

# KNOWLEDGE STRUCTURE OF LINCOMYCIN STUDIES: A BIBLIOMETRIC STUDY OF SHIFTING RESEARCH PARADIGMS OVER SIX DECADES



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## ABSTRACT

*Lincomycin is an important clinical and veterinary antibiotic targeting Gram-positive organisms with high tissue affinity. It is used to treat tissue infections in both humans and veterinary applications. Despite its long history of use and wide applications, no bibliometric study has assessed the full potential of lincomycin. Therefore, we aim to detail and highlight the emerging trends, areas, and gaps in lincomycin research. The Scopus database was used to retrieve relevant lincomycin records over the past six decades. We used both the VOSviewer software and the Bibliometrix R package to identify key indicators, such as institutional affiliations, keyword co-occurrence, country productivity, annual scientific production, and research themes and trending topics. The bibliometric analysis included 963 lincomycin-related articles across 452 journals, authored by 2,777 researchers, with an average of 16.05 citations per article. Scientific output showed an early surge in the late 1960s, followed by a long period of moderate activity and a renewed rise after 2012, peaking in 2023. The highly cited papers in lincomycin research reflect the multidisciplinary impact of this antibiotic, spanning plant photoinhibition, ribosomal binding, biosynthesis, veterinary therapy, environmental degradation, and analytical detection. International collaboration in lincomycin research was relatively limited, with only 6.75% of publications involving international co-authorship. Thematic analyses revealed a shift from earlier pharmacology topics to resistance-oriented topics and advanced analytics (LC-MS/MS), with aptasensor and electrochemiluminescence methods emerging as recent focal areas. Lincomycin research has gained focus since 2012, driven by increasing antimicrobial resistance and a shift towards biosynthetic optimization and advanced detection technologies.*

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## INTRODUCTION

Antibiotics administered to livestock can impose significant risks due to drug residues in edible tissues (Kamouh et al., 2024), milk (Niu et al., 2023), eggs (Owusu-Doubreh et al., 2023) and honey (Shoaei et al., 2024), all of which can be introduced into the human food supply and cause a selection pressure on bacteria and induce drug resistance (Ali et al., 2025). As well as affecting the health of human consumers (Arsène et al., 2022). In addition, these residues can interfere with the human gut microbiome (Chen et al., 2022) and trigger allergic reactions in susceptible individuals (Bacanli, 2024). This creates a need for sensitive, reliable, high-throughput analytical methodologies capable of detecting trace-level contamination across different food matrices (Zhang et al., 2024). The development of coordinated detection platforms from novel technologies such as electrochemiluminescence (Althomali et al., 2024) and LC-MS/MS methods (Er Demirhan & Demirhan, 2022).

The application of bibliometric tools is an effective method for systematic evaluation of veterinary antibiotic research (Yang et al., 2021). Assessment of publication patterns, citation analysis, keyword trends, and co-occurrence

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studies can identify the most significant contributors to a research topic (Ding et al., 2025; Yuan et al., 2023). For veterinary antibiotic lincomycin, bibliometric analysis can provide a map of the evolution of antibiotic research, from predominant topics such as pharmacokinetics and clinical efficacy to methodologies for detecting antibiotic residues, environmental persistence, and mechanisms of resistance development. Bibliometric studies can assist stakeholders, such as researchers, authorities, and policymakers, in assessing the trends and themes of their investigated topic (Kajikawa, 2022). Citation analysis can identify the foundation for quantitative analysis of the investigated topics. Co-authorship analysis can show the international collaboration patterns (Velez-Estevez et al., 2022).

By using bibliometric approaches to the veterinary antibiotics literature, we can directly address gaps in institutional collaboration and evidence-based policymaking. Thematic evolution analyses can be used to trace the development and dissemination of certain methodological advances. Bibliometric studies would help collate disparate studies into a unified intellectual structure.

## LITERATURE REVIEW

Lincomycin is a lincosamide antibiotic extracted from *Streptomyces lincolnensis* (Macleod et al., 1964). Lincomycin can prevent Gram-positive bacterial infections by inhibiting protein synthesis by binding to the ribosomal 50S subunit (Krawczyk et al., 2024). Furthermore, lincomycin has been considered for the treatment and prevention of several bacterial infections, including respiratory tract infections (Lawhorne, 1991), streptococcal and staphylococcal skin infections (Kanee, 1965; Ruke et al., 2024), and bone infections (Chelpanova, 2024; Paus, 1971).

Lincosamides are an important class of antibiotics in veterinary medicine. Lincosamides accounted for about 125 tons in the USA in 2018, representing about 2% of antimicrobial sales used in food-producing animals (Mehrtens et al., 2021). Lincomycin has significant value for animal health and productivity, given its role in treating bacterial infections in dairy cows, such as mastitis, and its wide applications in aquaculture (Mehrtens et al., 2021; Timonen et al., 2021). Furthermore, lincomycin has been effective in patients with allergies to beta-lactam antimicrobials, especially penicillin allergies (Yang et al., 2024).

There are clinical and veterinary studies that demonstrated the use of lincomycin in the treatment of respiratory dental and surgical infections (Ruke et al., 2023). Clinical trials also showed that oral lincomycin is clinically effective and well-tolerated for the treatment of upper respiratory tract infections. Lincomycin is also effective for treating surgical site infections and skin and soft-tissue infections (Ruke et al., 2023). In dentistry, lincomycin has also been shown to have therapeutic value. Besides established and new indications for lincomycin, traditional and innovative formulations, such as lincomycin HCl-loaded borneol-based in situ gels, became available for treating localised periodontitis (Puyathorn et al., 2023). All of these clinical and therapeutic data suggest that lincomycin is still used in the clinic today for both systemic and localised antimicrobial therapy.

Lincomycin is a widely used antibiotic for the treatment and growth promotion in livestock and poultry industries. The use of lincomycin as a growth promoter is linked with metabolic disruption and weakened immunity in animals (Ni et al., 2024). Several studies have evaluated the effects of lincomycin supplementation on the expression of genes involved in nutrient absorption, immune function, and blood biochemistry in broiler chickens (Saleh et al., 2024). Moreover, the pharmacokinetics of lincomycin in domestic geese have been studied, and the disposition kinetics and animal tissue residues were evaluated after administration via different routes, including intravenous, intramuscular, and oral (Bourdo et al., 2026). Pharmacokinetic studies help forecast the withdrawal period and facilitate food safety, as antibiotics persist in the tissues of edible organs and products derived from animals.

