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Probiotics In Poultry Nutrition: A Comprehensive Bibliometric and Thematic Analysis of Two Decades of Research (2000-2025)

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Abstract

This study presents a comprehensive bibliometric and thematic analysis of two decades of global research on probiotics in poultry nutrition (2000-2025) using the R bibliometric library version 4.4.3 and VOSviewer software version 1.6.20. Based on a documentary corpus of 4 447 publications from 317 scientific journals indexed in Scopus and Web of Science (WoS), it maps the evolution of scientific production, major actors, international collaboration networks, and thematic structure of the field. According to the analyses, China, the United States, and Egypt are the most productive countries in this field, and the United States appears as a central actor, with collaborations connecting several continents. Wang Y., Wang J., and Liu Y appear as major contributors to research on probiotics in poultry nutrition, and Zagazig University, an Egyptian university, appears as the most influential institution. The results also reveal exponential growth in publications particularly from 2016 onwards, as well as progressive structuring of the field around dominant themes such as “broilers”, “growth-performance”, “performance”, “probiotics”, and “supplementation”, shifting from primarily zootechnical approaches towards more integrated investigations, including interactions between intestinal microbiota, growth performance, and immune response. Despite this apparent maturity, the field remains fragmented, with dispersion of themes and approaches. This study thus constitutes one of the first bibliometric analyses specifically dedicated to probiotics in avian nutrition and highlights the need for better conceptual integration to guide future research and optimize the use of these additives in poultry production.

Keywords: *probiotics, chicken, feed additives, poultry nutrition, Biblioshiny, VOSviewer, bibliometric analyses*

Introduction

The global poultry industry plays a decisive role in global food security. According to FAO (2021), global poultry meat production increased from 9 to 133 million tons between 1961 and 2020, representing 40% of total global meat production. In 2019, the global poultry flock exceeded 27 billion birds (Yıldız, 2021). Furthermore, the demand for animal proteins continues to grow under the combined effect of population growth, urbanization, and rising incomes (Henchion et al., 2017). In this dynamic, the poultry sector is expected to represent 43% of proteins from all meats consumed by 2033 (OECD & FAO, 2024), thus establishing itself as the most dynamic segment of contemporary livestock production.

This unprecedented growth in the poultry sector has, however, relied on farming practices that are now being questioned. Until 2006, poultry farming systems widely used antibiotics as growth promoters (AGP). Added to animal feed for more than 60 years at subtherapeutic doses (Castanon, 2007), they act by reducing intestinal microbial load and associated inflammation, which limits energy losses and allows the animal to devote more energy to its growth (Niewold, 2007).

Although this practice significantly improved zootechnical performance in animals (Gadde et al., 2017; Wickramasuriya et al., 2024), its prolonged use has favored the emergence of antibiotic-resistant bacteria, compromising their effectiveness in both veterinary and human medicine (Ben et al., 2019; World Health Organization, 2000). This awareness led to the progressive ban of AGP in the European Union from January 1, 2006 (Regulation (EC) No 1831/2003, 2003), then in California from 2015 (CA State Legislature, 2015) before extending to other countries.

While this ban responds to a public health imperative, it has profoundly modified production strategies, requiring the search for alternatives capable of maintaining zootechnical performance in the absence of AGP. In this context, probiotics have gradually emerged as a promising solution in avian nutrition. They are defined as live microorganisms that, when administered in adequate amounts, exert a beneficial effect on the host's health (FAO/WHO, 2002). In poultry, probiotics mainly include strains of Lactobacillus, Bifidobacterium, Bacillus, and Enterococcus (Chennoun & Zitouni, 2020). Their interest lies in their ability to modulate the intestinal microbiota, improve the integrity of the digestive barrier, and stimulate immune responses, thus contributing to the optimization of growth performance in the absence of AGP (Idowu et al., 2025; Naeem & Bourassa, 2025; Yosi & Metzler-Zebeli, 2023).

Since the early 2000s, scientific research on probiotics in avian nutrition has experienced considerable expansion, reflecting the sustained interest of the scientific community and industry in these feed additives. However, although Wickramasuriya et al. (2024) conducted a bibliometric analysis on alternatives to antibiotic growth promoters for poultry, no comprehensive bibliometric study has yet been exclusively devoted to mapping the evolution of research on the use of probiotics in avian nutrition over the past two decades. In this context, bibliometric analysis appears as an appropriate approach to analyze scientific production in this field. It allows the identification of research trends, major contributions, as well as interactions between authors and themes over time (F.-H. Liu et al., 2022; Nicolaisen, 2010). Based on statistical indicators and reproducible methods, it provides a synthetic view of the evolution of knowledge (Wallin, 2005).

This study therefore aims to analyze the temporal evolution of global scientific production, identify the main research actors (authors, institutions, countries, journals), and map international collaboration networks. Finally, it also intends to reveal the thematic structure of the field through the analysis of keywords and co-occurrences, as well as identify the most influential publications and foundational works that have structured this research field.

Materials and Methods

Databases, search strategies and article selection procedure

To analyze global scientific production on probiotics in avian nutrition between 2000 and 2025, two international bibliographic databases were used to constitute the documentary corpus. These include Scopus (Elsevier) and Web of Science (WoS) (Clarivate). These databases were selected because they offer broad and complementary coverage of international scientific literature. They provide complete bibliographic metadata necessary for bibliometric analyses (Birkle et al., 2020; Martín-Martín et al., 2018). To constitute the documentary corpus of this study, a search strategy was developed by combining keywords related to probiotics and avian species. The Boolean query was constructed according to the following model to capture all relevant publications while minimizing documentary noise: (probiotic* OR prebiotic* OR symbiotic* OR “direct-fed microbial*” OR “beneficial bacteria” OR “lactic acid bacteria” OR Lactobacillus* OR Bacillus* OR Bifidobacterium* OR Saccharomyces* OR Enterococcus* OR “microbial supplement*”) AND (poultry OR chicken* OR broiler* OR “laying hen*” OR avian OR “broiler chicken*”) NOT (human* OR patient* OR “clinical trial*” OR swine OR pig* OR porcine OR cattle OR bovine OR sheep OR ovine OR fish OR aquaculture OR shrimp)”. The search terms were applied in the title, abstract, and keywords fields of publications in Scopus. In WoS, these terms were searched in all fields. The covered period extends from January 1st, 2000 to December 31, 2025. Regarding the article selection process, this procedure was carried out in several stages as shown in Figure 1. After applying inclusion and exclusion criteria and removing duplicates, a total of 4,447 documents were used to conduct this study. Only documents in English, published in journals as articles, and available in open access were retained. Furthermore, to avoid excessive documentary noise, certain research categories were excluded as shown in Figure 1.

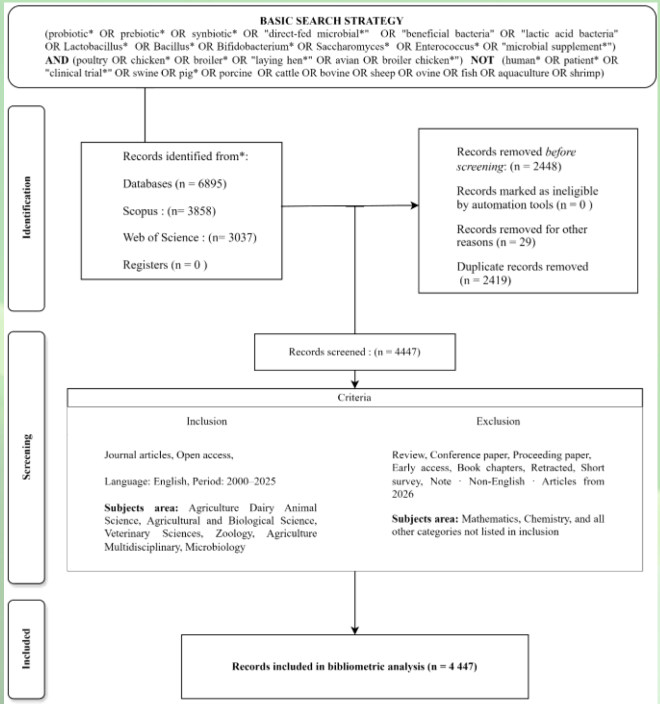

Figure 1: Data collection PRISMA flow diagram

Bibliometric analysis tools and bibliometric indicators analyzed

Two complementary software programs were mobilized to conduct this bibliometric analysis. The RStudio program (version 4.4.3) was used via the *biblioshiny()* interface of the *bibliometrix* package (Aria & Cuccurullo, 2017) for data processing and analysis. In complement, VOSviewer (version 1.6.20) (van Eck & Waltman, 2017) enabled the construction and visualization of bibliometric networks, particularly keyword co-occurrence.

