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Potencial de los bacteriófagos como alternativa terapéutica a los antibióticos:Análisis Cienciométrico

Potential of bacteriophages as a therapeutic alternative to antibiotics: Scientometric Analysis

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Abstract

This scientometric article is based on an analysis of the relevance of bacteriophages as a therapeutic alternative to antibiotics, in light of the growing resistance of microbial agents. For this study, two fundamental databases were used: Scopus and Web of Science, both of which are recognized for compiling current and relevant research. These databases provided effective information on how bacteriophages have evolved from being merely infectious agents to becoming a therapeutic alternative against bacterial resistance. To filter the large number of articles initially retrieved from these databases, a preprocessing step was applied to extract the most relevant publications, resulting in an organized Excel sheet. The analyzed results focused on the total number of annual publications, the most prominent authors and countries, and the journals that have shown the greatest interest in the topic.

Keywords: Bacteriophages, Phage therapy, Antibiotic resistance, scientometric analysis.

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Resumen

Este artículo cienciométrico se basa en un análisis sobre la relevancia de los bacteriófagos como alternativa terapéutica a los antibióticos, frente a la creciente resistencia de agentes microbianos. Para este estudio se utilizaron dos bases de datos fundamentales, Scopus y Web Of Science, las cuales son reconocidas por reunir investigaciones actuales y relevantes. Estas bases de datos proporcionaron información eficaz acerca de cómo los bacteriófagos han pasado de ser solo simples agentes infecciosos a convertirse en una alternativa terapéutica frente a resistencias bacterianas. Para filtrar la abundancia de artículos conseguidos inicialmente en estas bases de datos, se utilizó un preprocesamiento que extrajo los artículos más relevantes, dando una hoja de excel organizada. Los resultados analizados fueron sobre el total de publicaciones anuales, los autores y países más relevantes, y las revistas que más se han interesado sobre el tema.

Palabras clave: Bacteriófagos, Fagoterapia, Resistencia a antibióticos, Cienciometría.

1. Introduction

Bacteriophages, or phages, are viruses that infect and lyse specific bacterial strains. Scientific literature emphasizes their potential as an alternative to antibiotic treatments, particularly in combating infections caused by bacteria that have developed resistance to antimicrobial drugs [1]. Notably, their significance lies not only in offering a novel therapeutic option but also in providing a targeted approach that eliminates pathogenic bacteria without adversely affecting the host's beneficial microbiota. Furthermore, studies such as [2] demonstrate that phage therapy extends beyond the treatment of conventional pathogens and can be effectively applied to infections related to Cardiac Implantable Electronic Devices (CIEDs) and vascular grafts—some of the most concerning complications associated with these devices. Since such infections can transform life-saving technologies into life-threatening risks, phage therapy emerges as a promising alternative in these critical scenarios.

Antibiotic resistance also poses a substantial threat to the veterinary sector, which supplies many of the food products consumed by the public. In this context, phage therapy plays a key role in food safety and, consequently, in the economic stability of workers in industries such as livestock farming. It offers an alternative treatment for animals that produce essential commodities such as milk, eggs, and meat [3]. As evidenced in the literature, bacteriophages are essential components in the development of effective therapeutic strategies against various bacterial strains.

Phage therapy has gained increasing attention within the scientific community in recent years. However, to date, only a limited number of review articles have highlighted the relevance of bacteriophages as a treatment against drug-resistant bacterial pathogens. For instance, one article presents a critical analysis from a legal and regulatory standpoint regarding the clinical implementation of phage therapy in Europe [4]. A second article explores clinical and genetic aspects, emphasizing the application of phage therapy to

specific microbial pathogens in various regions of Eastern Europe [5]. A third review focuses on the concept of personalized phage therapy, underscoring the clinical value of combining phages with antibiotics to enhance efficacy [6]. In light of this, the present article examines, from a scientometric perspective, the therapeutic potential of bacteriophages against antibiotic-resistant microorganisms, addressing the relative scarcity of research on this topic in recent years.

To achieve this objective, a bibliographic search was conducted for the period between 2014 and 2025 using two internationally recognized databases: Scopus and Web of Science (WoS). The collected results were subsequently preprocessed to organize and structure the data. This analysis made it possible to assess the scientific and medical relevance of bacteriophages and to highlight the latest developments in their applications.

The following sections will describe in detail the methodology used to conduct the database searches and identify the core literature. The results will then be presented, focusing on annual scientific production, country-level contributions, journal analysis, and author productivity. This will demonstrate that phage therapy has gained increasing relevance in recent years and is expected to continue growing in terms of citations and publications.

2. Methodology

For the development of this article, information was gathered from the WoS and Scopus databases, which provided relevant data on phage therapy (see Table I). A scientometric analysis of the scientific literature was conducted, covering publications from 2014 to 2024.

