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Systematic Review

A Bibliometric Review of COVID-19 Vaccines and Their Side Effects: Trends and Global Perspectives

Santiago Benites [1], Félix Díaz [1,*], Rafael Liza [2], Luis Sánchez [3] and Luis Rivera [4]

[1] Vicerrectorado de Investigación, Universidad Autónoma del Perú, Lima 150142, Peru
[2] Instituto de Investigación FCCTP, Universidad de San Martín de Porres, Lima 150140, Peru; rlizan@usmp.pe
[3] Estudios Generales, Universidad Privada del Norte, Trujillo 13011, Peru
[4] Gestión Académica, Universidad Tecnológica del Perú, Lima 15011, Peru
* Correspondence: felix.diaz@autonoma.pe

Abstract: This bibliometric review analyzes global research on COVID-19 vaccine side effects, focusing on publication trends, collaborations, and key topic areas. Using VOSviewer and Bibliometrix for data analysis and visualization, this study examines 1353 unique papers indexed in Scopus and Web of Science (2020–2024). The results indicate a significant increase in publications in 2021 and 2022, with the United States, China, and Europe contributing the most. While many studies focused on common side effects, such as headache, fatigue, and injection-site pain, rare but serious adverse events, such as myocarditis, thrombocytopenia, Guillain–Barré syndrome, pericarditis, and thrombosis, were also reported. However, regions with limited research infrastructure, particularly in developing countries, remain underrepresented despite the critical need for vaccine safety studies in these areas. Additionally, journals such as *Vaccines*, *Vaccine*, and *Human Vaccines and Immunotherapeutics*, all ranked Q1, dominate the publication volume, ensuring wide dissemination through open-access availability. This analysis also highlights global collaboration networks, identifying key authors and regions with high levels of co-authorship. Thematic mapping distinguishes niche topics focused on rare and severe side effects from driving topics addressing more common reactions. This review, therefore, underscores the importance of scaling up research efforts in underrepresented regions and strengthening global collaborations to ensure effective pharmacovigilance. Finally, future research should prioritize the long-term, ongoing monitoring of side effects and address disparities in scientific output, particularly in developing countries where vaccine safety data are urgently needed.

Keywords: bibliometric review; COVID-19; vaccine; side effects; adverse events

Received: 24 September 2024
Revised: 23 October 2024
Accepted: 7 November 2024
Published: 30 January 2025

Citation: Benites, S.; Díaz, F.; Liza, R.; Sánchez, L.; Rivera, L. A Bibliometric Review of COVID-19 Vaccines and Their Side Effects: Trends and Global Perspectives. *COVID* **2024**, *5*, 16. https://doi.org/10.3390/covid5020016

1. Introduction

In late 2019, the World Health Organization (WHO) received reports of 44 cases of atypical pneumonia of unknown etiology in Wuhan, China. These cases quickly evolved into a global pandemic caused by the SARS-CoV-2 virus, triggering an unprecedented health crisis [1–3]. The scientific community responded extraordinarily, achieving the development and approval of several COVID-19 vaccines in approximately one year, including those from Pfizer/BioNTech, Sinopharm, and AstraZeneca. By June 2023, more than 13 billion doses had been administered globally, marking a milestone in vaccination history [4–6].

Although vaccines have been instrumental in reducing mortality and morbidity associated with COVID-19, their rapid development and deployment have raised significant

concerns about their safety, especially regarding side effects. Since the start of mass vaccination, a variety of adverse events have been reported, ranging from mild and transient reactions such as fever, fatigue, and pain at the injection site to more severe and rare events such as vaccine-induced thrombosis with thrombocytopenia (VITT), myocarditis, and pericarditis [7–19]. For example, the AstraZeneca vaccine has been documented to be associated with a small risk of VITT, a serious condition involving the formation of blood clots accompanied by a low platelet count. Likewise, mRNA vaccines, such as those from Pfizer-BioNTech and Moderna, have shown an association, albeit rare, with myocarditis and pericarditis, particularly in young men [20,21]. These side effects have fueled skepticism and resistance to vaccination in specific population sectors, further complicating global efforts to control the pandemic [22–27].

The accelerated development of these vaccines, although necessary to address the health crisis, has raised questions about the long-term safety of these biologicals. Vaccines, like any other medicine, must undergo rigorous safety testing in multiple phases, including preclinical, clinical, and post-marketing surveillance phases [28,29]. However, due to the urgency of the pandemic, these processes were significantly shortened, leading to an increase in the number of studies and reports investigating and documenting adverse effects related to vaccination [30–33].

As of 2023, the COVID-19 pandemic has transitioned from a global health emergency to a more controlled situation in most countries, largely due to widespread vaccination efforts. Despite this, the virus continues to circulate, and new variants have emerged, keeping vaccines relevant not only for initial immunization but also for booster doses. This ongoing presence of the virus raises new questions regarding the durability of immunity and the potential for long-term side effects of the vaccines [34–38]. While the expedited development of COVID-19 vaccines was necessary, continuous post-vaccination surveillance is imperative to detect any rare or delayed adverse events, especially in vulnerable populations such as individuals with pre-existing conditions or those who are immunocompromised. Long-term monitoring is important for assessing vaccine safety and identifying potential risks, which plays a key role in maintaining public trust and guiding healthcare strategies [39–43].

In this context, there is a need for a comprehensive and systematic analysis of scientific research regarding the side effects of COVID-19 vaccines. A bibliometric analysis offers a powerful tool to understand not only the magnitude of research in this area but also the trends, patterns of international collaboration, and areas of greatest concern or controversy. This approach makes it possible to identify the most influential studies, the leading countries and institutions in research, and gaps in knowledge that could be addressed in future research. Therefore, the present study aims to analyze trends in the scientific literature on COVID-19 vaccine side effects, identify research gaps, and assess global collaboration patterns using bibliometric tools. This analysis will not only provide a comprehensive overview of the current state of knowledge but will also contribute to the discussion on the safety and effectiveness of vaccines in the context of global public health.