Various analytical and detection procedures have been presented to address lincomycin residue in food and environmental matrices. High-performance liquid chromatography (HPLC) is used to validate the presence of lincomycin residues in foods of animal origin (Hou et al., 2024). The more advanced analytical methods include LC-MS/MS platforms (Guo et al., 2021), electrochemiluminescence (Li et al., 2022), and photoelectrochemical sensors (Zhang et al., 2020), which are known for their high selectivity and sensitivity. Furthermore, the discovery of nanomaterial-based analytical detection, such as the utilisation of CdTe quantum dots and gold nanoparticles (Ge et al., 2015) and Ag nanoparticles (Zhi et al., 2024), has been successfully demonstrated with high sensitivity and selectivity.

Lincomycin has emerged as an environmental pollutant of interest (Li et al., 2025). Several published studies have examined methods to remove lincomycin from wastewater and water systems (Wang et al., 2025; Zhao et al., 2023), including adsorption using acid-modified biochar derived from activated sludge biomass (Minaei et al., 2024).

Antimicrobial resistance has included a wide range of antibiotics, especially lincomycin, due to its long-standing utilisation (Abdul-Jabbar et al., 2022). Therefore, emerging strategies have been employed to preserve the efficacy of lincomycin, given bacterial mechanisms that overcome its activity through ribosomal methylation and enzymatic inactivation (Leclercq, 2002).

In this bibliometric analysis, we provide a comprehensive overview of some aspects of lincomycin research. In this context, we presented the country, author, and institution productivity, citation impact analysis, publication trends, emerging themes and gaps related to lincomycin research and its antimicrobial resistance.

## MATERIALS AND METHODS

### Search Strategy and Inclusion Criteria

The Scopus database was used to retrieve relevant lincomycin records from 1963 to August 2025. The search query was as follows: (TITLE(Lincomycin) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (DOCTYPE, "ar"))) AND (EXCLUDE (PREFNAMEAUID, "undefined"))). Our inclusion criteria included only peer-reviewed original articles, with a limitation to English-language articles.

**Analytical Methods**

After extracting the data from the Scopus database into the R language program, we used both the VOSviewer software and the Bibliometrix R package to identify key indicators, including institutional affiliations, keyword co-occurrence, country, author, and institution productivity; co-authorship; citations; international networks; annual scientific production; research themes; and emerging topics.

**Data Visualization**

The Bibliometrix R package (version 4.3.2) was used to perform all bibliometric analyses, including analyses of leading countries, authors, institutions, and papers (Darvish, 2020). The VOSviewer (version 1.6.20) was used to generate visualisation maps, such as keyword co-occurrence and author collaboration networks (van Eck & Waltman, 2010).

**RESULTS**

The bibliometric dataset comprised 963 documents on lincomycin published between 1963 and August 2025, sourced from 452 journals. The annual growth rate of publications was modest at about 1.04%, with a mean document age of 32 years and an average of 16.05 citations per article. In total, 2,777 authors contributed, generating 89 single-authored papers, with an average of 4.14 co-authors per article and 6.75% international co-authorships (Table 1).

Table 1. Description of the included studies

Description	Results
Document Average Age	32
Average citations per doc	16.05
References	16919
Keywords Plus (ID)	6090
Author's Keywords (DE)	1309
Single-authored documents	89
Co-Authors per Doc	4.14
International co-authorships %	6.75

**Annual scientific production and most relevant sources**

From 1963 to August 2025, annual scientific production on lincomycin showed marked variability, with early peaks in the late 1960s and mid-1970s, followed by a long period of moderate activity and a renewed rise after 2018. The number of studies increased from 10 in 1963 to a first maximum of 40 in 1969, then fluctuated between single digits and the low 20s through the 1980s and 1990s. A more recent phase began in 2018, with 31 publications in 2019 and a peak of 36 in 2023, while remaining relatively high in 2024 and 2025 (Figure 1).

Antimicrobial Agents and Chemotherapy, with 52 articles, was the leading source, followed by the Journal of Pharmaceutical Sciences (23 articles) and Chemotherapy (18 articles). The Journal of Antibiotics contributed 17 articles, while the American Journal of Veterinary Research and the Journal of the Indian Medical Association accounted for 13 and 11 articles, respectively (Figure 2).

