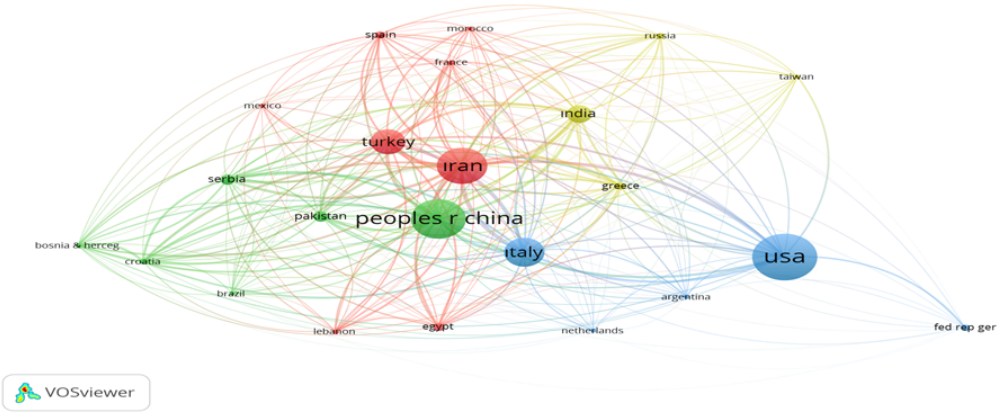

Fig.3: Bibliographic coupling between countries

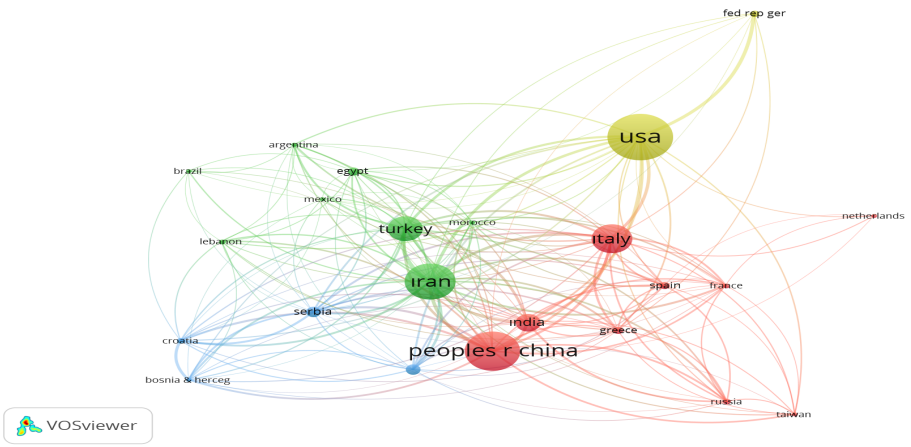

Fig.4: Citation network visualization map among nations with at least one publication. *Collaboration is shown with lines linking nations. Stronger cooperation is indicated by thicker lines. Countries with a bigger circle or text size had a higher level of international cooperation.

Network visualization of co-occurrence keywords

The minimum number of occurences a keyword is adjusted is 20. Overall, 1110 keywords that exceeded the threshold were drawn for the network visualization. The most used keyword is "M_1" with 235 occurrences, followed by "mycotoxins" (n = 127) and "contamination" (n=80) (Fig. 5). A three-field Graph (Sankey diagram) consisting of country, keywords and cited journals for the ten most researched topics is given in Supplementary Fig.S2.