To ensure data compatibility with *biblioshiny*, the documentary corpus was exported from each database according to a specific format. For Scopus, the export was performed in *.csv* format, while for WoS the Plain Text *(.txt)* format was used. In total, 17 bibliometric analyses were performed in this analytical environment.

Results

Main information

Table 1 presents the main information relating to scientific publications devoted to the use of probiotics in poultry nutrition between 2000 and 2025.

Table 1: Main Information

Description	*Results*
MAIN INFORMATION ABOUT DATA	
Timespan	2000:2025
Sources (Journals, Books, etc)	317
Documents	4447
Annual Growth Rate %	15,95
Document Average Age	6,42
Average citations per doc	19,9
DOCUMENT CONTENTS	
Keywords Plus (ID)	8144
Author's Keywords (DE)	7296
AUTHORS	
Authors	13716
Authors of single-authored docs	52
AUTHORS COLLABORATION	
Single-authored docs	84
Co-Authors per Doc	6,27
International co-authorships %	18,1
DOCUMENT TYPES	

From a targeted search strategy combining keywords related to probiotics and poultry, the Scopus and Web of Science databases identified a total of 4447 articles published between 2000 and 2025. Analysis of this documentary corpus reveals that these works were published in 317 specialized scientific journals, with an annual publication growth rate of 15.95%. Furthermore, the average age of publications is 6.42 years, while each article records an average of 19.9 citations. In terms of scientific collaboration, the analysis reports 13716 contributing authors, among whom 52 published without co-authors. Regarding international collaboration, it represents 18.1% of all publications.

Annual status and average annual citations of scientific publications

Figure 2 presents the joint evolution of the annual number of publications (blue curve) and the average number of citations per article (orange curve) on probiotics in avian nutrition over the period 2000-2025.

This superimposed representation allows observation of the inverse relationship between these two bibliometric indicators. Indeed, according to this figure, it is easy to note exponential growth in the number of publications, particularly marked from 2016 onwards. The annual volume increases from 17 articles in 2000 to 687 in 2025, with notable acceleration during the last five years where the number of publications rises from 337 in 2020 to 687 in 2025, representing a doubling of scientific production volume. Conversely, this same figure reveals a decreasing trend in the average number of citations per article. While publications from 2000 total approximately 91 citations on average, this number fluctuates between 35 and 71 citations during the period 2002-2014, before beginning a progressive decline. Recent years show the lowest values with an average number of citations around 27 citations in 2019. A drop to less than 10 citations for publications from 2023 to 2025 follows, with less than 2 citations on average per article in 2025. This figure clearly shows a contrasted dynamic. Indeed, the quantitative expansion of scientific production is accompanied by a decrease in the average number of citations per article.

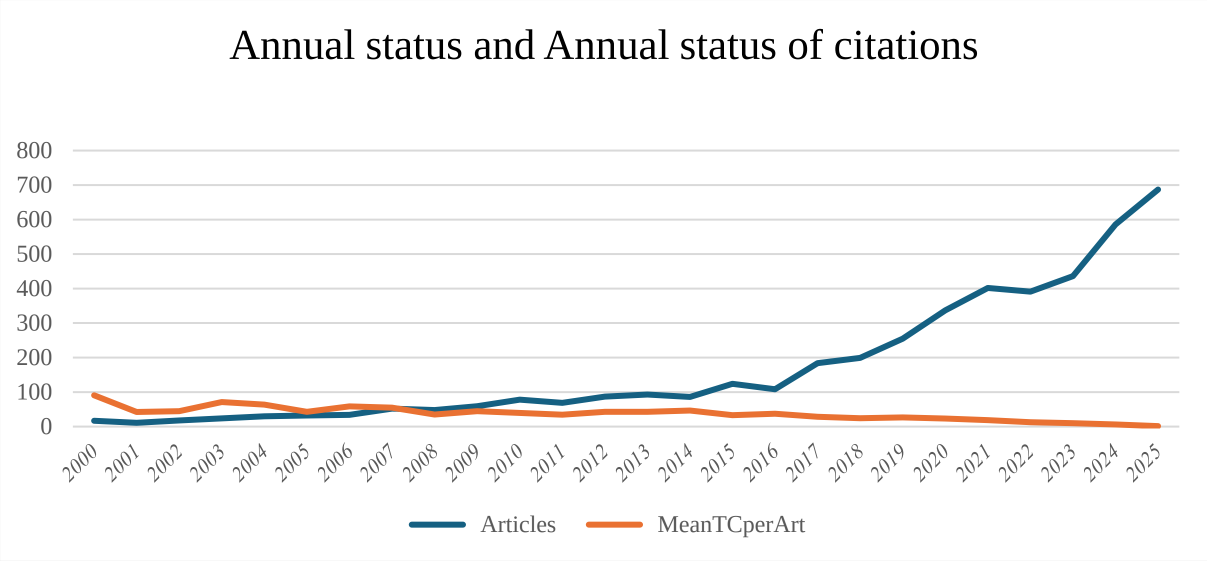

Figure 2: Annual status and annual status of citations

Sankey diagram

Figure 3 highlights the relationships between three key bibliometric dimensions: authors' countries of affiliation, the most productive authors, and the main keywords.

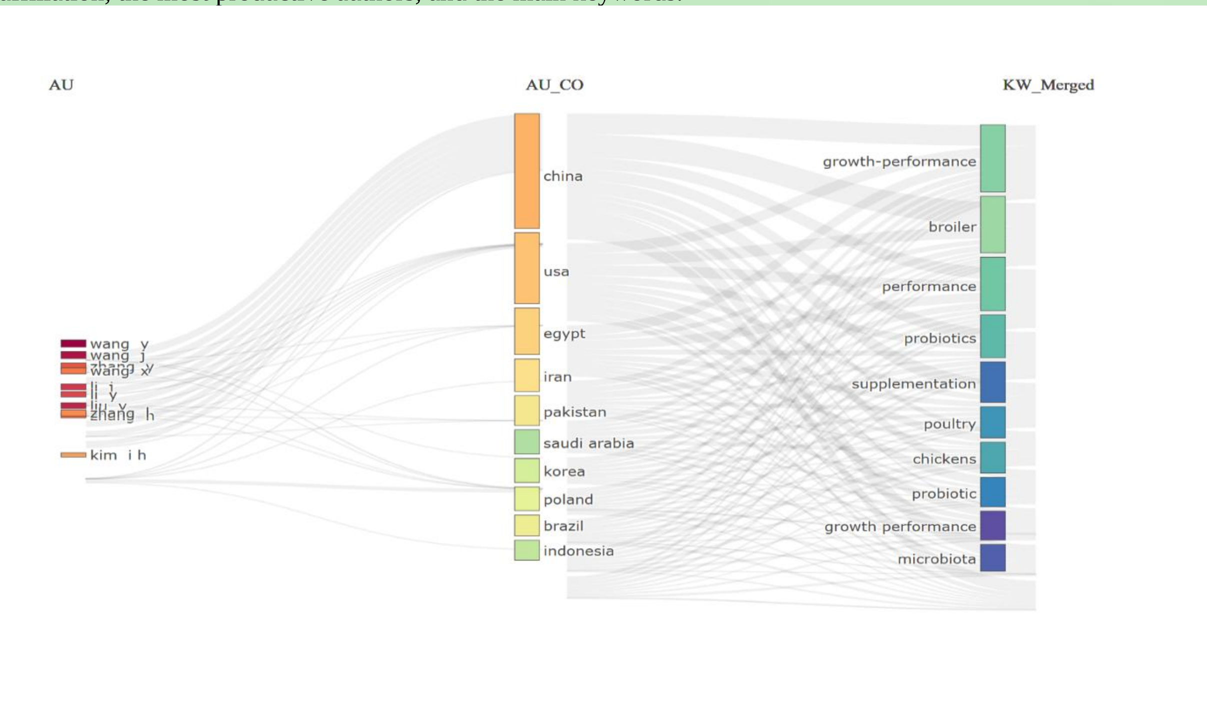

Figure 3: Three-Field Plot

Created using Biblioshiny, this figure allows identification of the most productive geographical areas and researchers as well as the most dominant keywords. Thus, geographically, China stands out clearly as the most contributing country in terms of scientific production related to the use of probiotics in avian nutrition between 2000 and 2025. Among the most prolific authors, Wang Y. appears as a major contributor to the production of scientific documents in this field. Keyword analysis reveals that “growth-performance”, “broilers”, “performance”, “probiotics”, and “supplementation” constitute the most recurrent terms for article indexing, thus reflecting the main research axes favored by authors in this field.

Most productive scientific journals

Table 2 presents the 10 most recurrent scientific journals in the publication of articles related to themes concerning the use of probiotics in avian nutrition between 2000 and 2025.