2. Methodology

This bibliometric analysis follows the PRISMA methodology [44] and is structured into several key stages, starting with the definition of a systematic search strategy to identify relevant literature on the side effects of COVID-19 vaccines (see Figure 1). Hence, specific terms were used in the Scopus and Web of Science databases, including those related to the pandemic (“COVID-19”, “SARS-CoV-2”, and “coronavirus”), vaccines and vaccination (“vaccine” and “vaccination”), and adverse effects (“adverse effects”, “side effects”, and “adverse events”, “adverse reactions”). These terms were applied exclusively

to the document titles to ensure that the articles retrieved focused centrally on the side effects of COVID-19 vaccines. The selection process covered documents published between 2020 and August 2024, reflecting the evolution of research in this field from the beginning of the pandemic to the most recent available date. Research articles, conference papers, reviews, and other academic works indexed in Scopus and/or Web of Science were included to maintain data quality and validity standards. No language restrictions were applied, and publications in English, Chinese, Russian, Spanish, Japanese, German, French, and Dutch were considered, which facilitated a truly global comparison and analysis. The initial search yielded 1175 documents from Scopus and 772 from Web of Science. In order to process these data, the R Studio software was combined with the Bibliometrix library, tools that allow for efficient and accurate management of bibliographic data. These tools removed duplicates, resulting in the exclusion of 594 repeated documents, leaving a final set of 1353 unique documents for analysis [45–47].

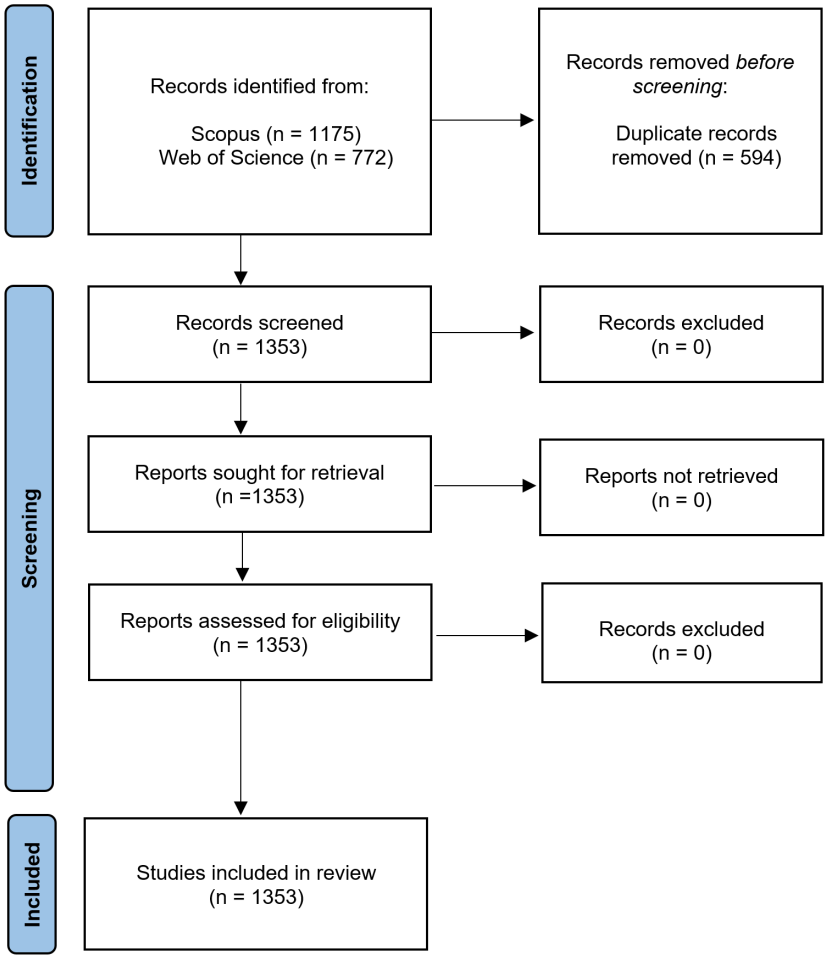

Figure 1. Flowchart describing the methodology used to select and filter documents related to the side effects of COVID-19 vaccines.

3. Results

The initial search results provided a clear and comprehensive overview of the distribution and evolution of research on COVID-19 vaccine side effects, both in terms of document types and publication chronology. Figure 2 shows the proportion of the different types of documents analyzed. According to this chart, 66.5% of the documents (905) are articles, indicating that most of the literature on COVID-19 vaccine side effects consists of traditional research articles. Letters account for 12.1% of the documents (165), constituting the second

most common type, followed by reviews at 7.6% (103). Meeting abstracts comprise 5.9% of the documents (81), while the "other" category, which includes editorial materials, notes, and book chapters, constitutes the remaining 7.9%. It is relevant to mention that there was no linguistic bias, as publications in a wide variety of languages were considered, including English, Chinese, French, German, Japanese, Spanish, Russian, and Italian, among others.

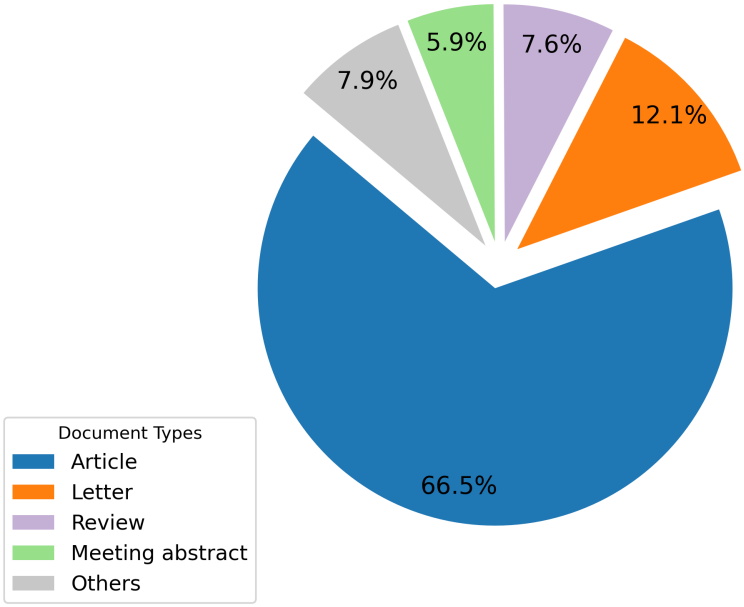

Figure 2. Percentage distribution of document types in the analyzed research.