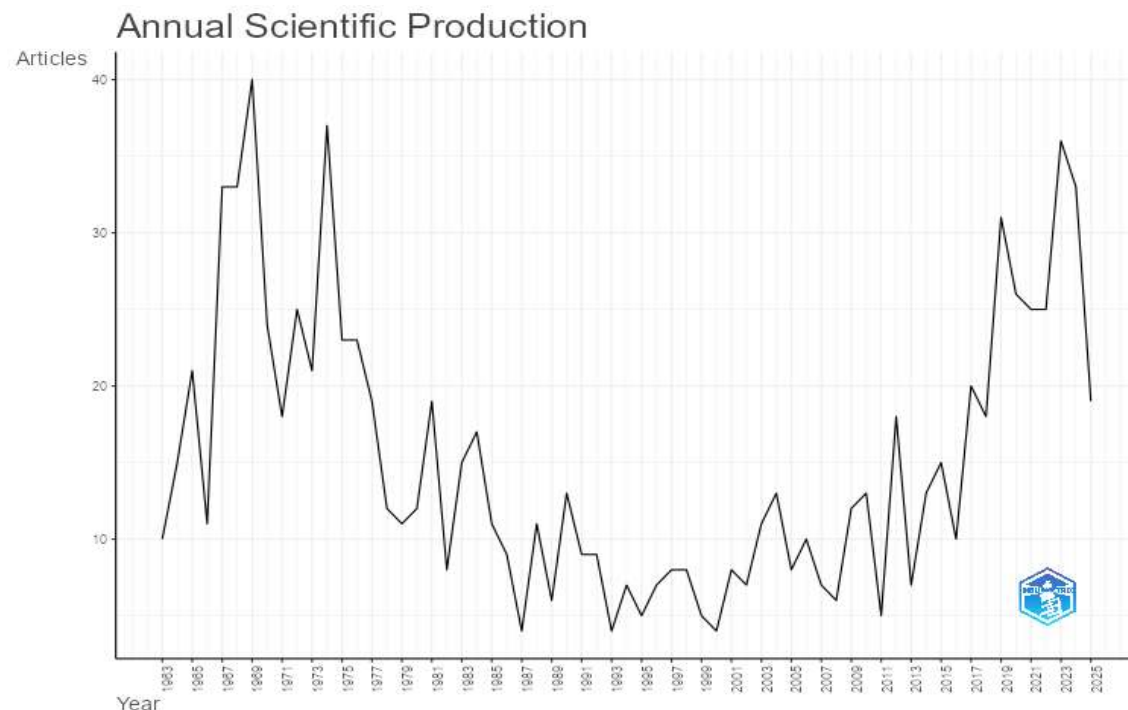


Figure 1. Annual scientific production

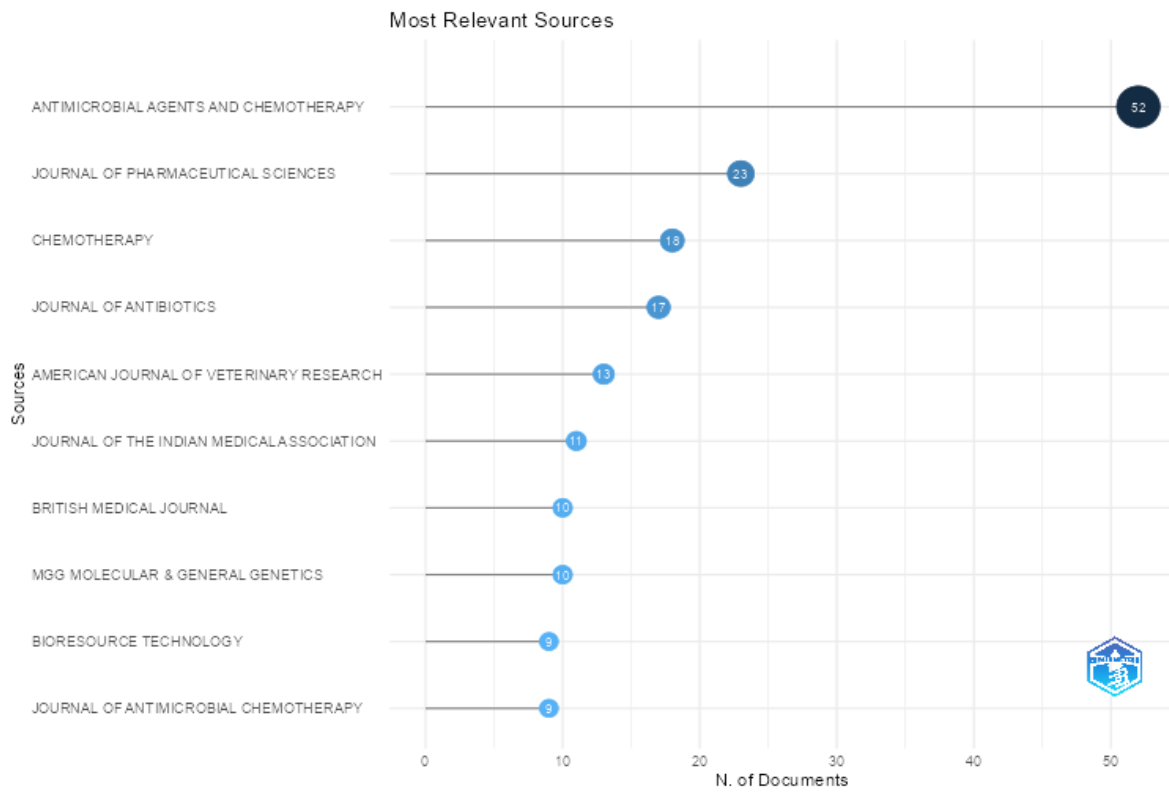


Figure 2. Most relevant sources

### Author productivity and affiliation

Wu H and Zhang H each contributed 25 articles. Wang Y, Wang R, and Ye J produced 22, 16, and 16 articles, respectively (Figure 3). East China University of Science and Technology was the leading institution, with 169 lincomycin-related articles, followed by Anhui University with 73 and the Institute of Microbiology with 66 articles (Figure 4).