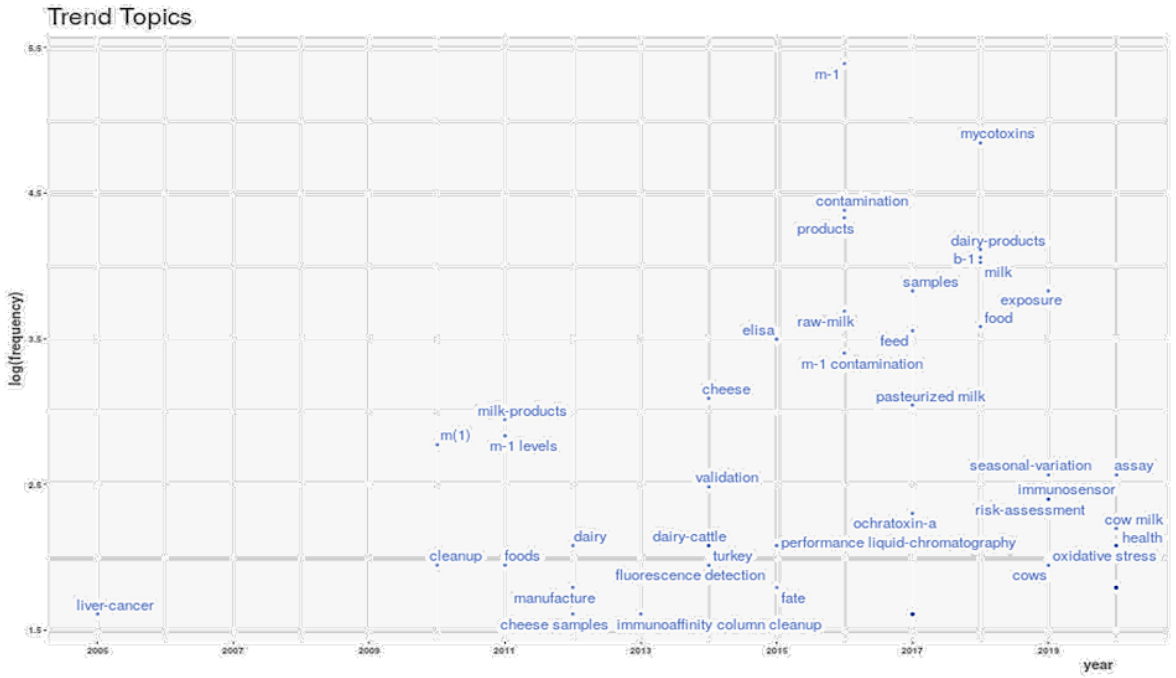

Fig. 5: Network visualization of trend topics with Vosviewer and Biblioshiny

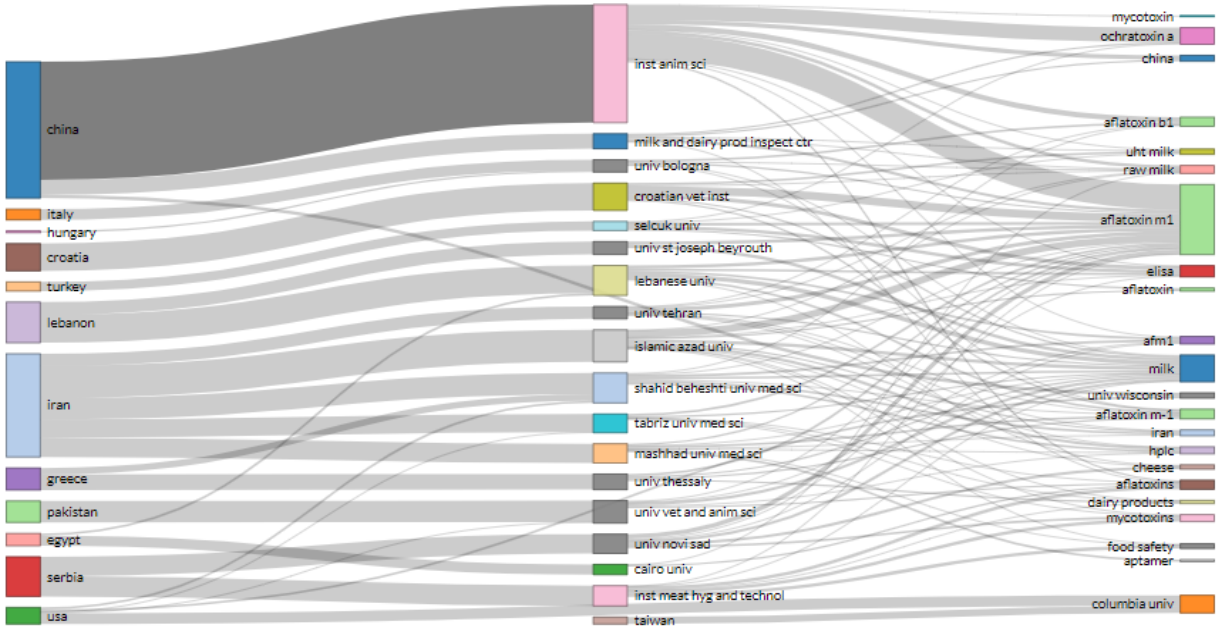

Fig. S2: Three-Fields Plot (affiliations-countries-keywords)

Network visualization of documents citation

The minimum number of citations of an article was set at 90. Of the total articles, only 20 met the threshold. Sun Z (1999) was the most cited author (24), followed by Diaz DE (2004)(25) and Micheli L (2005)(26). The most-cited literature in AFM_1 research was "Increased risk of hepatocellular carcinoma in male hepatitis B surface antigen carriers with chronic hepatitis who have detectable urinary aflatoxin metabolite M_1" (Sun Z et al., 1999) with 153 citations (24).

Discussion

The search engine of the WoS database found 679 documents published in the field of AFM_1 from 1970 to 2022, of which 540 were articles. The first publications began to be published in 1970. After that, the number of publications varied from year to year until 2008, but gradually increased with fluctuations every year after 2008. The year in which the publications were cited the most was 1999. The annual number of publications was the highest in 2019, indicating that the issues related to AFM_1 have become more important over time in the field of food safety and public health.

From the point of view of the research area, almost half of the published articles on AFM_1 have been conducted in the field of Food Science Technology. This result has not been surprising at all. We know that the quality of research carried out with multinational cooperation is higher and the impact is wider. When the bibliographic coupling between countries is analyzed, the USA, China, Iran, Turkey, and Italy appear in the top five. This is similar to the Citation analysis between countries. When the affiliates of these publications are analyzed, the Ministry of Agriculture Rural Affairs ranks first with 25 records. The Chinese Academy of Agricultural Sciences was the second institution with the highest number of articles published.