Figure 3 displays the annual number of publications from 2020 to 2024, along with a line indicating the cumulative total of publications over these years. In 2020, the number of publications was relatively low (four documents), which is expected, given that the pandemic was just beginning. However, in 2021, there was a significant increase in publications (248 documents), reflecting the global effort to understand and address the side effects of vaccines as they were widely distributed. The peak in publications occurred in 2022, with 557 documents, highlighting an intense focus on research during that year. In 2023, the number of publications decreased to 385 documents, suggesting a consolidation of existing knowledge and a possible shift in research priorities. As of August 2024, although the number of publications has decreased to 159 documents, the volume remains substantial, indicating that interest in this field continues to be significant.

In summary, Figures 2 and 3 underline that research on the side effects of COVID-19 vaccines has been dynamic and multifaceted, with a clear predominance of scientific articles. Furthermore, they reveal notable growth in literature output during the most intense years of the pandemic, followed by a stabilization in publications, thus reflecting the evolution of interest and research priorities in this crucial topic.

Figure 4 shows a world map illustrating the geographic distribution of scientific output related to COVID-19 vaccine side effects. At the global level, the United States stands out as the primary contributor, with 627 publications, reflecting its advanced research infrastructure, access to considerable funding, and close collaboration between universities, research centers, and the pharmaceutical industry. Canada also plays a vital role in North America's output, with 106 publications, underlining its commitment to public health research. Moreover, Mexico leads the output from Central America with 60 publications. In South America, Brazil is the leader with 53 publications, reflecting its role as a critical research hub in the region. Other South American countries, such as Argentina, Peru, and

Colombia, have a smaller but significant output, considering their limited resources. In Europe, Italy stands out with 263 publications, likely driven by its early and severe impact during the pandemic, which motivated intense research activity. The United Kingdom and Germany are also key contributors, with 221 and 135 publications, respectively, reflecting their strong medical research traditions and leadership in the European response to the pandemic. France and Spain, with 79 and 24 publications, respectively, have also made significant contributions, although to a lesser extent. Other European countries, such as Poland, the Netherlands, Sweden, and Denmark, also show considerable activity, suggesting a relatively equal distribution of scientific production in the region.

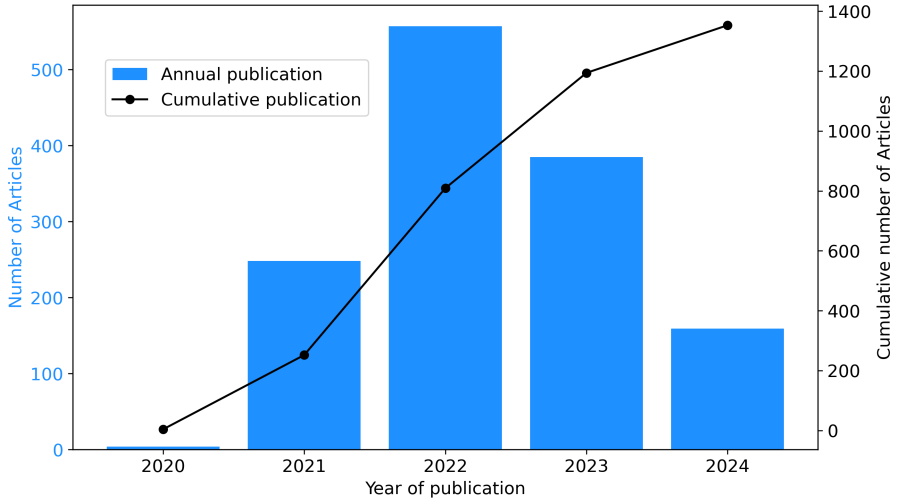

Figure 3. Annual and cumulative number of publications from 2020 to August 2024.

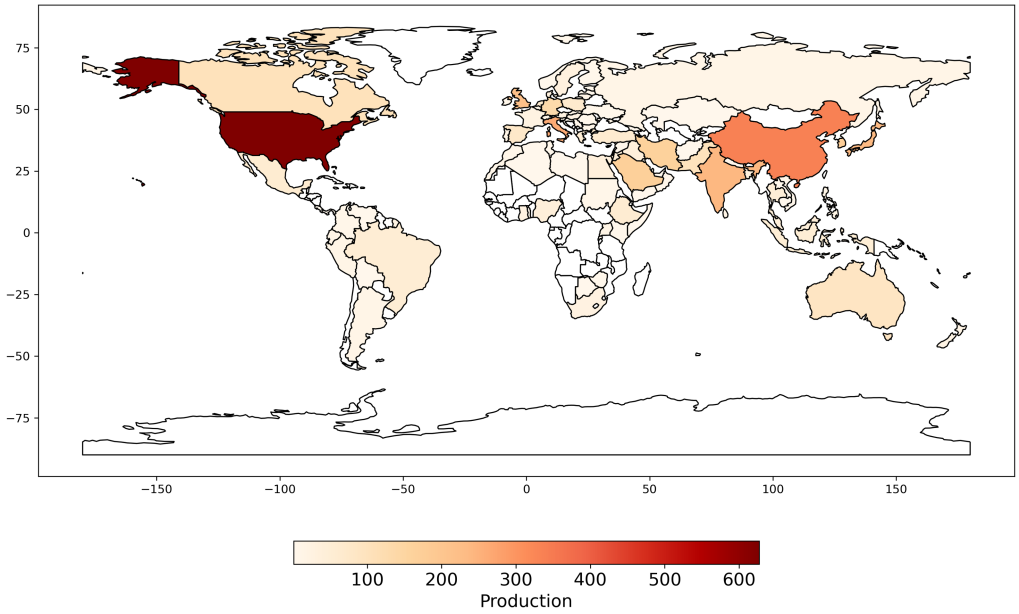

Figure 4. Global distribution of scientific output.