Table 2: Most important journals

Sources	*Articles*
POULTRY SCIENCE	1166
ANIMALS	359
JOURNAL OF APPLIED POULTRY RESEARCH	168
FRONTIERS IN VETERINARY SCIENCE	149
BRAZILIAN JOURNAL OF POULTRY SCIENCE	108
INTERNATIONAL JOURNAL OF POULTRY SCIENCE	95
ITALIAN JOURNAL OF ANIMAL SCIENCE	95
EFSA JOURNAL	85
VETERINARY WORLD	73
ASIAN-AUSTRALASIAN JOURNAL OF ANIMAL SCIENCES	63

According to the analysis of this table, it appears that the main publication journals in the studied field are "Poultry Science", "Animals", and "Journal of Applied Poultry Research". The journal Poultry Science ranks widely first with 1,166 articles, followed by Animals with 359 publications. Journal of Applied Poultry Research occupies third position with a total of 168 articles.

Most productive authors

Figure 4 presents the ranking of the most relevant authors according to their scientific production in the field of probiotics in avian nutrition from 2000 to 2025.

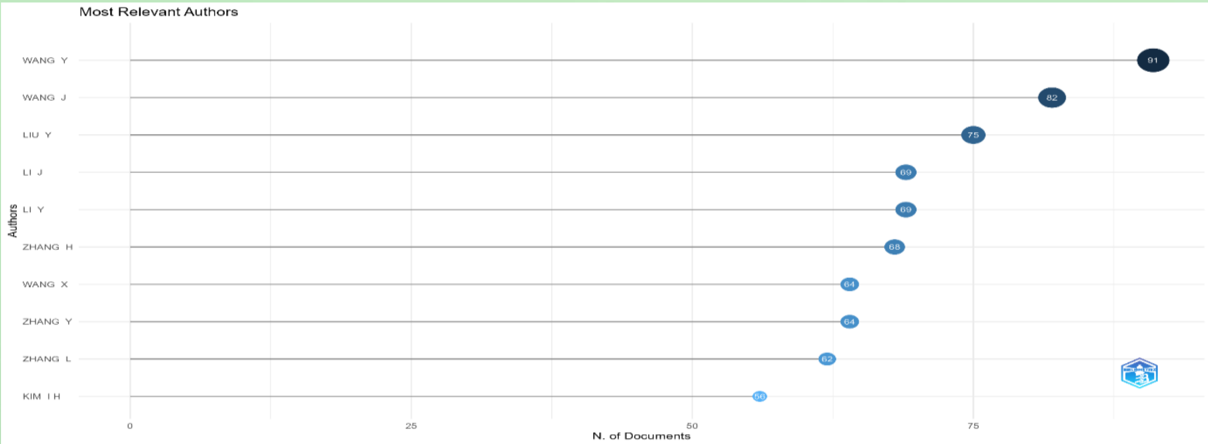

Figure 4 : Most prolific Authors

Wang Y. positions himself as the most prolific author with 91 publications, followed by Wang J. with 82 documents. Liu Y. occupies third position with 75 publications. These three authors total 248 publications, representing 35.4% of the cumulative production of the ten main authors, while the seven other authors contribute 452 publications, representing 64.5%. Although the first three authors are more productive, the difference with the other authors remains modest. Indeed, the three most productive authors present an individual production of 82.7 publications, compared to 64.6 for the other authors.

Universities with the most publications

Table 3 presents the ranking of the 10 most productive institutions in the field of probiotics in avian nutrition.

Table 3: Most important universites

Affiliation	*Articles*
ZAGAZIG UNIVERSITY	186
ISLAMIC AZAD UNIVERSITY	159
UNIVERSITI PUTRA MALAYSIA	158
CHINA AGRICULTURAL UNIVERSITY	137
UNIVERSITY OF ARKANSAS SYSTEM	125
UNIVERSITY OF ARKANSAS FAYETTEVILLE	122
KING SAUD UNIVERSITY	120
UNITED STATES DEPARTMENT OF AGRICULTURE (USDA)	102
UNIVERSITY OF VETERINARY AND ANIMAL SCIENCE - PAKISTAN	93
UNIVERSITY OF GEORGIA	90

Zagazig University ranks first with 186 publications, followed by Islamic Azad University (159 articles) and Universiti Putra Malaysia (158 articles). China Agricultural University ranks fourth with 137 publications, while the University of Arkansas System completes the top 5 with 125 articles. This distribution highlights geographical diversity of institutions, with contributions from Africa (Egypt), Asia (Iran, Malaysia, China), and North America (United States).

Scientific Production by Country

Figure 5 illustrates the geographical distribution of global scientific production related to the use of probiotics in avian nutrition between 2000 and 2025.

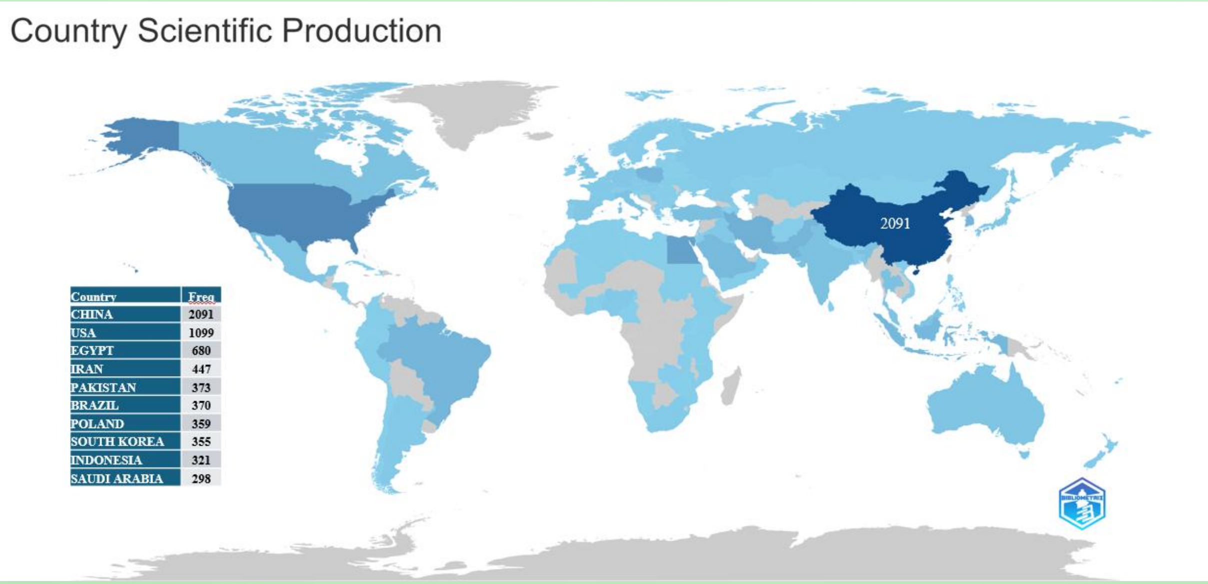

Figure 5: Most productive countries

The map is based on a gradient of three colors indicating the volume of publications by country. Dark blue corresponds to high production, light blue to moderate production, while gray indicates low or almost non-existent production (Hodonou et al., 2025).

China positions itself as the undisputed world leader with 2,091 publications, nearly double American production. The United States occupies second position with 1099 articles, followed by Egypt with 680 publications, Iran with 447 publications, and Pakistan with 373 publications. These five countries have a total of 4549 publications, representing a significant share of global scientific production in this field. The map reveals a concentration of research in four major regions, namely East Asia (dominated by China), the Middle East (Iran, Saudi Arabia), North Africa (Egypt), and North America (United States). Europe, South America, and sub-Saharan Africa show lighter color intensities, reflecting more modest or even non-existent scientific production.

Scientific collaboration between countries

Figure 6 represents the world map of bilateral scientific collaborations in the field of probiotics in avian nutrition from 2000 to 2025.

Collaboration flows materialized by lines connecting partner countries, while the intensity of the red color indicates the degree of involvement of countries in these international collaborations. Thus, the three most active bilateral partnerships are: the Egypt-Saudi Arabia collaboration with 75 joint publications, the China-United States partnership with 41 publications, and the United States-Mexico collaboration with 31 publications. Other notable partnerships include collaborations between China and Egypt, China and Pakistan, as well as between Pakistan and Saudi Arabia. Furthermore, the United States appears as a central actor, with collaborations established with Canada, Egypt, Mexico, South Korea, and Iran. These cross-border scientific collaborations underscore the priority nature of research on probiotics in avian nutrition on a global scale during the last two decades.

Most cited countries

Table 4 presents the ranking of the 10 most cited countries according to the total number of citations received by their publications in the field of probiotics in avian nutrition from 2000 to 2025. This indicator reflects the scientific impact and international visibility of research work produced by each country.

China dominates widely with 21,185 total citations, representing 55% more than the United States, which occupies second position with 13,617 citations. South Korea completes third position with 4,732 citations. These three countries alone total 39,534 citations, representing 69% of the cumulative total of the ten countries presented and more than double the citations of the seven other countries combined (17,769 citations). This thus reflects the quality and international visibility of the work produced and published by these nations.