The initial results of this search identified 335 articles in the WoS database and 549 in Scopus. To improve and ensure the accuracy of this dataset, a preprocessing step was carried out, resulting in an Excel file with 22 organized sheets. This facilitated the classification and analysis of the most relevant articles and documents based on citation metrics, authorship, and countries of origin. It is worth noting that this preprocessing method is widely used in academic research: [7], [8], [9], [10].

Figure 1 outlines the methodological process that was carried out, which began with the collection of scientific article records from both databases. Duplicate records were subsequently removed through a filtering process, consolidating a total of 741 articles. The data was then preprocessed, resulting in an Excel file with 22 sheets. Based on this, a comprehensive scientometric analysis was conducted, including an examination of scientific output by country, an analysis of the journals that publish most frequently on the subject, and the identification of the most relevant authors in the field of bacteriophage studies. This analysis provided a comprehensive overview of the topic, enabling the identification of trends, gaps in the literature, and opportunities for future research.

Table I. Search parameters used in both databases.

Parameter	Web of Science	Scopus
Range	2014-2024	
Date	April 09, 2025	
Document Type	Paper, book, chapter, conference proceedings	
Words	"bacteriophage" OR "phage AND for AND bacteriophage" OR "phage AND therapy"	
Results	335	549
Total (Wos+Scopus)		884

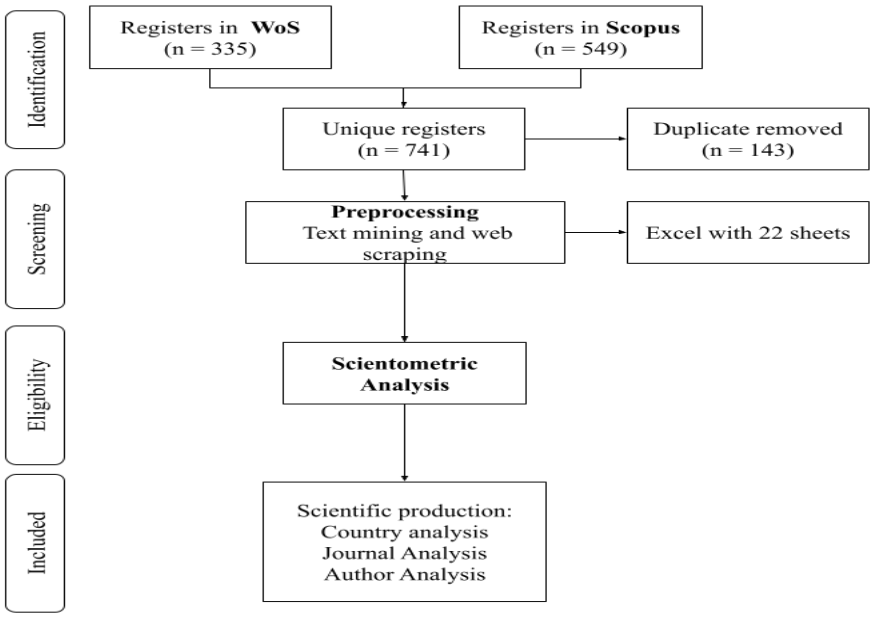

Figure 1. Detailed illustration of collected information

3. Results

Scientific Annual Production

Figure 2 illustrates the annual evolution of scientific output and its impact in terms of total citations regarding the use of bacteriophages as a therapeutic alternative to antibiotics. Three key stages can be identified in this figure.