On the other hand, in Asia, China ranks as the second-largest contributor to the scientific literature on vaccine side effects, with 337 publications, reflecting its massive research capacity and rapid response to the pandemic. India follows closely with 242 publications, consistent with its role in vaccine manufacturing and vast population. Japan and South Korea also stand out in the region, with 236 and 176 publications, respectively, both being countries with advanced economies and strong research capabilities. Iran

and Saudi Arabia, with 164 and 172 publications, respectively, also show considerable scientific output, underlining the importance of research in these Middle Eastern countries. Additionally, in Africa, Ethiopia leads with 59 publications, reflecting a growing focus on public health research and collaboration with international institutions. South Africa and Nigeria have also made significant contributions, representing the main research centers on the continent, with 27 and 42 publications, respectively. Other African countries, such as Ghana, Uganda, and Egypt, have made smaller contributions. Finally, in Oceania, Australia stands out with 91 publications, reflecting its presence in research due to its advanced science and public health resources. Despite having a smaller output, New Zealand contributed 18 publications, showing its commitment to research in this field.

Figure 5 shows the number of publications in different scientific journals, listed on the y-axis, while the x-axis indicates the number of publications, ranging from 0 to 125. The journal *Vaccines* stands out with 125 publications, occupying the first position in terms of volume. This journal belongs to the Q1 quartile and is open-access. It is followed by *Vaccine*, with 38 publications in the Q1 quartile. However, unlike the previous journal, it is not open-access, meaning its articles are mostly available by subscription or payment. In third place is *Human Vaccines and Immunotherapeutics* with 28 publications. This journal, classified in the Q2 quartile, is not open-access and limits access to its content through subscriptions. Next, with 20 publications, is *Cureus Journal of Medical Science*, an open-access journal in the Q4 quartile. In fifth place, with 18 publications each, are *Drug Safety* and *Journal of the European Academy of Dermatology and Venereology*. Both journals belong to the Q1 quartile, reflecting their high influence in their respective fields, and both have restricted access. Additionally, in sixth place, with 17 publications, is *Frontiers in Public Health*, an open-access journal classified in the Q2 quartile. *Pharmacoepidemiology and Drug Safety* is in seventh place with 15 publications; this journal, belonging to the Q2 quartile, is not open-access. In eighth place, with 14 publications, is *Scientific Reports*, an open-access multidisciplinary journal classified in the Q1 quartile, known for its broad coverage in various scientific areas. The journals *Frontiers in Medicine* and *PLOS ONE* share ninth place, with 13 publications each. *Frontiers in Medicine* is in the Q2 quartile and is open-access, while *PLOS ONE*, also in the Q2 quartile, is open-access and recognized for its multidisciplinary nature. Eventually, in tenth place, with 11 publications each, are *Frontiers in Immunology*, *JAMA Network Open*, and *Journal of Clinical Medicine*. *Frontiers in Immunology*, belonging to the Q1 quartile and open-access, stands out in the field of immunology. *JAMA Network Open*, also in the Q1 quartile and open-access, is part of the JAMA family. *Journal of Clinical Medicine* also focuses on clinical medicine in the Q1 quartile and is open-access. Finally, with 10 publications, *Revista da Associação Médica Brasileira* is an open-access journal in the Q4 quartile. Although its impact is less influential, it is relevant to the regional context and offers free access to its content.

Figure 6 shows that in the red cluster, "Wiwatnikit V", with 28 publications, is the most prolific author in the network. Authors connected to him, such as "Sookaromdee P" and "Kleebayoon A", have fewer publications, suggesting that "Wiwatnikit V" acts as a mentor or coordinator in multiple projects. Therefore, his role in this cluster seems central, with a high degree of influence over his collaborators. On the other hand, in the orange cluster, "Kim J" and "Lee Y" have 16 publications each, while "Kim S" stands out with 18 publications, which shows a close collaboration within the cluster. In addition, the strong ties between these authors, coupled with "Kim S" having a higher number of publications, suggest that this author plays a leadership role within the cluster. Likewise, "Lee J", with 14 publications, is also a key contributor to this team, consolidating the group as one of the most cohesive in the network. The green cluster, on the other hand, is another relevant group within the network. "Kim M", with 14 publications, is the central author,

accompanied by important collaborators such as "Agarwal V", with 17 publications, and "Gupta L", with 8. In addition, this cluster maintains important links with the orange cluster, indicating a significant collaboration between both groups. Likewise, the green cluster has some connections with the blue cluster, although to a lesser extent, which could reflect more sporadic or specific collaborations. In the blue cluster, "Li X" is the central author with 15 publications, while "Liu Y" and "Wang Y" have 10 and 11 publications, respectively. The dense structure of this cluster indicates a high frequency of co-authorship among its members. On the other hand, in the brown cluster, "Marquez P" has 10 publications, placing him as a central author, although not as dominant as those in the other clusters. Other authors, such as "Moro P" and "Zhang B", with nine publications each, suggest an equal collaboration within the group. This cluster is composed of a small but cohesive team with a balanced distribution of scientific output. Finally, the purple cluster is led by "Riad A", with 13 publications, followed by "Klugar M", with 10. Although it is one of the smallest clusters in the network, the density of its connections reflects close collaboration among its members, which highlights the intensity and specialization of this team.