Most important documents

Table 5 presents the ranking of the 10 most cited publications in the field of probiotics in avian nutrition between 2000 and 2025. The total number of citations (TC) reflects the academic influence and scientific scope of each article within the research community.

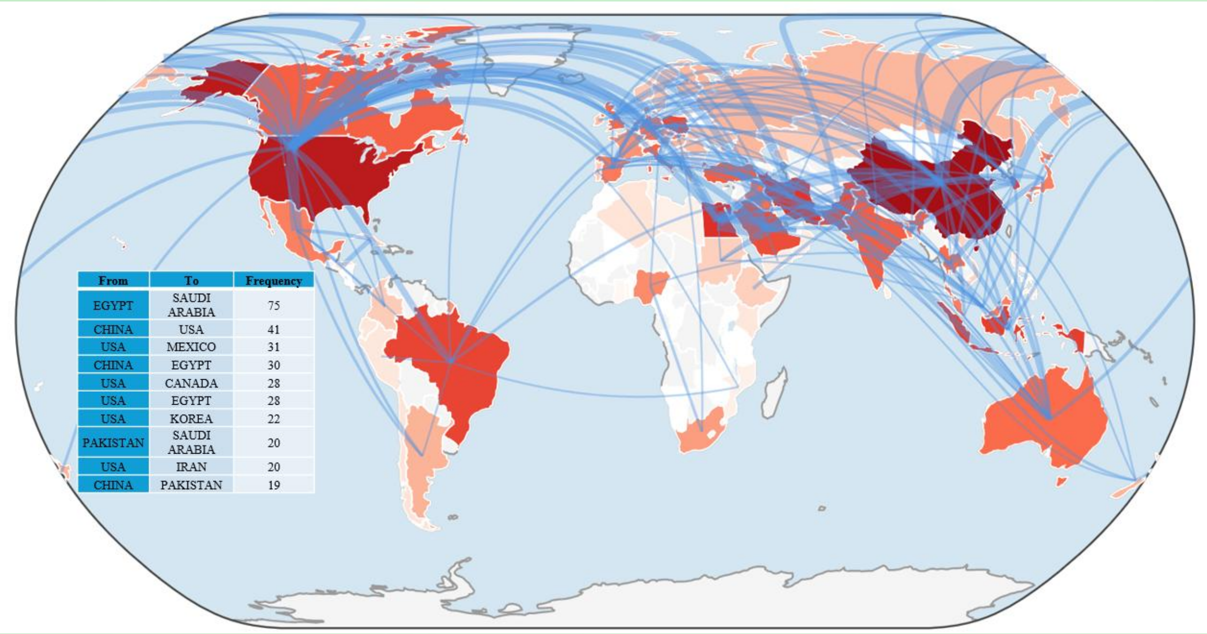

Figure 6: Cooperation map of countries

Table 4: Most Cited Countries

Country	*TC*
CHINA	21185
USA	13617
KOREA	4732
EGYPT	3267
CANADA	2911
IRAN	2878
POLAND	2633
MALAYSIA	2135
SPAIN	2050
AUSTRALIA	1895

Table 5: Most cited publications

Paper	*DOI*	*TC*
XU Z, 2003, POULTRY SCI	https://doi.org/10.1093/ps/82.6.1030	663
AWAD W A, 2009, POULTRY SCI	https://doi.org/10.3382/ps.2008-00244	626
SPRING P, 2000, POULTRY SCI	https://doi.org/10.1093/ps/79.2.205	573
WEI S, 2013, POULTRY SCI	https://doi.org/10.3382/ps.2012-02822	412
SONG J, 2014, POULT SCI	https://doi.org/10.3382/ps.2013-03455	401
CROSS D E, 2007, BRIT POULTRY SCI	https://doi.org/10.1080/00071660701463221	380
VIVEROS A, 2011, POULTRY SCI	https://doi.org/10.3382/ps.2010-00889	376
MOUNTZOURIS K C, 2010, POULTRY SCI	https://doi.org/10.3382/ps.2009-00308	365
ZHANG A, 2005, POULT SCI	https://doi.org/10.1093/ps/84.7.1015	354
BAURHOO B, 2007, POULTRY SCI	https://doi.org/10.1093/ps/86.6.1070	345

The article by Xu et al. (2003), published in Poultry Science, ranks first with 663 citations. Entitled “Effects of Dietary Fructooligosaccharides on Digestive Enzyme Activities, Intestinal Microflora and Morphology of Male Broilers”, this pioneering work likely laid the foundations for the study of prebiotics in avian nutrition. Awad et al. (2009), also published in Poultry Science, rank second with 626 citations thanks to their article entitled “Effects of dietary inclusion of probiotic and synbiotic on growth performance, organ weights, and intestinal histomorphology of broiler chickens”. Spring et al. (2000) complete this ranking in third position with 573 citations for their study entitled “The effects of dietary mannaoligosaccharides on cecal parameters and the concentrations of enteric bacteria in the ceca of salmonella-challenged broiler chicks”, which is also published in Poultry Science. Collectively, these three foundational articles accumulate 1,862 citations and share the distinction of having been published in the same journal, confirming the central role of the journal “Poultry Science” in the dissemination of research on the use of probiotics in poultry nutrition during these two decades.

Top 5 most cited articles by decade

Table 6 presents the top 5 most cited articles across three distinct periods.

Table 6 : Most cited articles by publication period

Year	*Paper*	*DOI*	*TC*
2000	XU Z, 2003, POULTRY SCI	https://doi.org/10.1093/ps/82.6.1030	663
-	AWAD W A, 2009, POULTRY SCI	https://doi.org/10.3382/ps.2008-00244	626
2009	SPRING P, 2000, POULTRY SCI	https://doi.org/10.1093/ps/79.2.205	573
	CROSS D E, 2007, BRIT POULTRY SCI	https://doi.org/10.1080/00071660701463221	380
	(Amit-Romach et al., 2004)HOO B, 2007, POULTRY SCI	https://doi.org/10.1093/ps/86.6.1070	345
2010	WEI S, 2013, POULTRY SCI	https://doi.org/10.3382/ps.2012-02822	412
-	VIVEROS A, 2011, POULTRY SCI	https://doi.org/10.3382/ps.2010-00889	376
2019	MOUNTZOURIS K C, 2010, POULTRY SCI	https://doi.org/10.3382/ps.2009-00308	365
	SOHAIL M U, 2012, POULTRY SCI	https://doi.org/10.3382/ps.2012-02182	308
	SVIHUS B, 2014, J APPL POULTRY RES	https://doi.org/10.3382/japr.2014-00937	293
2020	REHMAN A, 2020, POULTRY SCI	https://doi.org/10.1016/j.psj.2020.09.043	149
-	HU R, 2021, J ANIM SCI BIOTECHNO	https://doi.org/10.1186/s40104-020-00532-4	148
2025	REDA F M, 2020, ANIMALS-BASEL	https://doi.org/10.3390/ani10050754	143
	XU Y, 2021, POULTRY SCI	https://doi.org/10.1016/j.psj.2021.101358	139
	ALAGAWANY M, 2021, POULTRY SCI	https://doi.org/10.1016/j.psj.2021.101172	133

Temporal analysis confirms the historical dominance of foundational works from the first decade. Unsurprisingly, the three most cited articles globally (Awad et al., 2009; Spring et al., 2000; Z. Xu et al., 2003), described in Table 5, also dominate their respective period 2000-2009. These alone total 1862 citations. This correspondence would underscore their role as structuring references that shaped the field’s orientations for the following two decades. Of the five articles from this period that accumulate 2767 citations, four are published in Poultry Science. The 2010-2019 decade reveals the emergence of new references. Wei et al., (2013) dominate with 412 citations, followed by Viveros et al. (2011) with 376 citations and Mountzouris et al. (2010) with 365 citations. Poultry Science remains the primary publication vehicle for this period, also hosting four of the five most cited articles. The 2020-2025 period shows lower absolute totals, a direct consequence of their lesser seniority. The articles by (Rehman et al., 2020, 149 citations), (Hu et al., 2021, 148 citations), and (Reda et al., 2020, 143 citations) occupy the first three positions respectively. This period is distinguished by a diversification of publication outlets, with the appearance of journals such as “Animals” and “Journal of Animal Science and Biotechnology” alongside “Poultry Science”.

Word cloud

Figure 7 presents a word cloud generated from all keywords in the analyzed documentary corpus. Created using Biblioshiny, this visualization allows identification of central concepts and dominant themes in the field of probiotics in avian nutrition between 2000 and 2025. In this figure, the size of each term is proportional to its frequency of appearance in the publications.