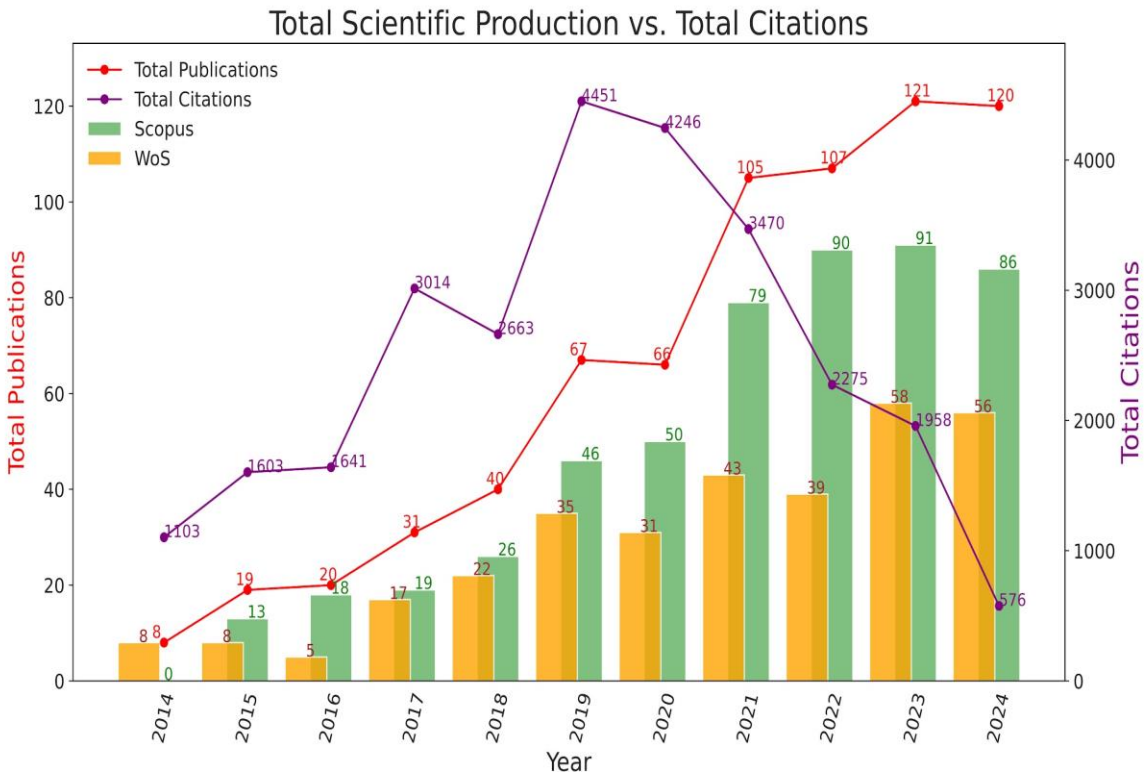

Figure 2. Total Scientific Production vs Total Citations.

Initial Stage: 2014–2017

During the initial period, a low but steadily increasing scientific output is observed, with a progressive rise in publications (from 8 to 31) and a similarly gradual increase in citations. This suggests the early development of the topic of bacteriophages within the scientific community, accompanied by strong interest, as evidenced by the rise in citations from 1,103 in 2014 to 1,641 in 2017 and an annual production growth rate of 57.07%. This increase can be attributed to growing interest in phages as a therapeutic alternative, as highlighted in the study [11], which discusses the possibilities and limitations of such therapies in the context of antibiotic-resistant infections, or in the article [12], which underscores how, despite the underutilization of phage therapy due to challenges like bacterial resistance, phages have emerged as a key tool in the synthetic biology era.

Growth Stage: 2018–2021

This stage shows a moderate but steady growth in publications, with an annual increase of 28.65%. Notably, a peak in citations (4,451) occurred in 2019, alongside 67 publications, indicating significant scientific impact and increasing interest in bacteriophage research. For

example, the article [13] emphasizes the potential of phage therapy in addressing antibiotic-resistant infections, underlining the need for new approaches in response to the growing threat of resistance. It also presents a paradigm shift, envisioning personalized therapies by the year 2035. Along the same lines, articles such as [14] and [15] explore phage therapy as a promising tool for combating pathogens and a viable alternative to antibiotics.

Recent Stage: 2022–2024

In this final period, the number of publications continues to rise, surpassing 120 in 2023. However, the annual growth rate during this phase drops to 16.12%. Citations also decreased significantly, falling from 4,451 in 2019 to just 576 in 2024. This suggests a decline in the impact of recent publications, despite an increase in output. Possible reasons include a maturation process in the bacteriophage research field, the publication of studies in lower-impact journals, or the fact that newer articles have not had sufficient time to accumulate citations. Nevertheless, the quality and relevance of current publications remain high, as demonstrated by the study [16], which presents recent advances and mechanisms in phage-based therapies for cancer treatment. Another example of innovation in the field is [17], which analyzes how CRISPR-engineered phages can be used as novel antibacterials to combat antibiotic resistance, while also discussing the scientific, economic, and health challenges that must be overcome for safe implementation of phage therapy.

In conclusion, the annual scientific output on bacteriophages has shown an average growth rate of 31.10%, indicating that while the research field has matured, it still presents significant opportunities for innovative studies. This is evident in one of the most recent articles [18], which explores an innovative approach using 3D skin models, organoid systems, and hydrogel-based platforms to evaluate the effectiveness of phage therapy in patients with diabetic foot ulcers (DFUs). However, this does not diminish the importance of earlier publications such as [19], [20] and [21], as these foundational studies laid the groundwork for the development of more effective therapies applied across various fields.

Country Analysis

Table II presents a qualitative and quantitative summary of scientific output, impact within the scientific community (citations), and quality based on the quartile rankings of the journals associated with different countries involved in articles on bacteriophage-based treatments, covering the period from 2014 to 2024.