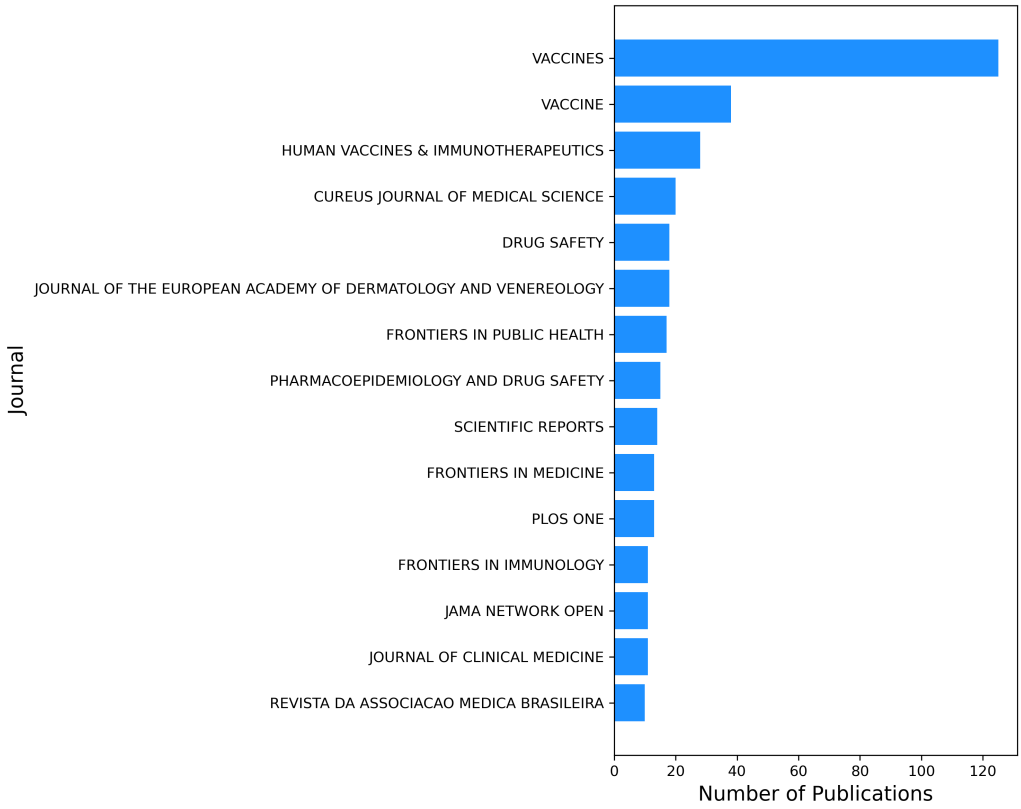

Figure 5. Number of publications by journal.

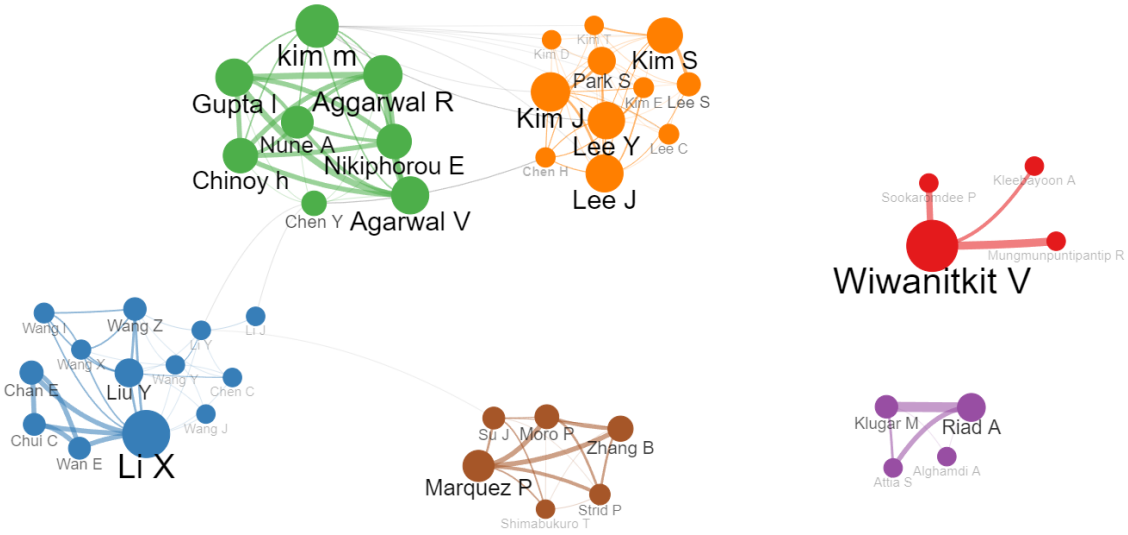

Figure 6. Collaboration network.

Figure 7 presents a word cloud of Keywords Plus, in which the most significant words reflect the adverse effects and the most studied vaccines, allowing for the identification of the main trends in pharmacovigilance studies. Among the most common symptoms, headache stands out with 184 mentions, fever with 183, myalgia with 146, and fatigue with 137. These symptoms are characteristic of a normal immune response to vaccination and are usually mild and transient. Injection-site pain, with 102 mentions, is another common side effect, reflecting the frequency of local reactions in many vaccinated individuals. Moreover, regarding the most frequently mentioned vaccines, tozinameran (Pfizer-BioNTech) appears 163 times, reflecting its prominence in the scientific literature. Vaxzevria (AstraZeneca) is next with 144 mentions, followed by elastomer (Moderna) with 122. These three vaccines, widely used in vaccinations worldwide, have received the most attention in studies on side effects. Although less frequent, severe adverse reactions have a significant presence in the studies. Myocarditis, with 63 mentions, is one of the most relevant adverse side effects, especially in young men, which is mainly associated with mRNA vaccines. Anaphylaxis, reported 52 times, and thrombocytopenia, with 46 mentions, stand out as rare but significant side effects, which have been the subject of detailed analyses in the medical literature. Guillain–Barré Syndrome, mentioned 38 times, is another severe adverse reaction to some vaccines, particularly those based on viral vectors, such as Vaxzevria. Although it is a rare condition, it has been analyzed in several studies due to its severity. On the other hand, gastrointestinal symptoms, such as nausea (86 mentions), diarrhea (81), vomiting (72), and dizziness (71), are also common, although less frequent than symptoms related to the immune response. Dyspnea (difficulty breathing), mentioned 68 times, is a more serious symptom that has been documented in some cases. The importance of pharmacovigilance is evident in the word cloud. Terms such as pharmacovigilance and adverse drug reaction reporting systems, mentioned 52 and 46 times, underline the need for continuous monitoring systems to identify and manage side effects on a large scale. In addition, the term drug surveillance program, with 35 mentions, reinforces the idea that post-marketing surveillance is essential in vaccine safety studies. Other vaccines, such as Sputnik V (39 mentions), Coronavac (48 mentions), and Covaxin (24 mentions), have also been highlighted, reflecting the scientific interest in different regions of the world where these vaccines have been widely administered. The attention to these vaccines in the bibliometric literature demonstrates the diversity of approaches to monitoring their side effects. Among the milder skin effects and reactions, rash (eruptions) stands out with 58