Five terms stand out clearly by their preeminence. These include “probiotics”, “growth-performance”, “broiler”, “performance”, and “chickens”, which reflect the major research axes. Intermediate-sized terms reveal keywords such as “supplementation”, “microbiota”, “lactobacillus”, “microflora”, and “intestinal morphology”.

Tree map

Figure 8 presents a tree map (TreeMap) of keywords from the corpus. The area of each rectangle is proportional to the frequency of occurrence of the term in all analyzed publications. This hierarchical visualization allows simultaneous comprehension of the distribution and relative importance of different concepts structuring the field of probiotics.

Figure 7: Word Cloud

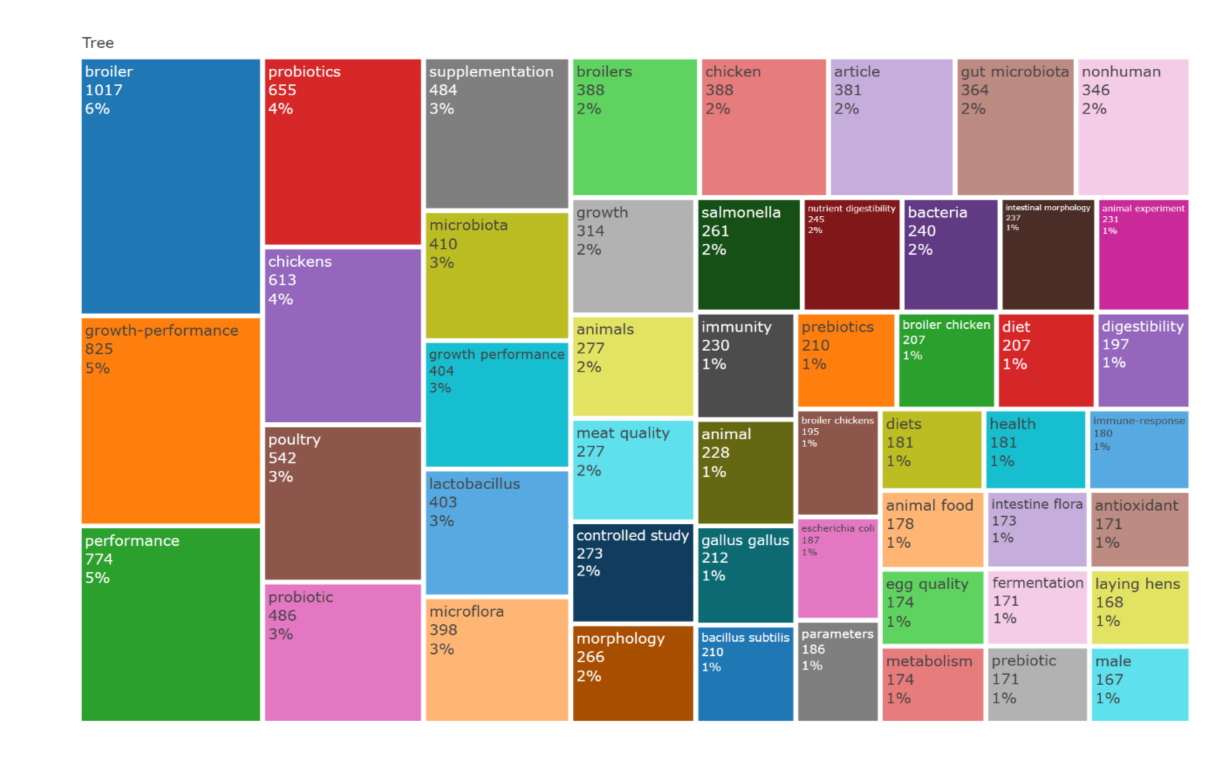

Figure 8: Tree map

Three thematic categories emerge by their predominance. First, terms related to avian species that total a substantial share, with “broiler” (1017 occurrences, 6%), “chickens” (613, 4%), “broilers” (388, 2%), and “poultry” (542, 3%) collectively representing approximately 15% of keywords. Second, performance parameters dominate with “growth-performance” (825, 5%) and “performance” (774, 5%), which total 10% of occurrences. Finally, in third position come the additives studied represented by “probiotics” (655, 4%), “probiotic” (486, 3%), and “prebiotics” (210, 1%), totaling 8% of occurrences.

Temporal evolution of keywords

Figure 9 illustrates the temporal evolution of cumulative occurrences of the ten principal keywords over the 2000–2025 period. The curves represent the progressive accumulation of each term over the years.

All curves display a similar two-phase trajectory. The 2000-2015 period shows slow, quasi-linear growth. From 2016 onwards, an exponential acceleration begins for all terms. The term "broiler" clearly dominates with approximately 1000 cumulative occurrences in 2025. "Chickens" and "growth-performance" follow with approximately 850 occurrences each. Then come "performance", "microbiota", "probiotics", "poultry" and "supplementation", which reach comparable levels, ranging between 500 and 650 occurrences.

Trend topics

Figure 10 presents the temporal evolution of 50 emerging keywords over the 2005–2025 period. The temporal evolution of all keywords was analyzed using the «Trend Topics» function of Biblioshiny. A minimum frequency threshold of 25 occurrences was applied to exclude terms that appear very rarely, to focus the analysis on recurring concepts. Furthermore, for each year, only the 5 most frequent keywords were retained to ensure a balanced representation of the different periods while maintaining the readability of the graph. This approach made it possible to identify progressive changes in the major research themes without informational overload. In this figure, each line represents a term, the bubbles indicate the median year of appearance, and their size reflects the total frequency of occurrence.