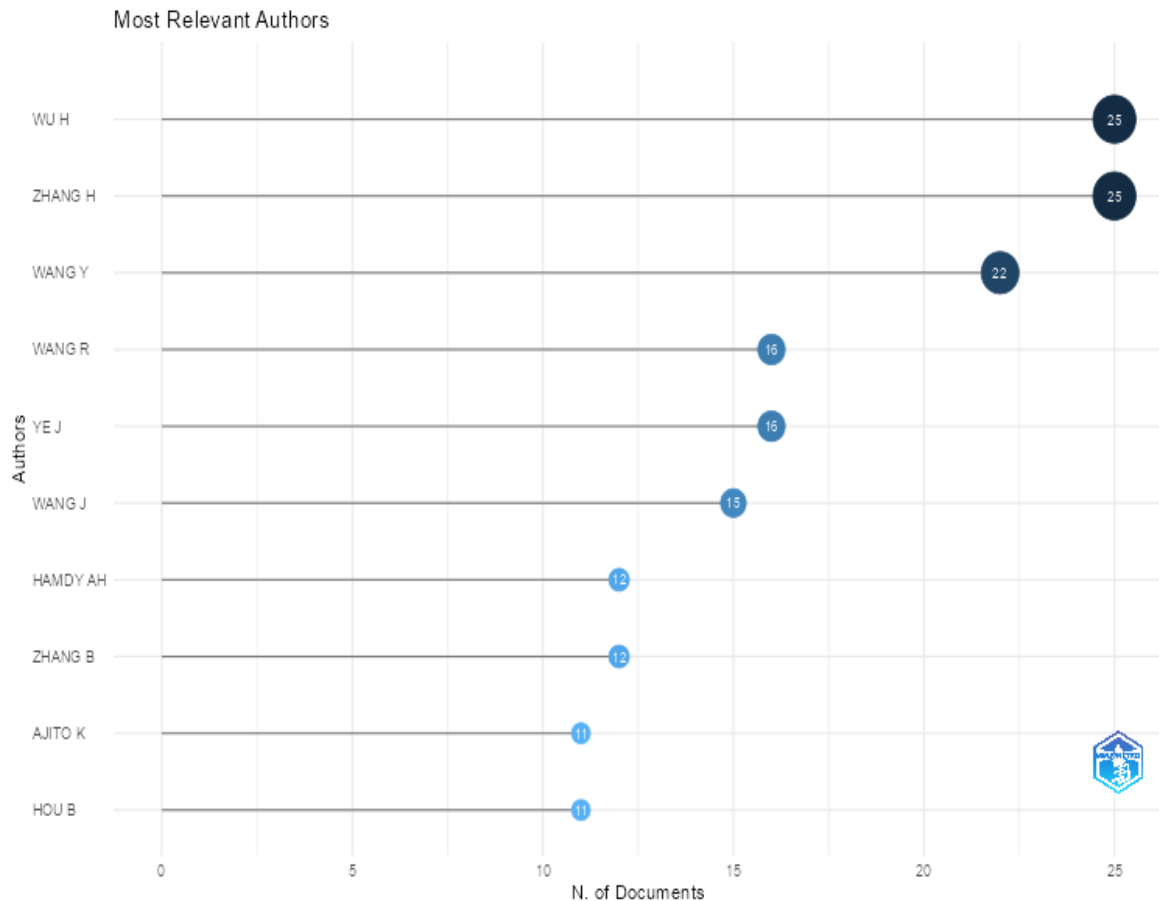


Figure 3. Most relevant authors.

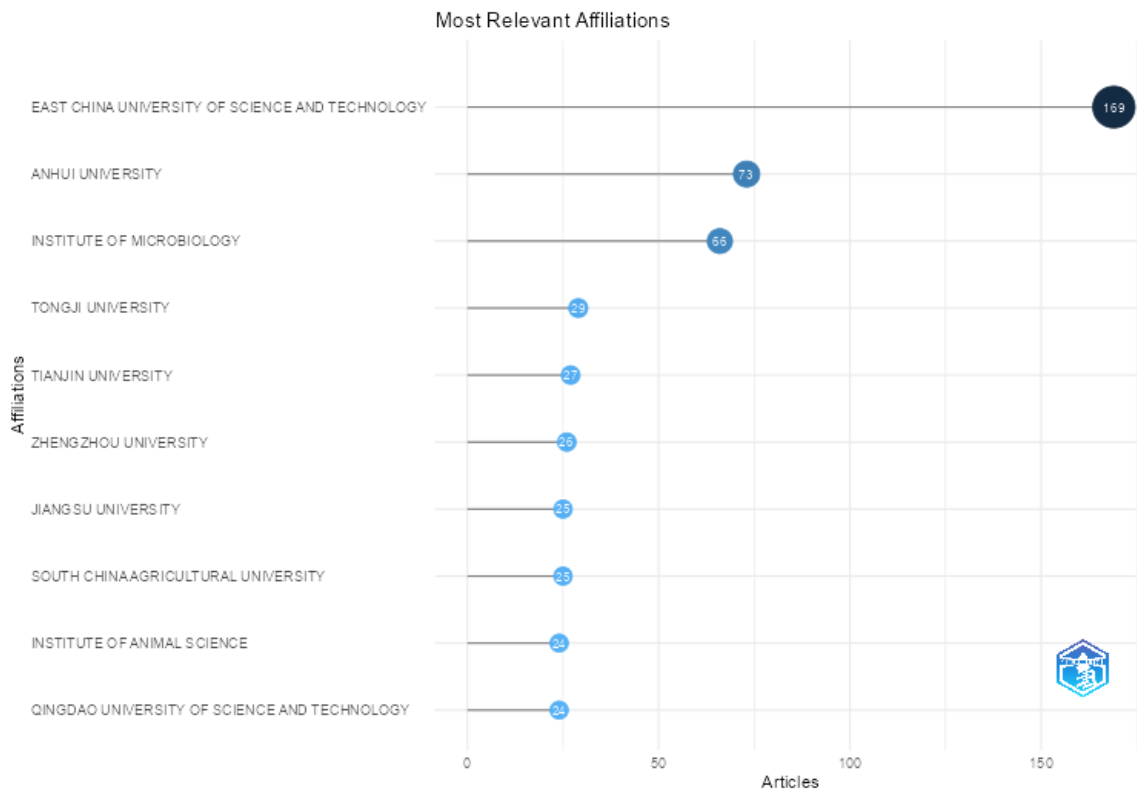


Figure 4. Most relevant affiliations

**Country Productivity and Collaboration**

China was the leading contributor, with 149 articles (15.5% of the total), and a predominance of single-country publications (135 SCP) alongside 14 multi-country publications (MCP). The USA, Japan, Korea, Canada, and the Czech Republic also showed notable output, with 25, 22, 16, 15, and 15 articles, respectively (Figure 5).

The collaboration map indicated that international co-authorships were frequently centred on a few key country pairs. China collaborated with Germany (2 publications), Hong Kong (2), Japan (3), Pakistan (2), and especially the USA (10 joint publications). European and Middle Eastern collaboration links were also evident, including Italy–Poland (2 publications), Czech Republic–Germany (2), and Egypt–Saudi Arabia (3) (Figure 6).