mentions and urticaria (hives) with 47, suggesting that dermatological reactions have also been the subject of study, although to a lesser extent than the more common symptoms. For the Keyword Plus analysis, a manual keyword filter was applied to eliminate generic terms such as "human", "male", "female", "adult", "aged", "young adult", "middle-aged", "adolescent", "child", "children", "age", and "sex", since these terms do not provide relevant thematic information for the study and only describe broad demographic characteristics. Similarly, terms such as "article", "letter", "review", "major clinical study", "case report", "clinical article", "questionnaire", "cross-sectional study", "controlled study", "retrospective study", and "cohort analysis" were eliminated. Although these terms describe the type of publication or the design of the study, they do not contribute to identifying thematic trends specific to the field investigated. Likewise, methodological, administrative, and geographic terms that were not very informative for the objectives of this research were excluded. This filtering process was necessary to increase the accuracy and relevance of the analysis since these terms did not provide details about the thematic content of the reviewed studies. By excluding these terms, it was possible to focus the analysis on keywords that more accurately reflect the research trends in the field of study.

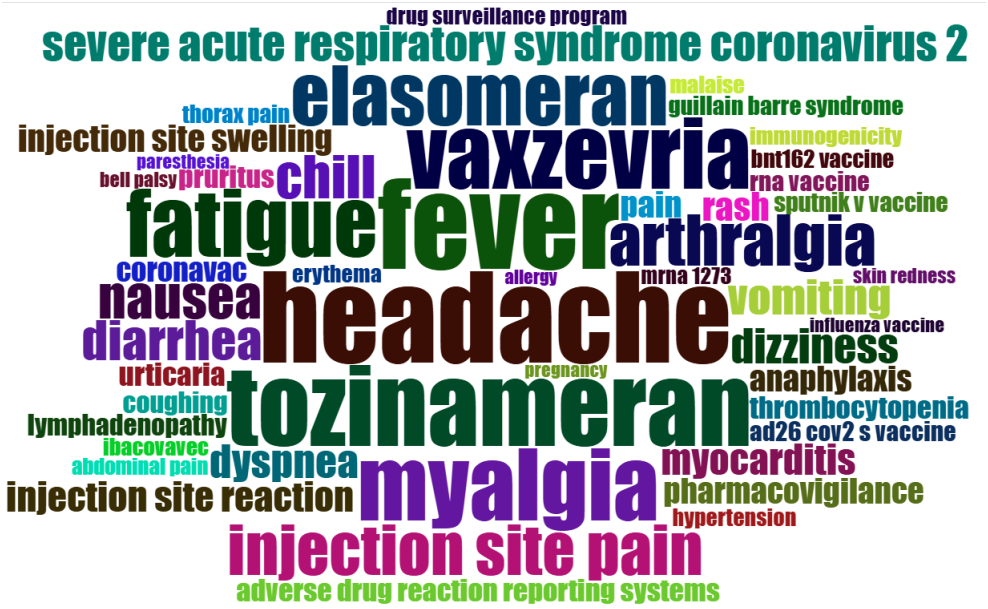

Figure 7. Word cloud of Keywords Plus.

Figure 8 presents a word cloud generated from author keywords. The most prominent terms are "COVID-19 vaccine" and "side effects", indicating that many studies have focused on investigating the adverse reactions that may arise after the administration of these vaccines. In addition, "adverse events" and "adverse effects" are relevant, underlining the interest in evaluating safety and unwanted responses after vaccination. Likewise, "pharmacovigilance" highlights the importance of continuous monitoring systems to record and follow up on adverse effects post-vaccination. On the other hand, expressions such as "healthcare workers" and "COVID-19 vaccination" suggest that studies have paid attention to the impact of vaccination on high-risk groups, such as healthcare workers, who were prioritized during immunization campaigns. As for specific vaccines, names such as "AstraZeneca" and "bnt162b2" (Pfizer-BioNTech) stand out, reflecting that these vaccines have been the subject of numerous studies. In addition, other vaccines such as "Moderna" and "Sinopharm" are mentioned, indicating the diversity in research on the different vaccines used globally. On the other hand, terms such as "vaccine safety" and "adverse events following immunization" reflect the concern about ensuring the safety of vaccines. In

contrast, the technical term "AEFI" (Adverse Events Following Immunization) is commonly used in pharmacovigilance systems to identify and monitor these events. In addition, terms associated with serious side effects, such as "myocarditis" and "thrombosis", appear, as they have been the subject of attention in medical research. In addition, words such as "pregnancy" and "allergy" reflect the interest in analyzing the effects of vaccination in vulnerable populations or those with special conditions. It is important to note that author keywords are selected explicitly by the authors of the articles to reflect the central themes of their research. These terms are more specific and aligned with the immediate objectives of the study, as researchers choose keywords that accurately describe the aspects they wish to highlight, such as particular side effects or the names of specific vaccines. On the other hand, Keywords Plus are terms automatically generated from the bibliographic references of the articles, providing a broader context of the field in which the research is embedded. Furthermore, not limited by the perspective of a single study, Keywords Plus captures more general themes. It may include related areas that, although not the direct focus of the article, are relevant within the general corpus of literature. Keywords Plus, therefore, offers a more comprehensive view of the field, allowing connections between research to be identified that might not have been explicitly linked by the authors.