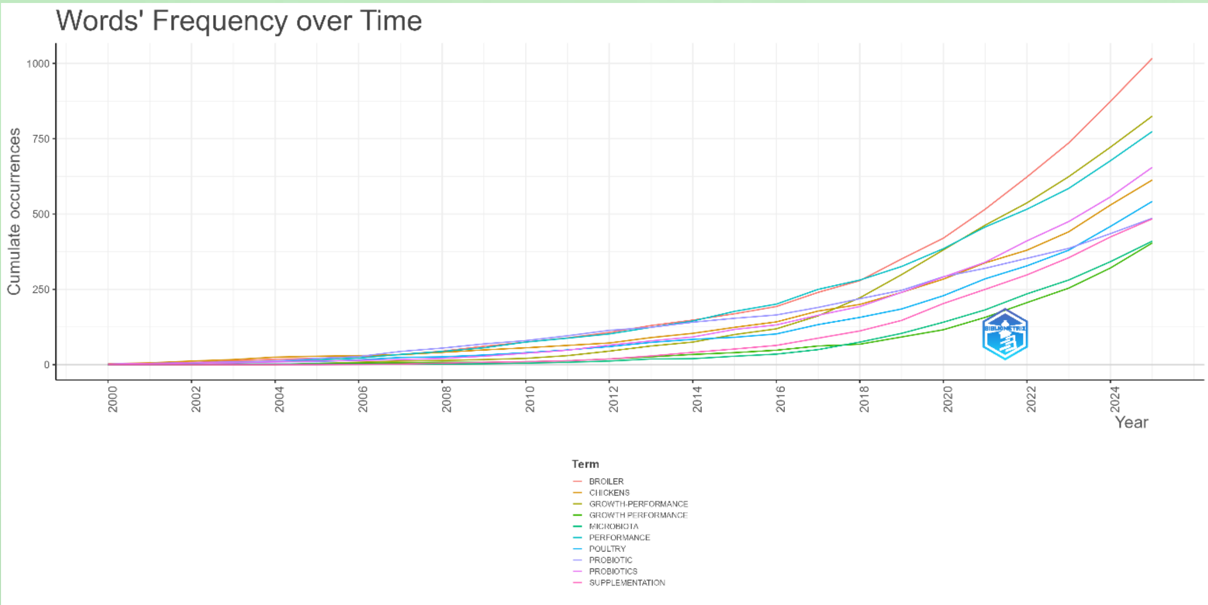

Figure 9: Words' Frequency over Time

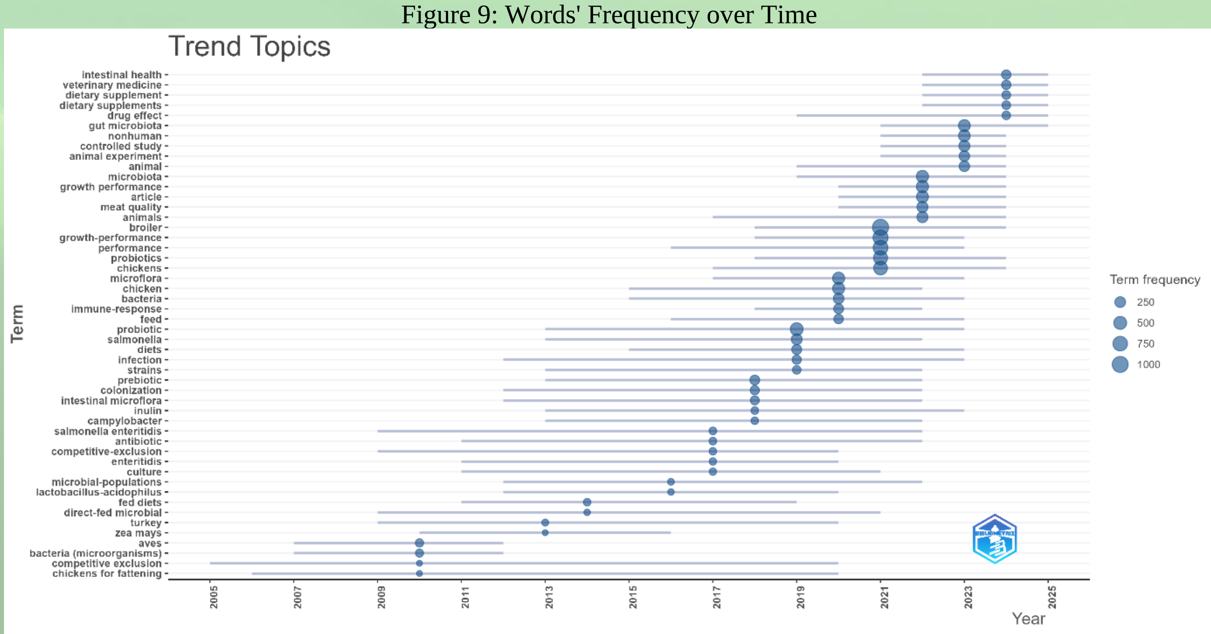

Figure 10 : Trend topics

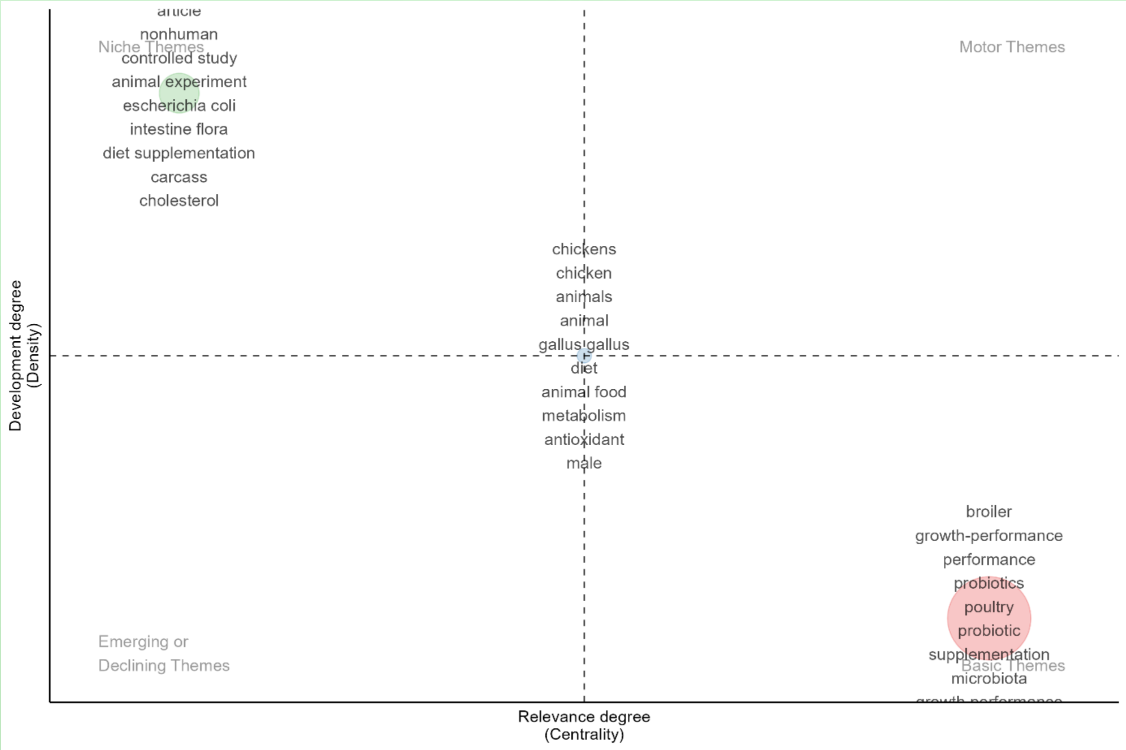

Figure 11 : Thematic map

Over the 2005-2012 period, research focused primarily on microorganisms and pathogenic agents. The terms "Lactobacillus acidophilus", "direct-fed microbial", "competitive exclusion", "Salmonella enteritidis", "Campylobacter" and "antibiotic" appeared frequently, reflecting an interest in microbial strains, mechanisms of action, and pathogen control in the context of antibiotic use. Between 2013 and 2020, the themes evolved toward the study of the intestinal ecosystem. The keywords "intestinal microflora", "prebiotic", "probiotic", "colonization", "immune response" and "strains" were widely represented, reflecting growing attention to host-microbiota interactions and immune responses. In the most recent period (2021-2025), research has shifted toward more integrative approaches. The terms "gut microbiota", "intestinal health", "veterinary medicine", "dietary supplement", "growth performance" and "broiler" appear with high frequency, indicating a focus on intestinal health and zootechnical performance. Overall, these results reflect a progressive evolution of research themes over time.

Thematic map of author keywords

Figure 11 illustrates the thematic mapping of keywords according to their centrality and density. The quadrants of the map allow the distinction between basic themes, motor themes, niche themes, and emerging or declining themes.

Basic themes, located in the lower-right quadrant, present high centrality but low density. They represent concepts that are essential to the field but have yet to be extensively developed. Keywords such as "probiotics", "poultry", "microbiota", "growth-performance" and «supplementation» belong to this category. This indicates their central role in the overall understanding of the subject, despite the limited development of research associated with them. Regarding motor themes located in the upper-right quadrant, these combine both high centrality and high density. They constitute the dominant and well-structured axes of research. In this analysis, no group of keywords is visible in this zone. This suggests the current absence of strongly consolidated and central themes. Niche themes, located in the upper-left quadrant, present high density but low centrality. They correspond to specialized or technical subjects, developed in depth by restricted groups of researchers. Among the keywords found in this zone are: "Escherichia coli", "intestinal flora", "carcass", "diet supplementation" and "nonhuman". As for emerging or declining themes, in the lower-left quadrant, they are poorly central and weakly developed. They indicate research areas either in emergence or losing interest and are here entirely absent. Keywords located at the junction of the vertical and horizontal axes, close to the center of the map, occupy an intermediate position in terms of centrality and density. This position reflects a transversal role. In other words, keywords such as "chickens", "animals", "diet" and "metabolism" connect multiple themes and serve as bridges between different research domains, without being themselves strongly developed or dominant themes. Their importance therefore lies in their capacity to connect and structure the overall scientific field under study.

Co-occurrence analysis of keywords

Figure 12 presents a network map of the 500 most frequent keywords in the documentary corpus. Of the 13,637 keywords identified, 976 reach the minimum threshold set at 10 occurrences across the entire corpus, of which 500 were retained for visualization with VOSviewer.

The **green cluster** groups terms related to probiotics and performance. “Probiotics”, “probiotic”, “broiler” and “growth-performance” dominate this group. “Supplementation”, “microflora” and “Bacillus subtilis” complete this theme. This cluster represents the applied core of the field, centered on the use of probiotics in poultry production.

The **blue cluster** brings together general methodological and descriptive terms. “Animals”, “microbiology”, “chickens” and “growth” structure this group. “Dietary supplements”, “probiotic agent”, “Gallus gallus”, “diet” and “anti-bacterial agents” also feature here. This cluster constitutes the basic vocabulary common to all research.

The **red cluster** contains experimental and physiological terms. “Article”, “controlled study”, “animal experiment” and “intestinal flora” dominate. “Diet supplementation”, “cholesterol” and “immune response” complete this group. This cluster reflects the methodological approaches and physiological parameters studied.

The **yellow cluster** at the center groups terms including “Escherichia coli”, “Staphylococcus aureus”, “antimicrobial resistance”, “antibiotic resistance”, “Enterococcus faecium”, “Lactobacillus plantarum” and “food safety”. This cluster gathers terms related to pathogens, antibiotic resistance and food safety. The dense connections between clusters reveal strong thematic integration. The green cluster connects intensely to both the blue and red clusters. This structure reveals a coherent field despite its thematic diversity.

Factorial analysis of keywords

Figure 13 presents a conceptual map obtained from a factorial analysis of keywords. This representation highlights the organization of the scientific field under study through several distinct thematic groupings identifiable by clusters of terms sharing semantic proximity. The distribution of keywords shows that research is not organized around a single dominant axis, but rather around several complementary thematic poles.