Table II. Scientific Output, Impact, and Quality by Country in the Literature on Bacteriophages

Country	Production		Citation		Quality			
	Count	%	Count	%	Q1	Q2	Q3	Q4
Usa	143	18.45	5689	22.5	106	14	8	0
China	94	12.13	1917	7.58	65	9	8	3
United Kingdom	56	7.23	1732	6.85	29	8	5	0
Poland	44	5.68	1908	7.55	29	11	2	0
India	39	5.03	644	2.55	12	12	7	2
Australia	32	4.13	1361	5.38	25	1	2	0
France	29	3.74	1330	5.26	23	1	0	3
Switzerland	24	3.1	1367	5.41	16	2	0	2
Belgium	23	2.97	1580	6.25	16	1	0	0
Germany	23	2.97	784	3.1	19	1	1	0

The United States emerges as the leading country in terms of scientific output (18.45%) and also ranks highest in terms of citation impact, accounting for 22.5% of total citations. China follows, with 12.13% of the total output and 7.58% of citations. Interestingly, although Poland contributes only 5.68% of the total scientific output, it achieves a citation impact nearly equal to that of China, with 7.55%, indicating a strong influence in the field despite a lower volume of publications.

In terms of research quality, notable differences emerge among these three countries, particularly regarding the number of studies published in Q1 journals. The United States leads with 106 Q1 publications, followed by China with 65 and Poland with 29. It is also worth noting that China has three publications in Q4 journals, whereas both the United States and Poland have no publications on bacteriophage-based antibiotic alternatives in Q4-ranked journals.

Likewise, two recent and distinct studies by Chinese researchers focused on the antimicrobial activity of phages against the coccobacillus bacterium *Acinetobacter baumannii*. One of the articles reports a clinical case in which phage therapy was used to treat a pulmonary infection caused by a multidrug-resistant strain of this bacterium [22]. The therapy was administered via inhalation, and after several tests, various changes were observed in the patient, including the detection of phage DNA in the bloodstream and alterations in the gut microbiota throughout the treatment period.

The second study experimentally evaluates the effectiveness of a novel phage, P1068, against *A. baumannii*, highlighting it as a significant therapeutic breakthrough for combating carbapenem-resistant strains [23]. The article details several novel findings, including gene transfer between morphologically distinct phages and the efficacy of P1068 against bacterial biofilms. Both studies contribute valuable insights to the scientific community by assessing

the potential of phage therapy against *A. baumannii* and serve as a foundation for continued research, particularly in evolutionary aspects of phage-bacteria dynamics.

Figure 3 presents a graphical representation of the various affiliations between authors from countries involved in bacteriophage research as an alternative treatment for multidrug-resistant bacterial strains. It identifies five groups of interconnected countries that share scientific output on this topic.