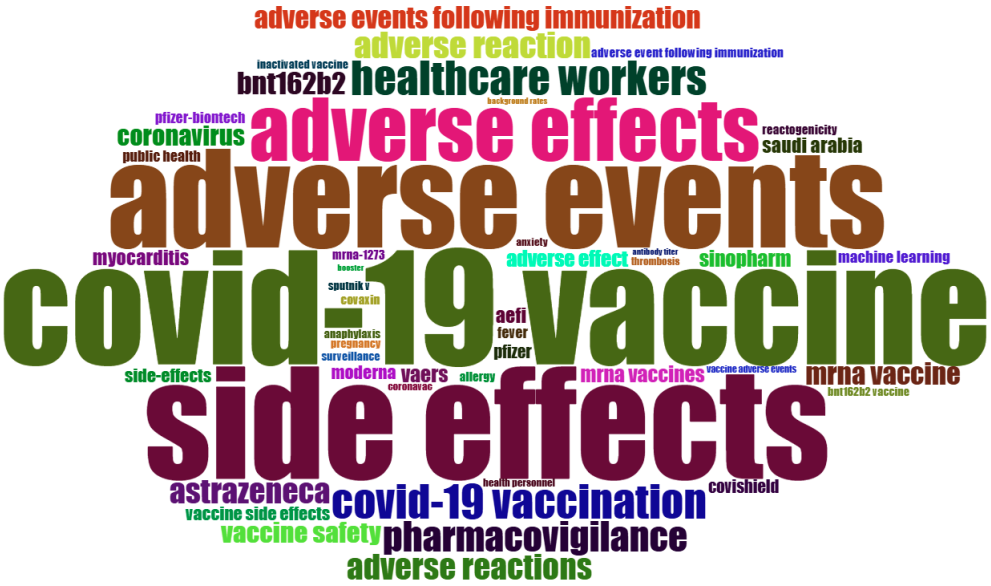

Figure 8. Word cloud of author keywords.

Figure 9 presents a thematic map that organizes and classifies various topics related to COVID-19 vaccines and their adverse effects. This map is based on two axes: the horizontal axis, which measures the degree of relevance or centrality, and the vertical axis, which assesses the degree of development or density of the topics. This structure allows for the analysis of both the importance and the maturity of the different research topics. The niche themes, which are shown in the upper-left quadrant, are very specific topics characterized by a high density but low centrality. The latter means that they are well developed, but their impact is limited to a specialized context within the scientific literature. These topics include severe adverse effects such as myocarditis, thrombocytopenia, Guillain–Barré syndrome, pericarditis, and thrombosis. Although these events are serious, they are relatively rare, which justifies their specialization in more limited research. On the other hand, in the upper-right quadrant, we have the motor themes, which represent key areas with high centrality and high density. These themes, such as myalgia (muscle pain), fatigue, injection-site pain, and nausea, are the main focus of current studies. Their high frequency and relevance to vaccine safety have made them fundamental to understanding

the most common adverse effects, engaging researchers in their comprehensive study. In the lower-right quadrant, we have the basic themes, which have high centrality but low density. These fundamental topics in research, such as tozinameran (Pfizer-BioNTech), Vaxzevria (AstraZeneca), elasomeran (Moderna), and topics related to pharmacovigilance and adverse reaction reporting systems, have not yet been as profoundly developed as the motor themes. However, they reflect the importance of the main vaccines and the constant monitoring of their adverse effects, which are essential to guarantee long-term safety in vaccination campaigns. Finally, the emerging or declining themes are in the lower-left quadrant, characterized by their low centrality and low density. The only term present in this quadrant is COVID-19 vaccination, which could suggest that, although vaccination was a crucial issue at the beginning of the pandemic, its relevance has decreased as research has focused more on adverse effects and the specific characteristics of the different vaccines.

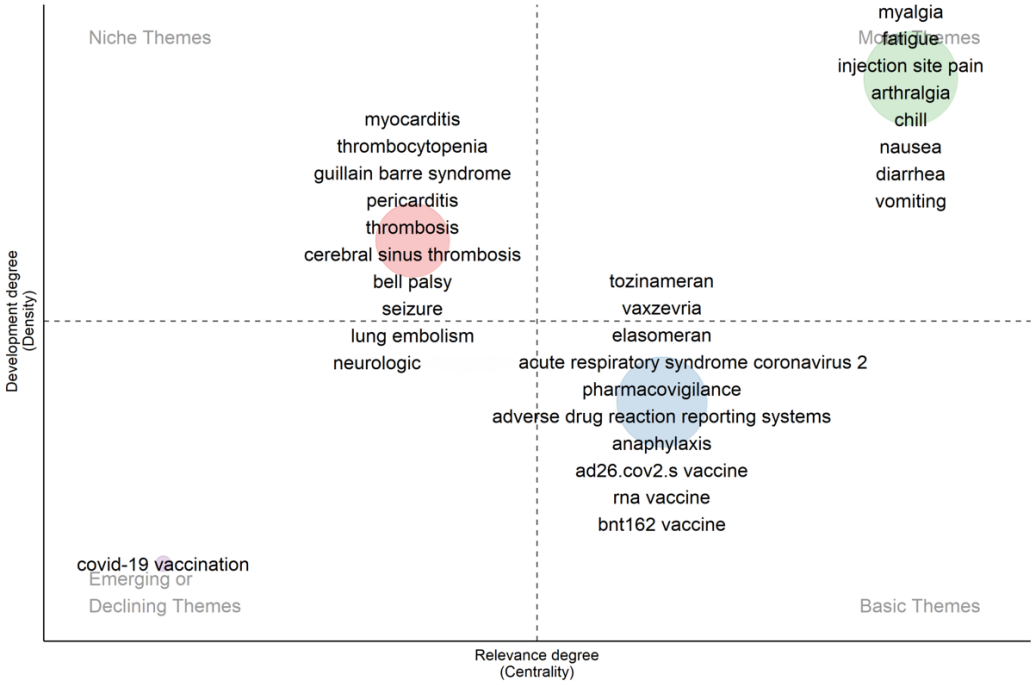

Figure 9. Thematic map.