In the **upper-left section**, the **violet thematic group** brings together terms related to physiology, growth and dietary supplements. Terms such as “dietary supplement”, “animal feed”, “physiology”, “growth development” and “veterinary medicine” appear closely associated. This grouping reflects a general approach to the field, centered on the biological and nutritional foundations as well as the physiological mechanisms related to the use of dietary supplements in animals. Adjacent to this group, a second **green thematic group** focuses more on animal health and avian diseases. Terms such as “poultry diseases”, “microbiology”, “bird disease”, “animals” and “diet” indicate a more applied orientation, centered on the study of interactions between pathologies, diet and animal health. This group shows that research is not limited to zootechnical performance but also places considerable importance on sanitary and microbiological aspects.

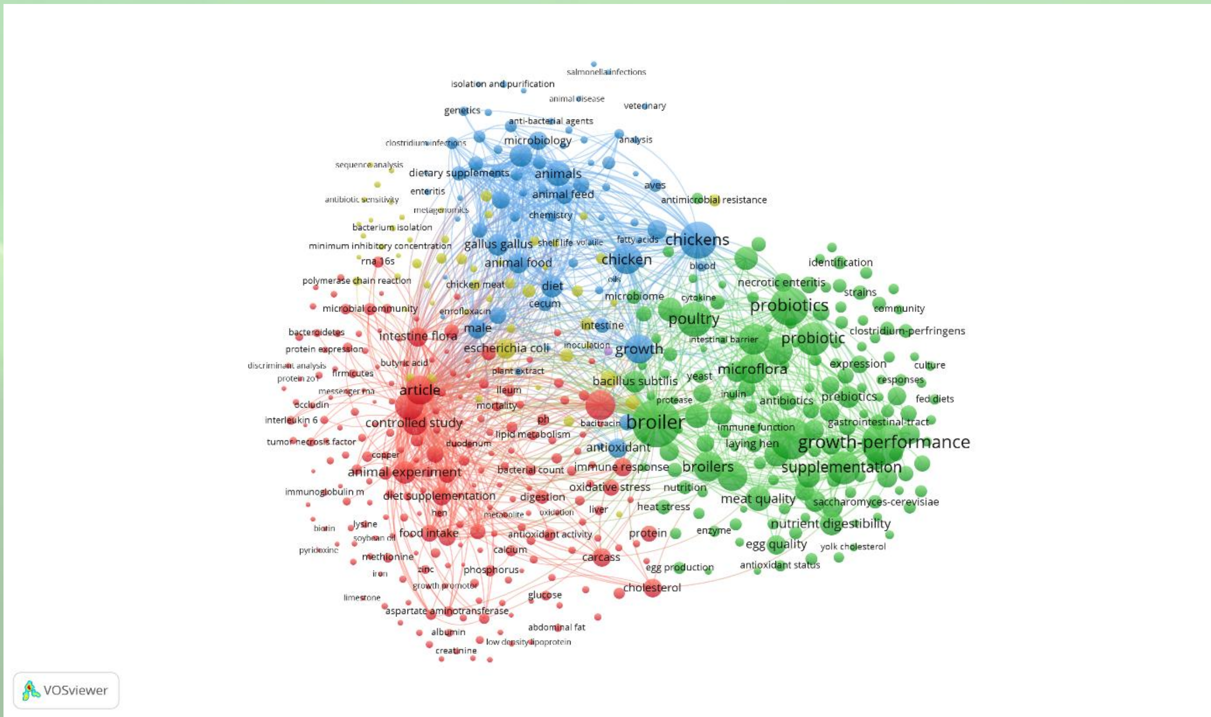

Figure 12: Keyword network map

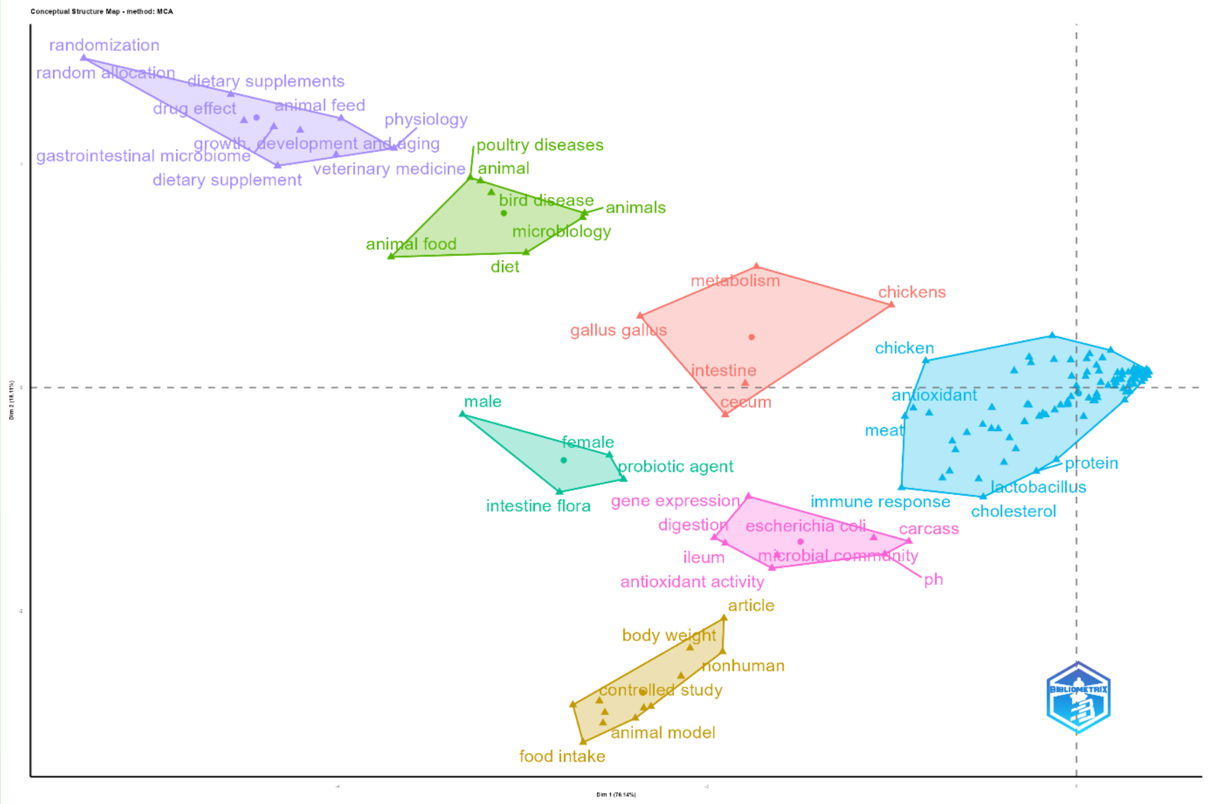

Figure 13: Factor analysis of all-keywords

In the **upper-central section** of the figure, a distinct group identified by the **red color** brings together terms related to digestive anatomy and metabolism. The keywords “intestine”, “cecum”, “metabolism”, “Gallus gallus” and “chickens” indicate a more targeted approach, oriented toward the study of internal physiological mechanisms. This pole highlights the importance of research on the functioning of the digestive system and metabolic processes in poultry, which constitute a central element in the evaluation of probiotic effects.

On the **right side** of the map, a particularly structured group appears around performance and biological responses. Identified by the **blue color**, it clusters keywords such as “protein”, “antioxidant”, “immune response”, “cholesterol”, “Lactobacillus” and “meat”, revealing that research is strongly oriented toward evaluating the effects of probiotics on product quality, growth performance and physiological responses. This grouping reflects an applied and experimental orientation of the field, centered on measurable outcomes and zootechnical performance.

In the **lower-central section**, another group of keywords represented by the **pink color** is associated with molecular and microbial mechanisms. The terms “gene expression”, “microbial community”, “digestive system”, “antioxidant activity”, “ileum” and “carcass” indicate a more recent specialization, oriented toward the study of probiotic mechanisms of action at a deeper level. This group highlights the evolution of the field toward more analytical approaches, based on molecular biology and microbiology.

Another grouping in **turquoise**, located in the **lower-left section**, clusters terms such as “probiotic agent”, “intestinal flora”, “male” and “female”. This grouping shows that some studies focus more on the functional effects of probiotics on intestinal flora and on biological differences between animals. This represents a more specific research axis, but one that remains linked to the other themes of the field.

Finally, in the **lower section** of the figure, a **yellow thematic group** brings together methodological terms such as “animal model”, “controlled study”, “body weight” and “food intake”. This grouping reflects the importance of experimental approaches in the field under study and shows that research relies heavily on controlled protocols designed to precisely measure the effects of probiotics. Keywords located near the center of the figure indicate transversal concepts used across several research axes simultaneously. Conversely, groups located at the periphery correspond to more specialized research axes.