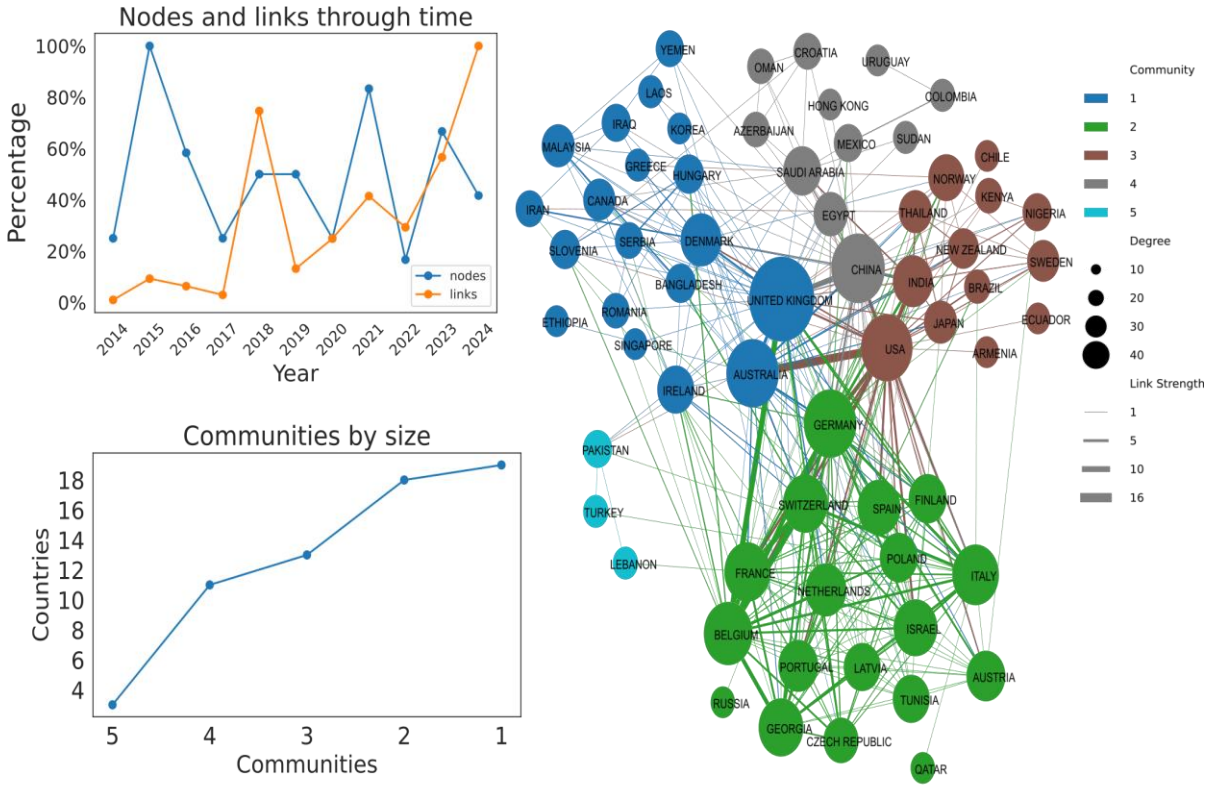

Figure 3. Country Analysis

Figure 3 comprises three graphs. First, the visual representation of country-community connections is noteworthy. The community with the most countries involved (depicted in blue) exhibits several interlinked networks, with the United Kingdom emerging as a central hub, maintaining strong ties with other countries in the group, such as Australia. Notably, the UK also displays significant intergroup collaborations, particularly with Belgium and China. China, in turn, shares a robust network with the United States, which also maintains meaningful connections with Australia.

The second community (green) consists of 28 countries with relatively similar degrees of centrality, and most collaborative links within the group are strong. The third community (brown) is led by the United States, which maintains a notable link with India. The fourth community (gray) is headed by China, featuring strong connections with Egypt, India, the United Kingdom, and the United States. Finally, a smaller community composed of only

three countries—Pakistan, Turkey, and Lebanon—also maintains connections with various countries from the other communities.

Additionally, a graph displays the number of countries forming each community, while a second graph of nodes and links highlights peak periods, such as in 2018 and 2024, where the proportion of links increased relative to the number of new countries (nodes). It is important to emphasize that from 2022 to 2024, there has been a significant increase in international collaboration networks, indicating a strengthening of the global academic community engaged in bacteriophage research as an alternative treatment against microbial pathogens.

An article that highlights the collaborative network between the United States and India—both part of the third community (see Figure 3)—emphasizes the importance of applications beyond the laboratory regarding the use of phages as a potential complementary treatment alongside antibiotics against multidrug-resistant bacteria. In this regard, the researchers compiled various clinical cases, illustrating how phage therapy may not entirely replace antibiotics but serves as a fundamental tool for treating microbial resistance [24].

Another noteworthy collaboration involves researchers from Austria, the United Kingdom, Nigeria, and the United States, who authored a scientific literature review that compiles ten years of research on phage therapy as an alternative or complementary approach to treating antibiotic-resistant bacterial strains. The review notably describes phage therapy as a viable and non-experimental treatment that can be associated with biotechnology and genetic engineering to enable safe and effective use of phages in personalized therapies targeting specific strains [25].

Both articles underscore the importance and potential of bacteriophages, while also acknowledging the ongoing challenges facing the field, including regulatory hurdles, limited clinical practice, and the possible emergence of bacterial resistance to phages.

Additionally, one particularly interesting international collaboration is between researchers from the United States and Brazil. Two articles highlight this connection. The first presents a literature review emphasizing the clinical use of bacteriophages against antibiotic-resistant bacterial strains. It addresses the historical context, the resurgence of phage therapy as a viable treatment option, existing advantages, implementation challenges, research limitations, and importantly, how phage therapy could serve as a key solution for addressing infections in low-income and resource-limited communities [26].

The second article proposes an innovative implementation of bacteriophages, evaluating their antibacterial effect against *Enterococcus faecalis*, a strain that demonstrates antibiotic resistance in 30% to 89% of post-endodontic surgery cases [27]. The results were promising, demonstrating the efficiency of genetically modified phages as a strategy for disinfecting root canals infected by this bacterium—thus reinforcing the promise of phages as an alternative treatment for antibiotic-resistant bacteria.

One network that exemplifies the strengthening of scientific communities is the collaboration between researchers from Belgium and the United Kingdom. Authors such as Helen Stacey,

Steven De Soir, and Joshua Jones are frequently featured in co-authored publications on phage therapy.

A first article proposes and emphasizes the importance of the legal and clinically prudent implementation of unlicensed phage therapy within the UK's public healthcare system [28]. A second article provides a review of clinical and safety trials analyzing the efficacy of various phage therapies, pointing out frequent issues such as improper administration, insufficient dosing, and poor phage selection [29].

A third study presents a systematic review demonstrating the effectiveness of purified phages in treating infected skin surfaces, including dermatological cases, chronic wounds, and burns [30]. A fourth article offers another systematic review, this time focused on bone and joint infections such as osteomyelitis and prosthetic joint infections [31]. This final study reports a low incidence of safety issues and further reinforces the potential of phage therapy in treating deep infections caused by multidrug-resistant bacteria.

Overall, these four articles—representing the Belgium–United Kingdom collaboration—provide strong evidence that phage therapy is a promising treatment strategy which, with proper regulatory management, could become a viable alternative in the fight against rising antimicrobial resistance.