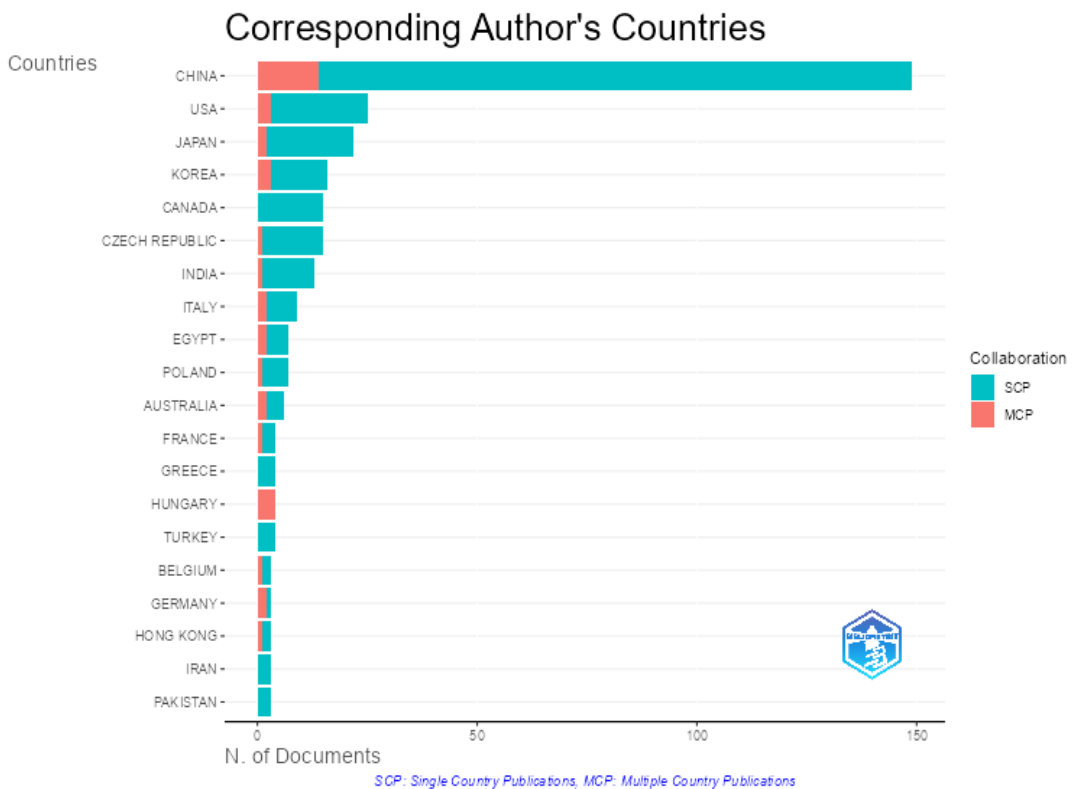


Figure 5. Country's scientific production

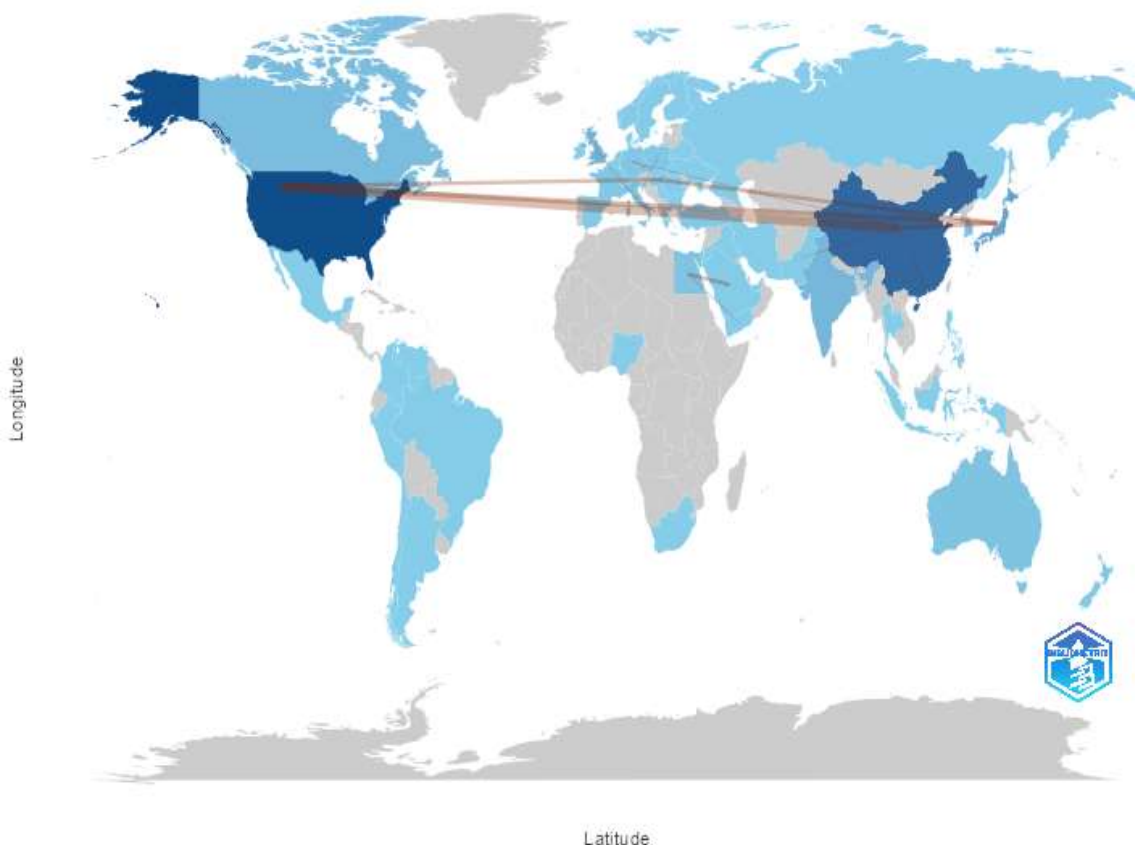


Figure 6. International Research Collaborations

### Highly Cited Papers

The top-cited lincomycin-related papers cover diverse scientific domains. Tyystjärvi and Aro (1996, 390 citations) measured photoinhibition in plant leaves modulation by lincomycin (Tyystjärvi & Aro, 1996). Lin et al. (1997, 244 citations) reported that the oxazolidinone eperzolid binds the 50S ribosomal subunit and competes with chloramphenicol and lincomycin (Lin et al., 1997). Peschke et al. (1995, 194 citations) characterised the lincomycin biosynthesis gene cluster in *Streptomyces lincolnensis* (Peschke et al., 1995). Berry et al. (2012, 162 citations) examined bovine digital dermatitis lesions after topical lincomycin HCl (Berry et al., 2012). Andreozzi et al. (2006, 154 citations) studied lincomycin photodegradation and removal by ozonation (Andreozzi et al., 2006). Scott et al. (1973, 126 citations) linked lincomycin to cases of pseudomembranous colitis (Scott et al., 1973). Zhao (2015, 116 citations) described chemical aspects in lincomycin A biosynthesis (Zhao et al., 2015). Fernández-Muñoz (1971, 108 citations) mapped lincomycin/chloramphenicol binding sites at the ribosomal peptidyl-transferase centre (Fernandez-Muñoz et al., 1971). Li (2017, 104 citations) developed a biosensor for the detection of lincomycin (Li et al., 2017) (Table 2).