The common language of the publications on AFM_1 is English, constituting 499 (92,407) of the total publication, while German is the second language of the articles published on this subject with 17 articles and a share of 3,148%. English and German were followed by Italian (n=9), French (n=6), Czech (n=4), Spanish (n=3), Japanese (n=1) and Portuguese (n=1), respectively. The reason for this finding may be due to the wide English journal coverage of WoS and the widespread use of English in the scientific language globally (12, 14). A previously published study on All Aflatoxins (27) also reported that English is the most common language in the Scopus index.

When all the articles investigating AFM_1 are examined, we see that the USA (n=96, 17.77%) is the leader in the publication ranking. This finding was found to be compatible with many other bibliometric analysis findings (28- 32). After the USA, China (n=62, 11.48%), Iran (n=56, 10.37%) and Italy (n=50, 9.25%), and Turkey (n=39, 7.22%) are the top 5 countries in the publication ranking. The possible explanation for these results can be understood by examining the institutions that funded the studies. When we examine the institutions that finance AFM_1 research, the National Natural Science Foundation of China, National Institutes Of Health USA, the United States Department Of Health Human Services, National Institutes of Health (NIH)-National Cancer Institute, and National Institutes of Health (NIH) are in the top 5 places. -National Institute of Environmental Health Sciences. It is at the top of the table because of the efforts of the China National Natural Science Foundation (NSFC), headquartered in Beijing, to raise funds for aflatoxin research (33). The increase in carcinoma case deaths in China, which appears to be associated with an increase in aflatoxin contamination in food, may have made AFM_1 research a high priority in China (34). Because of this scientometric analysis, we conducted on AFM_1, two of the top 10 countries (India and Turkey) where the articles were published are developing countries, and we see that these two countries perceive this issue as a serious problem. Iran, Italy, Turkey, and India are the main con-