Journal Analysis

Table III presents an analysis of scientific journals that have made the most significant contributions to the dissemination of phage therapy as an alternative to antibiotics. *Frontiers in Microbiology* ranks first, with 40 combined publications in both WoS and Scopus, followed by *Viruses* with 32 publications and *Antibiotics* with 25. These journals focus primarily on microbiology and public health. For example, *Frontiers in Microbiology* emphasizes viruses, pathogens, and fungi, which explains its high level of interest in phage therapy, as evidenced in articles such as [32] and [33]. Similarly, *Viruses* specialize in the field of virology, as reflected in publications such as [34] and [35].

Table III. Scientometric indicators of the Journal Analysis in phage therapy research.

Journal	Wos	Scopus	Total
Frontiers in microbiology	27	23	40
Viruses	0	32	32
Antibiotics	0	25	25
Antibiotics-basel	37	0	23
Clinical infectious diseases	4	14	15
antimicrobial agents and chemotherapy	6	13	14
Scientific reports	1	14	14
Pharmaceuticals	6	8	12
Viruses-basel	26	0	12
Frontiers in medicine	6	9	11

It is important to note the disparity between the databases: some journals, such as *Antibiotics*, show strong representation in Scopus (25 articles) compared to none in WoS, while others like *Antibiotics-Basel* have 37 publications indexed in WoS but none in Scopus. This suggests a diversity in the visibility or orientation of studies on phage therapy. For example, the article [36] focuses more on biotechnology and medicine, highlighting the complexity of phage behavior during therapeutic treatments and the challenges this poses in clinical practice. In contrast, the study by Kowalska et al. (2024) explores the application of bacteriophages in veterinary medicine, particularly in the treatment of Nile tilapia. It evaluates the viability of this therapeutic alternative to reduce antibiotic use in aquaculture [37].

This diversity explains why some journals are indexed exclusively in one of the two databases analyzed, reflecting the wide range of disciplinary approaches—clinical, biotechnological, or veterinary—addressed in the phage therapy literature.

Figure 4 illustrates how relationships among scientific journals are structured, highlighting three main communities. The first community (orange) is oriented toward clinical and veterinary studies, consolidating the medical approach to phage therapy. Notable journals in this group include Veterinary Microbiology and Poultry Science. This community also contains the largest number of journals, indicating that the clinical-veterinary focus is the dominant perspective within the field of phage research.

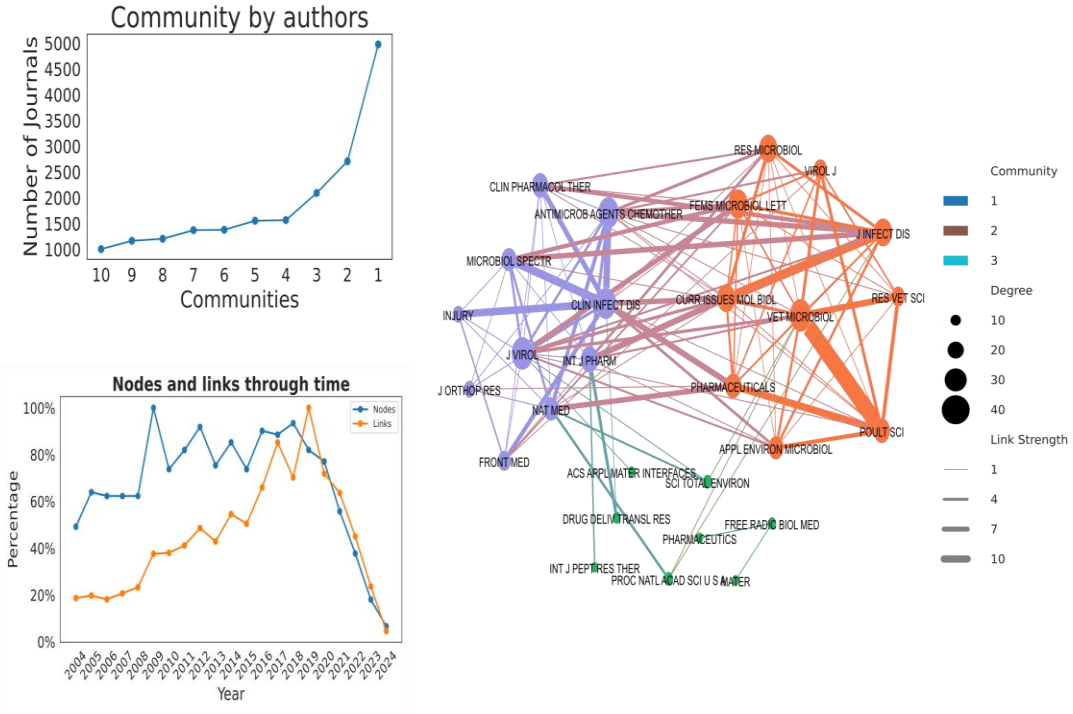

Figure 4: Network of Journal Citations Highlighting Collaborative Communities

The second community (purple) centers on microbiology and biotechnology, with key journals such as Microbiology Spectrum and Clinical Infectious Diseases. Finally, the third community (green) focuses on pharmacological studies and recent research into novel applications of phage therapy.