Table 2. Most globally cited papers. TC: total citations

Paper	Total Citations	TC per Year	Normalized TC
Tyystjärvi and Aro, 1996, Proc Natl Acad Sci U S A	390	13	5.699373695
Lin, 1997, Antimicrob Agents Chemother	244	8.413793103	6.196825397
Peschke et al., 1995, Mol Microbiol	194	6.258064516	3.959183673
Berry et al., 2012, Vet J	162	11.57142857	4.917369309
Andreozzi et al., 2006, Water Res	154	7.7	3.6492891
Scott et al., 1973, Lancet	126	2.377358491	5.764705882
Zhao et al., 2015, Nature	116	10.54545455	4.554973822
Fernandez-Muñoz, 1971, Eur J Biochem	108	1.963636364	7.363636364
Li, 2017, Biosens Bioelectron	104	11.55555556	6.933333333

### Topic evolution and trend themes

Trend topic analysis highlighted the changing thematic focus of lincomycin research over time. Early topics such as "lincomycin resistance," "spectinomycin," "honey," and "tylosin" gained attention. Molecular biology and antibiotic detection themes emerged in recent years, including "transcriptional regulation," "aptasensor," "electrochemiluminescence," "LC-MS/MS," and "validation" (Figure 7).

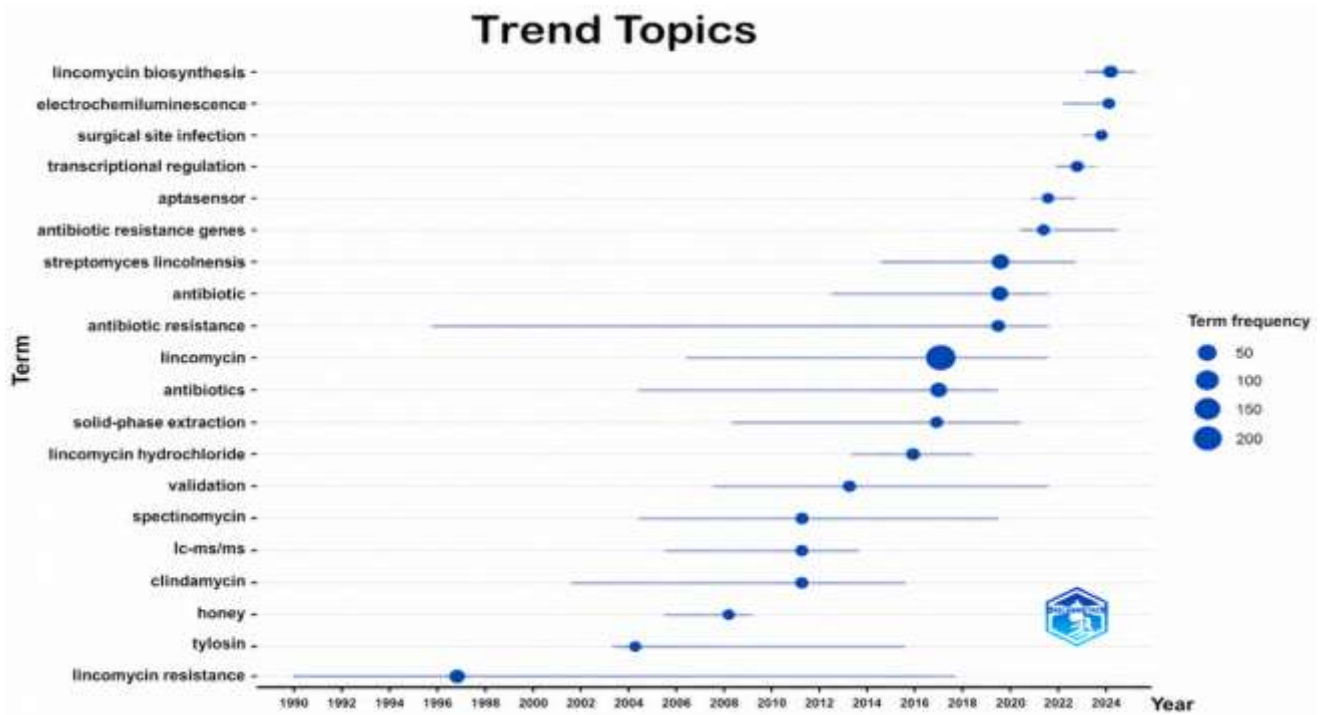


Figure 7. Trend topics

**Relationship among Countries, Institutions, Sources, and Research Topics**

Major Chinese institutions, such as East China University of Science and Technology, the Institute of Microbiology, and Anhui University, made China the leading country in lincomycin research, employing keywords such as lincomycin, *Streptomyces lincolnensis*, transcriptional regulation, and antibiotic resistance genes. These institutions were published with prominent international journals, including Applied Microbiology and Biotechnology and Bioresource Technology (Figure 8).