4. Discussion and Conclusions

In the previous section, a comprehensive analysis of scientific output, collaboration between researchers, and the evolution of study topics was carried out, allowing us to identify patterns that highlight the importance of adverse effects on vaccine safety. Figure 2 shows the distribution of scientific output by type of document, with original articles representing the majority of publications, suggesting that a large proportion of the studies are based on empirical research and clinical data. Furthermore, systematic reviews and meta-analyses occupy a significant portion, highlighting the effort to synthesize the existing literature and draw global conclusions. Other types of documents, such as letters to the editor and abstracts of scientific meetings, also contribute to academic debate and the rapid dissemination of preliminary findings or important interpretations. Therefore, the diversity in the type of publications reflects a multidimensional approach that encompasses both the detailed analysis of empirical data and the critical interpretation of results globally. In terms of scientific output over time, the analysis shows a significant increase in the number of publications since the start of the pandemic, with a peak during 2021 and 2022, coinciding with the acceleration of global vaccination (see Figure 3). Annual output reveals how studies focused on side effects in the early years of mass vaccine rollout, while cumulative output

highlights that research continues, albeit at a more stable pace. This trend is consistent with the need to monitor not only the immediate effects of vaccines but also the medium- and long-term effects. Likewise, the global distribution of scientific output indicates that most studies are concentrated in regions with robust research infrastructure, such as the United States, China, and some European countries, such as Germany and the United Kingdom. In addition, countries such as Brazil and India have also played an important role, reflecting a global and collaborative approach to vaccine safety research. However, the lower scientific output in developing countries underlines the need to strengthen research capacity in these regions, given that vaccination and its side effects may manifest differently in resource-limited contexts. The analysis of the output by journals shows that journals such as *Vaccines*, *Vaccine*, and *Human Vaccines and Immunotherapeutics* are the most prolific in publishing studies related to the adverse effects of COVID-19 vaccines. These journals, belonging to the Q1 quartile, indicate that studies on vaccine safety are being published in high-quality, open-access media, which facilitates the dissemination of findings to a global audience and ensures that information is available to more researchers and health professionals. Regarding the thematic map, the analysis reveals a clear differentiation between niche, motor, basic, and emerging topics. Niche topics, such as myocarditis, thrombocytopenia, and Guillain–Barré syndrome, are severe but rare side effects. These topics are well developed in specialized studies but have less general relevance due to their low prevalence. Still, they have received significant attention due to their potential clinical impact on certain population subgroups. On the other hand, motor topics include the most common side effects, such as myalgia, fatigue, and pain at the injection site, which have been widely investigated due to their high prevalence in the vaccinated population. These topics are crucial for vaccine safety, as they allow for continuous and detailed monitoring of the most frequent effects and are, therefore, fundamental in managing the safety of vaccination campaigns. Likewise, basic topics, such as those related to the primary vaccines (Pfizer-BioNTech, AstraZeneca, and Moderna) and pharmacovigilance, are essential in the scientific literature on side effects. Although these topics have high centrality, their low density suggests they need further development. The importance of these topics lies in the need for constant long-term monitoring to ensure the safety of vaccines and detect possible adverse effects that may arise over time. In contrast, the term COVID-19 vaccination in the emerging or declining topics reflects that, although it was initially a priority topic, attention has shifted to the specific effects of different vaccines and their adverse reactions. This change in focus can be interpreted as maturity in research, which now focuses on more complex and specific details.

5. Future Perspectives

From the present bibliometric analysis, several areas of future research have emerged that can significantly contribute to a better understanding of vaccine safety and optimizing vaccination strategies globally. First, although considerable progress has been made in the study of the most common side effects, such as pain at the injection site, headache, and fatigue, future research must focus on long-term monitoring of these effects, especially in specific population groups, such as people with comorbidities, pregnant women, and children, whose immune responses may differ considerably from the general population. In addition, serious adverse effects, such as myocarditis, thrombocytopenia, Guillain–Barré syndrome, pericarditis, and thrombosis, which have been classified as niche issues due to their low prevalence, require multicenter studies that include a larger number of patients. This will allow for more robust and statistically significant data on the frequency, causes, and risk factors associated with these severe side effects. On the other hand, another key area of future research should be the evolution of new SARS-CoV-2 variants

and the development of new vaccines. This will help determine whether the side effects observed in early vaccine versions apply to new generations. Studies comparing side effects between different versions of vaccines, both current and those in development, will be needed, especially those designed to combat specific variants of the virus. Future research should focus on the global and regional impact of pharmacovigilance systems. While some countries have well-developed systems for monitoring adverse events, many developing nations lack the infrastructure to report and manage these events efficiently. Research should explore ways to improve these systems in resource-limited regions to ensure a more comprehensive and equitable understanding of vaccine safety worldwide. Additionally, it is crucial to examine the public perception of vaccine side effects. Addressing the fear of adverse effects, which remains a significant barrier to achieving optimal vaccination rates in many countries, is essential. Developing effective communication and education strategies to provide the population with accurate, evidence-based information on the risks and benefits of vaccination will be key to overcoming these challenges.

Author Contributions: Conceptualization, F.D.; methodology, S.B. and F.D.; software, F.D. and L.S.; validation, S.B., R.L. and L.S.; formal analysis, S.B., R.L. and L.S.; investigation, S.B., F.D., R.L. and L.S.; writing—original draft preparation, F.D., R.L. and L.R.; writing—review and editing, R.L., L.S. and L.R.; supervision, S.B. and F.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Conflicts of Interest: The authors declare no conflicts of interest.

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