Author Analysis

A scientometric analysis of authors was carried out to identify the most influential researchers in the field of bacteriophage use as a therapeutic alternative to antibiotics and to determine their networking strategies. This analysis was based on parameters related to productivity and collaboration. Table IV displays the most impactful authors according to the number of publications, total citations, and the H-index, as explained in the article [38]. The table also includes the size of the authors' collaboration networks, their structural constraints, and the Collaborative Diversity Index (CDI).

Table IV. Scientometric indicators of the leading authors in phage therapy research.

Author	Papers Total	Total Citations	H-Index	Effective_Size	Constraint	CDI
Pirnay J	26	1417	20	333.44	0.01	0.02
Górski A	21	954	15	287.58	0.02	0.05
Merabishvili M	18	1002	14	310.99	0.01	0.02
Aslam S	16	1118	12	174.8	0.02	0.04
Hazan R	16	641	11	209.04	0.02	0.02
Schooley R	14	1254	13	182.6	0.02	0.03
Abedon S	13	679	11	28.62	0.1	0.23
Chan B	13	361	8	79.95	0.04	0.11
Clark J	13	568	10	148.6	0.02	0.06
Doub J	13	247	9	24.06	0.11	0.11

It can be observed that Pirnay J is the most prolific author, with a total of 26 publications. He also stands out with a total of 1,417 citations and an H-index of 20, reflecting significant influence in this field. Furthermore, he presents the highest effective size (333.44), which indicates a broad collaboration network, with a low constraint of 0.01 and a CDI of 0.02.

Following him are Górski A and Merabishvili M, with 21 and 18 publications respectively. Both authors show high citation levels and effective sizes above 280, underscoring their importance in the field.

In contrast, Abedon S shows lower productivity and an effective size of 28.62, but stands out due to a high CDI (0.23) and a relatively high constraint (0.10). This suggests that Abedon mainly collaborates with a small, tightly interconnected group of authors. This pattern is

evident in publications such as [39], [40], and [41], which reflects a closed network of collaboration centered on similar research lines. Although such networks can promote depth and specialization in research, they may also limit exposure to innovative or interdisciplinary ideas compared to more diverse and loosely connected networks.

Figure 5 illustrates the scientific collaboration network among the leading authors, built from the individual collaboration networks of each researcher. This network enables the identification of patterns such as nodes and author communities. Each node represents an author, with its size determined by the degree of collaboration with other authors, while each link indicates co-authorship relationships, with thicker lines representing more frequent collaborations.