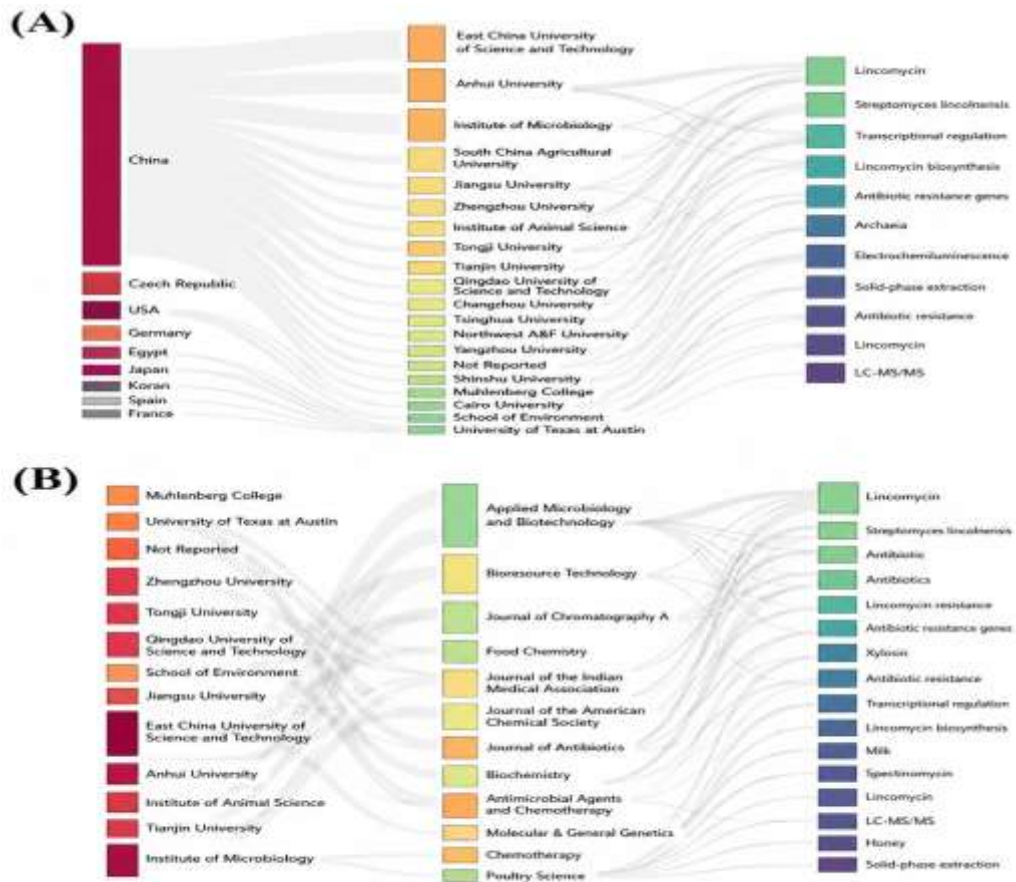


Figure 8. Relationship among Countries, Institutions, Sources, and Research Topics

**Emerging topics and new themes**

Motor themes encompass central and well-developed topics, including lincomycin, antibiotics, *Streptomyces lincolnensis*, transcriptional regulation, and lincomycin biosynthesis. The fundamental topics included antibiotics. Niche themes showed specialised yet emerging areas, such as surgical site infection, skin and soft tissue infection, surgery and silver particles. Emerging or declining themes included antibiotic resistance genes, lincomycin resistance, and lincomycin hydrochloride, indicating evolving research priorities (Figure 9).

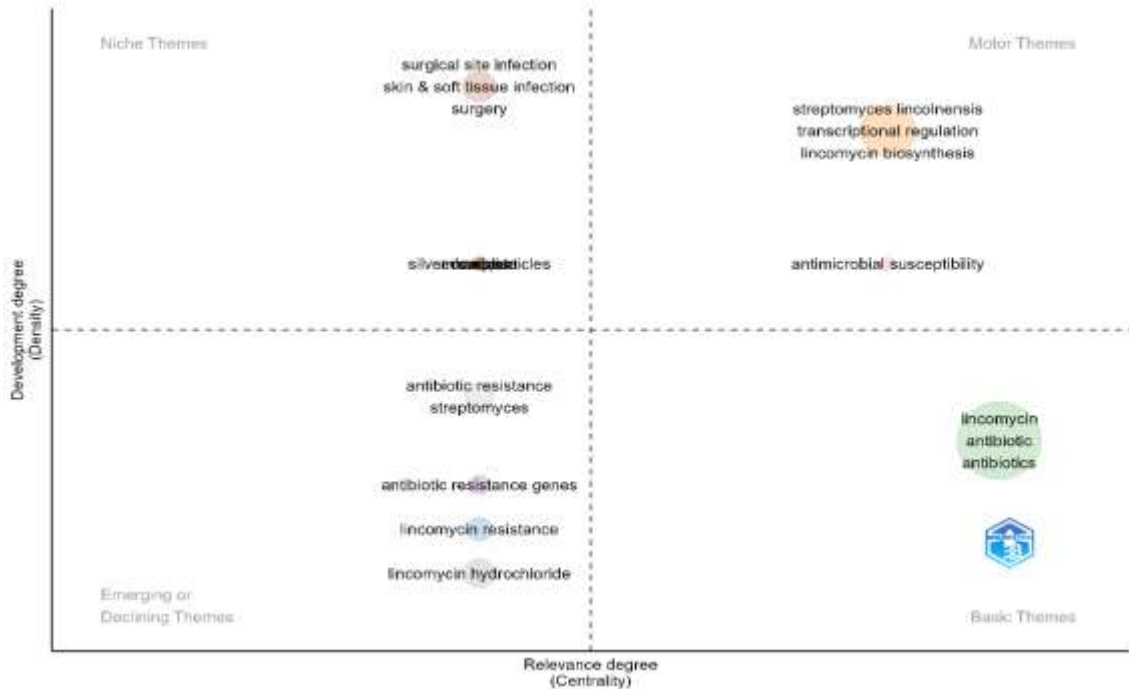


Figure 9. Core, Niche, and Emerging Themes

**Keywords co-occurrence**

Figure 10A shows a keyword network centred on lincomycin. Lincomycin is closely related to other macrolide or lincosamide antibiotics, such as clindamycin, spectinomycin, and tylosin. A cluster showed food safety and instrumental analysis, including terms such as LC-MS/MS, validation, and honey (residue studies). A clear connection to *Streptomyces lincolnensis* implies the drug’s microbial origin. Emerging analytical approaches included aptasensor and aptasensor-based detection.

Figure 10B presents the same network overlaid over time, with colours shifting from earlier (blue) to more recent (yellow). Foundational topics (lincomycin, related antibiotics, and LC-MS/MS) appear earlier, whereas newer themes—such as aptasensors become more prominent in later years.