tributors to research from Europe and the Middle East. Consecutive outbreaks of acute aflatoxicosis (35), in developing countries (17, 36) especially Turkey (18-20), Iran (21, 37) and India (38-40) have increased the morbidity and mortality associated with such outbreaks (41, 42), and all of this data may explain why more research has been done on AFM_1 in these countries since then (43).

When the best journals are analyzed according to the number of published articles, the impact factor of Food Control, which is in the first place, is 6,652. The journal is indexed in not only the Web of Science but also indexed in Scopus, EMBiology, Research Alert, Current Contents, Food Science and Technology Abstract, Bulletin of the International Institute of Refrigeration, Food Safety Microfile, CAB International indexes. CAB Health, Science Citation Index, and Science Citation Index Extended indexes. Overall, 540 articles on AFM_1 have been published in 220 journals. The top three journals published 121 articles on AFM_1 research, accounting for 22.40% of the articles on this topic. Sun ZT's article published in the journal "Hepatology" in 1999 was the article that received the most citations (n=153).

Overall, 1.110 keywords were identified by keyword analysis that appeared together in VOSVIEWER. In the analysis of the number of keywords, the most common keywords were "M_1", "mycotoxins" and "contamination". The fact that AFM_1, the milk mycotoxin, is a dangerous contaminant makes all three keywords the most frequently used keywords. Five main sets of keywords have been obtained in VOSVIEWER according to the co-formation keyword cloud map analysis limitations: 1) Current methods of analysis of AFM_1; keywords such as biosensor, aptamer, gold nanoparticles, liquid chromatography, etc.; 2) Materials for which AFM_1 analyzes are performed; pasteurized milk, UHT milk, contamination, etc. 3) Contamination options and effective factors of AFM_1; keywords such as exposure assessment, risk assessment, season, cheese 4) Common methods used to prevent and detect restrictions of AFM_1; keywords such as HPLC, food safety, lactic acid bacteria, yogurt 5) AFM_1-like food mycotoxins; keywords such as Ochratoxin A, Aflatoxin B_1, Aflatoxin M_1.

Limitations

The status and direction of AFM_1 research were analyzed in this study using a bibliometric methodology. There were a few limitations, though, some of which were present in earlier research. First, the usage of the search word "AFM_1" in title searches merely placed restrictions on the current study. This analysis may have overlooked publications that specifically utilized "AFM_1" as a keyword or within the paper.

Second, it examined only the works included in the WoS database. The WoS database is the most popular and reliable search engine, however, some outlier publications might not have been taken into account. Third, because some authors may have more than one name or multiple name spellings, the standardization of author names and terms based on findings from the VOSviewer may not be correct. For some authors, this could result in erroneous research output. Despite these drawbacks, this report offers a general overview of AFM1 research.

Conclusion

This bibliometric analysis reveals worldwide AFM_1 research over a long period. In the last two decades, there has been a tremendous increase for literature published on AFM_1 in the world as a whole. An assessment of the historical situation and development trend in AFM_1 scientific research can serve as an important roadmap for future research. Thus, regional decisions can provide a basis for improving management practices for the healthcare and dairy industries. The dominance of the research activities of the USA and China in the SCI-Expanded index shows the competition of these two countries to be a world power both in the economy they allocate for research funds and in the publications between them. Lack of funds, inadequacy of laboratory

infrastructures, insufficient international cooperation may be the factors responsible for the shortcomings in developing countries. Furthermore, this bibliometric analysis showed that it is important for researchers in developing countries to collaborate with researchers in developed countries to implement new developments and effective control strategies for AFM_1.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interests.

Data availability

No supplementary materials are published here so the respected readers may contact the corresponding author to access them, if needed.

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