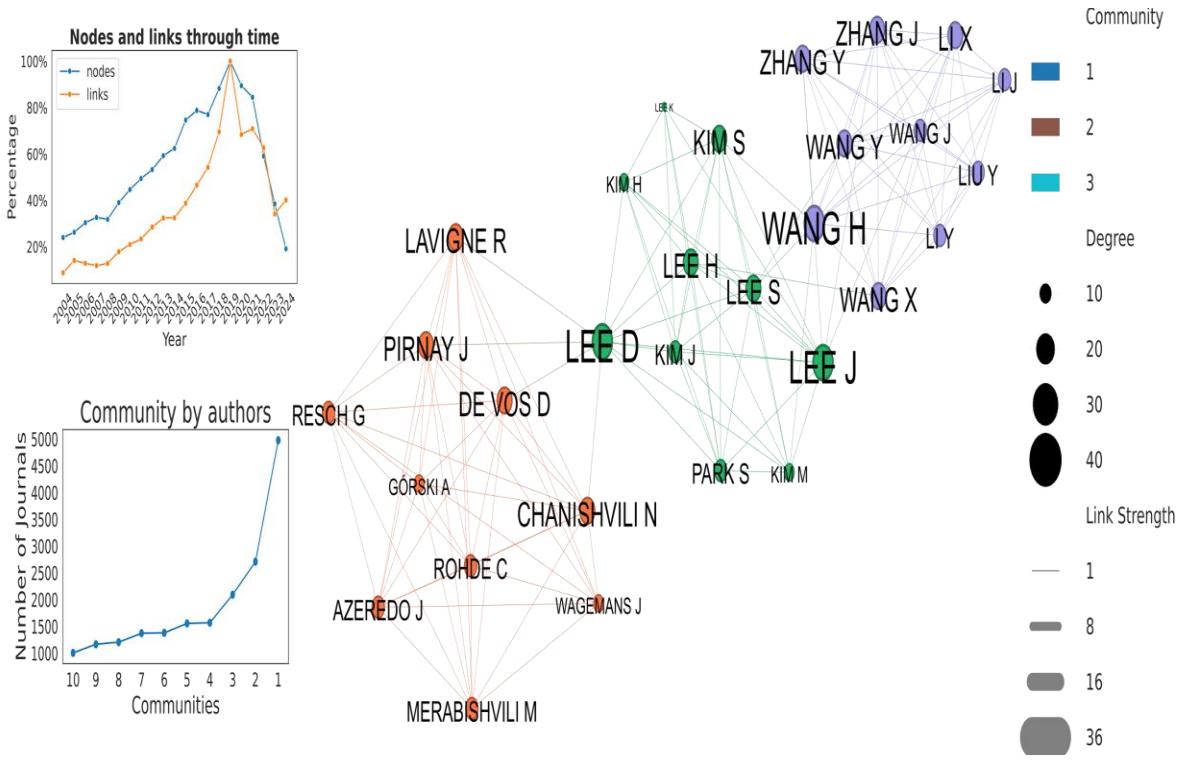

Figure 5: Collaboration network of prominent authors and their interconnections

For instance, the co-authorship network highlights Pirnay J and Chanishvili N as central figures, both showing a high number of publications and citation counts. Their effective size indicates a broad and diverse collaboration network.

Additionally, the "nodes and links through time" graph reveals a growing trend in author collaboration networks up until 2019, which marks the peak year in terms of both the number of nodes and links. This indicates that 2019 was the most collaborative year within the field. From 2020 onward, there is a noticeable decline in both metrics: links drop significantly, reaching only about 20% by 2024, while nodes decrease as well but slightly recover in 2024, reaching close to 40%. This trend may reflect external factors impacting collaboration or shifts in research dynamics within the field.

Conclusions

This scientometric article focused on a comprehensive analysis of scientific studies from databases such as WoS and Scopus, which were merged using sophisticated web scraping and data mining algorithms. A total of 741 documents were utilized in this analysis, centered on the potential of bacteriophages as a therapeutic alternative to antibiotics. The study identified key patterns in scientific output, country-level contributions, journal analysis, and scientific collaboration networks among prominent authors in the field.

One of the main findings of this scientometric study is the identification of a steady annual growth in the number of publications, alongside signs of field maturation in recent years. The presence of a diversified scientific collaboration network highlights the increasing strength of interdisciplinary research.

The results show a 10-year evolution with an average annual growth rate of 31.10%, transitioning from an exploratory phase to a peak in research impact, and finally to a maturation phase between 2022 and 2024. This last phase is characterized by high productivity but lower impact, as evidenced by a decline in citations to only 576 in 2024. This suggests current challenges in the field, such as the need for more innovative approaches and greater visibility in high-impact journals. Nevertheless, recent advances indicate that phage therapy continues to hold strong potential, especially in molecular biology and biotechnology.

The country-level analysis revealed that the United States leads in scientific production, impact, and research quality, followed by China, which is closely rivaled by Poland due to its high citation rate and significant academic influence. Moreover, between 2022 and 2024, an increase in international collaboration networks was observed, underscoring a growing interest in global cooperation among researchers. Authors have explored bacteriophage therapy from multiple angles, including systematic reviews, experimental and clinical efficacy assessments, and regulatory and legal perspectives. Given the rising threat of multi-drug resistant bacterial strains, phage therapy is projected to remain a vital research area.

In the journal analysis, Frontiers in Microbiology emerged as the leading publication platform, with 40 publications across WoS and Scopus. Its focus on microorganisms, viruses, and pathogens aligns directly with the subject of phage therapy. It is followed by journals such as Viruses and Antibiotics, which specialize in microbiology, virology, and public health. However, a significant discrepancy in indexing between the two databases was observed—some journals like Antibiotics-Basel are well represented in WoS but absent from Scopus, and vice versa. This reflects the diversity of disciplinary perspectives and editorial policies shaping the visibility and dissemination of research on phage therapy, spanning clinical, veterinary, and biotechnological domains.

In terms of author analysis, Pirnay J. stands out as the most influential researcher in the field, with 26 publications, 1,417 citations, and an H-index of 20, indicating both high productivity and academic recognition. His high effective size also reveals a wide and diverse collaboration network, enhancing the interdisciplinary value of his research. Authors like Górski A. and Merabishvili M. also demonstrated strong citation and collaboration metrics, establishing themselves as key figures in the clinical development of phage therapy.

Conversely, Abedon S., although less productive and operating within a more closed collaboration network—as reflected in his low effective size (28.62) and high constraint—exhibits a high CDI, indicating an intensive collaborative strategy within specific academic communities. These more tightly connected networks may offer greater thematic depth and research consistency, albeit at the expense of exposure to diverse or innovative perspectives.

Throughout this scientometric process, a major challenge was the integration of data from different sources, especially due to the incompatible formats of Scopus and WoS. While this study successfully overcame this limitation, future analyses could benefit from improving data integration algorithms and incorporating additional sources such as OpenAlex. Although this is a data-driven scientometric study, future research should consider qualitative approaches to enrich the understanding of underlying trends. A thematic and qualitative replication of this analysis is recommended to identify emerging directions, research priorities, and narrative patterns in the development of phage therapy.

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