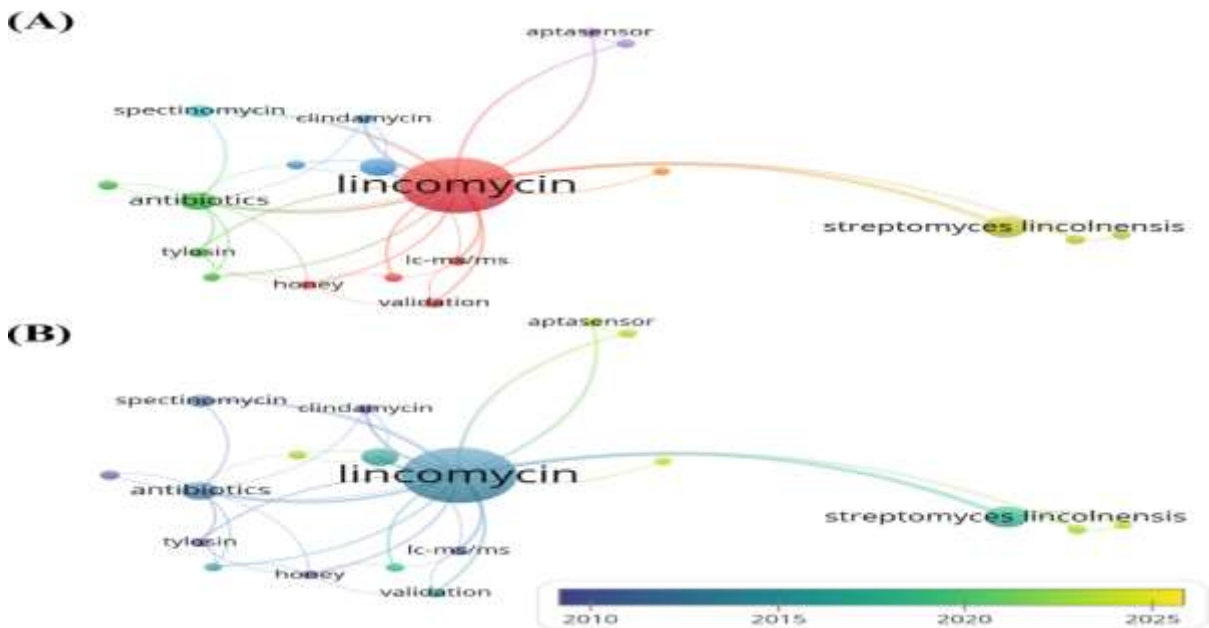


Figure 10. Thematic Clustering and Evolution

## DISCUSSIONS

This study analysed lincomycin research from 1963 to August 2025. It consisted of 963 records, with 2777 contributing authors, published in 452 journals, with an average annual growth rate of 1.04%. China was the leading country with 149 articles, which can be attributed to the involvement of leading universities and institutions, such as the East China University of Science and Technology. This can also be explained by the national interest in antimicrobials and food-related chemicals, as China is one of the world's largest food producers (Ablakimova et al., 2023; Lee et al., 2023; Liang et al., 2023).

In their bibliometric analysis, Cardoso et al. (2025) highlighted that genetic engineering and natural-product chemistry have steadily risen (Cardoso et al., 2025). They concluded that antibiotic production and biosynthesis were important clusters in keywords co-occurrence. Similarly, we found that lincomycin biosynthesis was a motor theme. Moreover, we found that electrochemiluminescence and aptasensor approaches were trending in lincomycin research, which was similar to the findings of the review of Hasanzadeh et al. (2017) on electrochemical aptasensors (Hasanzadeh et al., 2017).

Lincomycin research has shifted from clinical use and antimicrobial resistance towards genetic engineering and biosynthetic development. This shift suggests that researchers have changed their view of lincomycin from just an antibiotic to now examining its full potential for novel strategies in wide-scale production, antimicrobial resistance prevention, and the biosynthesis of new derivatives. The emergence of electrochemiluminescence detection tools and aptasensor technology has raised concerns among experts about antimicrobial residues in food supply chains, particularly in veterinary and agricultural settings (Mehrtens et al., 2021).

The range of publications covered in this study (1963-2025) is one of its strengths, as is its status as the first bibliometric analysis paper in lincomycin research. However, limiting the analysis to English articles might obscure other contributions, e.g., from Chinese publications.

## CONCLUSIONS

The goal of this research is to provide a critical bibliometric analysis of lincomycin research worldwide from 1963 to 2025, focusing on its patterns, key contributors, and emerging themes. The analysis of the 963 publications revealed two most active periods: the first from the late 1960s to the 1970s, and the second, which began recently in the last several years. The data showed that China is the most productive country regarding lincomycin research, with emerging collaboration with leading foreign institutions. Analysis of the themes reflected research shifts over time, with a moving focus from the clinical and pharmaceutical fields to molecular biological topics and mechanisms of the lincomycin biosynthetic pathways, mechanisms of antimicrobial resistance, and modern methods of analytical detection, including LC-MS/MS, ECL, and aptasensor-based technologies.

This research is the first comprehensive bibliometric mapping of lincomycin over six decades, along with a systematic and thorough exploration of the intellectual framework, productivity, and subject development. By applying bibliometric metrics based on keyword co-occurrence and thematic visualisation, this research identified emerging research directions and remarkable scientific contributors.

Theoretically, the study deepens knowledge of antibiotic research and development in line with scientific, environmental, and public health interests, particularly regarding antimicrobial resistance and food safety. From a managerial and practical perspective, the results may allow researchers, policymakers, and regulatory bodies to identify the needed research areas, strengthen international cooperation, and support surveillance- and detection-based research on antibiotic residues in food and environmental systems.

However, this study has some limitations. First, only the Scopus database was used in this study. Second, only English-language publications were included in this study. Therefore, non-English databases and non-English publications could not be assessed. Third, the search method was limited to the article title; therefore, publications that mentioned lincomycin only in the abstract and keywords could not be identified. These limitations can be addressed in future research. Future bibliometric research on lincomycin or lincosamide antibiotics can expand the scope by using other databases, such as Web of Science, PubMed, or Scopus; by exploring publications written in different languages; and by applying a wider search strategy, such as TITLE-ABS-KEY. Future research may also attempt to integrate scientometric approaches into systematic reviews of the clinical, environmental, and molecular performance of lincomycin and lincosamides.

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**Declaration of Generative AI and AI-Assisted Technologies in the Writing Process:** During the preparation of this work, the author(s) used Grammarly for proofreading and spell checking since the Authors are not native speakers. All intellectual content, analysis, and interpretations were produced solely by the authors. After using this AI tool/service, the author(s) reviewed and edited the content as needed, taking full responsibility for the publication's content.

**Conflicts of Interest:** The authors declare no conflict of interest.

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