Discussion

The growing awareness of issues related to animal health, food safety, the emergence of antimicrobial resistance, and the ban on the use of antibiotic growth promoters (AGPs) in 2006 has fundamentally redirected scientific research toward the exploitation of alternative solutions for poultry nutrition. Since then, studies devoted to probiotics have undergone an unprecedented expansion over the past two decades, as evidenced by the exponential increase in scientific publications in this field. Numerous researchers, countries, institutions and industrial partners have collaborated on studies examining the use of probiotics in poultry nutrition. This dynamic justifies the present bibliometric analysis, which aims to identify the milestones already reached, the identified research gaps, and the future trends of the field.

From 2000 to 2025, annual publications on the use of probiotics in poultry nutrition experienced a significant increase, with a peak observed in 2025 when 687 articles were recorded. The annual number of publications increased slowly from 2000 to 2011, with fewer than 50 articles per year. The increase observed from 2012 onwards could be explained by a growing awareness of the positive impacts of probiotics on intestinal health, growth performance and the modulation of the avian microbiota (Awad et al., 2009; Deng et al., 2012; Higgins et al., 2008; Jin et al., 2000; Lei et al., 2013; Yang et al., 2012). This period also corresponds to the intensification of research on AGP alternatives following the European regulations of 2006 (Regulation (EC) No 1831/2003, 2003). Furthermore, the emergence of concerns regarding antimicrobial resistance and food safety stimulated interest in natural feed additives (Baurhoo et al., 2007, 2009; Jung et al., 2008; Teo & Tan, 2007; World Health Organization, 2000). The last five years have been particularly productive, with more than 300 scientific documents published annually, representing 63.8% of total publications. From 2010 to 2020, the increase in the number of publications was positively associated with the rise in annual mean citations. However, a decrease in the mean number of citations per article over time was observed, particularly for the most recent publications. Whereas articles published in 2000 had accumulated an average of 91 citations, this number progressively declined to fewer than 2 citations per article in 2025. This decreasing trend could be explained by the fact that recent articles have not yet had sufficient time to accumulate citations.

China occupies a dominant position in research on the use of probiotics in poultry nutrition, ranking first in terms of scientific output, citation volume and author productivity. This result is consistent with observations made in other bibliometric analyses covering fields related to poultry science (Hodonou et al., 2025; Uyanga et al., 2023). The analysis of collaboration networks highlights significant interactions between China and several countries, notably the United States, Egypt and Iran. However, in terms of international collaboration, the United States is distinguished by a particularly high centrality, reflecting a structuring role in the scientific networks of the field. Furthermore, this Chinese dominance is not fully mirrored at the institutional level, where Zagazig University, an Egyptian university, appears as the most influential institution. Only one Chinese university, China Agricultural University, occupies the fourth position, while three American institutions the University of Arkansas System, the United States Department of Agriculture and the University of Georgia also figure among the most influential.

Regarding authors, Wang Y., Wang J. and Liu Y. emerge as the major contributors to research on probiotics in poultry nutrition. It should be noted that these authors are affiliated with Chinese institutions, which confirms China's position as a major hub of avian probiotic research. However, these authors appear as co-authors on numerous scientific publications (Y. Liu et al., 2024, 2025; J. Wang et al., 2021, 2023; Y. Wang et al., 2018, 2018). Consistent with this, the international collaboration rate among authors stands at 18.1%, suggesting that inter-institutional and international collaborative efforts in this research field are relatively moderate. This observation aligns with findings reported in the fields of heat stress and factors affecting egg quality in poultry, where international author collaboration rates remain below 25% (Hodonou et al., 2025; Uyanga et al., 2023).

Furthermore, the analysis of the most cited articles between 2000 and 2025 highlights a progressive evolution in the use of probiotics in poultry nutrition, shifting from a primarily zootechnical approach toward an integrated mechanistic understanding. Indeed, studies have demonstrated that probiotics significantly improve growth performance (ADG, FCR and live body weight), intestinal morphology, and exert effects comparable to, or even superior to, AGPs (Awad et al., 2009; Baurhoo et al., 2009; Mountzouris et al., 2010; Rehman et al., 2020; Z. Xu et al., 2003). The foundational phase from 2000 to 2009 also allowed the identification of specific effects, notably the action of prebiotics such as mannan-oligosaccharides (MOS) against *Salmonella* and fructo-oligosaccharides (FOS) on the stimulation of enzymatic activities, intestinal microflora and villous morphology in broiler chickens (Spring et al., 2000; Z. Xu et al., 2003). As for the decade 2010–2019, it is marked by the emergence of new landmark studies. Among these are the works of Wei et al. (2013), who established a phylogenetic census of the avian intestinal microbiome, as well as those of Sohail et al. (2012), who characterized the effect of supplementing broiler diets with a mixture of probiotics and prebiotics on growth performance and intestinal barrier integrity under heat stress conditions. The recent period from 2020 to 2025 marks a turning point toward far more integrated approaches. Indeed, studies now incorporate immunological biomarkers (IgY, IgA, cytokines and anti-inflammatory markers) as well as markers of antioxidant status. The works of Rehman et al. (2020) on the effects of probiotics on broiler immunity, those of Hu et al. (2021) on extracellular vesicles derived from *Lactobacillus reuteri*, and those of Y. Xu et al. (2021) on *Bacillus subtilis* and *B. licheniformis* illustrate this evolution. Overall, the effects of probiotics are essentially based on five major mechanisms: improvement of zootechnical performance, improvement of intestinal morphology, modulation of the caecal microbiota, reduction of intestinal pathogens, and regulation of immune and antioxidant capacities in poultry. Beyond experimental results, the structuring and dissemination of knowledge also relies on scientific journals, the analysis of which makes it possible to identify the most influential editorial outlets. In the communication of research results on probiotics in poultry nutrition, the journal *Poultry Science* has largely dominated the editorial landscape. Indeed, this journal has produced most of the most cited articles worldwide. The predominance of this journal could be explained by its long editorial history, its international recognition and its high impact factor. These attributes attract leading researchers, who view it as a legitimate vehicle for disseminating their findings.

From a bibliometric perspective, author-supplied keywords constitute an essential tool for analyzing the thematic structuring of a field, as they reflect the core concepts and dominant research orientations. In this study, certain terms stand out by their high frequency of occurrence within the analyzed corpus. These include notably "broilers", "growth-performance", "performance", "probiotics" and "supplementation". Several tools highlight this predominance, including the word cloud (WordCloud), the heat map (TreeMap) and trend analysis (Trend Topics). However, it is interesting to note that the keywords "growth-performance" and "broilers" present a higher occurrence than "probiotics" and other terms. This observation suggests that more researchers are interested in studies addressing growth performance in relation to probiotic supplementation in poultry diets. This same observation is accompanied by another reality: broilers represent the subjects on which many researchers work most of the time. Moreover, the thematic evolution of keywords (Words' Frequency over Time) confirms this dynamic. This consistency is also reflected in the keyword co-occurrence analysis and the factorial analysis of keywords, which confirm and systematize the major research orientations previously identified — namely growth performance, intestinal morphology and microbiota, molecular mechanisms, immunity and metabolites, as well as food safety and antimicrobial resistance (Abdul-Ratha et al., 2024; Al-Khalaifa et al., 2019; Amit-Romach et al., 2004; Baurhoo et al., 2009; Bjerrum et al., 2006; Kim et al., 2011; Nakadira et al., 2025; Sohail et al., 2010; Yang et al., 2012).

The analysis of the thematic keyword map reveals a particular structure that raises questions about the maturity of the field. Indeed, the total absence of motor themes and of emerging or declining terms constitutes an unusual observation. Such an observation suggests a phase of stabilization rather than innovation within the field. One could infer that the field currently favors the deepening of established concepts rather than the exploration of new frontiers. Such a situation may reflect a degree of maturity, but also a risk of conceptual stagnation. Future innovations will likely need to emerge from the convergence between niche themes and central themes.

Conclusion

This bibliometric analysis highlights the progressive structuring and strong dynamics of research on probiotics in poultry nutrition, in a context marked by the ban on antibiotics as growth promoters. The concentration of scientific output around a few countries — notably China, the USA and Egypt — could be explained by a combination of several factors. Indeed, these countries may benefit from higher levels of funding, incentive-driven science policies, more developed research infrastructures, and better integration into international collaboration networks compared to other countries.

Beyond its quantitative growth, this bibliometric analysis demonstrates that the field of research on probiotics in poultry nutrition is mature in its fundamentals, dynamic in its innovations, but incomplete in its understanding of mechanisms of action and in its operational deployment on farms. The transition toward a microbiota-centered approach has been initiated but requires methodological consolidation and field validation. In the future, research should move toward more targeted and integrative approaches, including the development of precision probiotics, the exploration of postbiotics and synbiotics, as well as the integration of tools derived from advanced biotechnologies. These developments will be decisive in optimizing the efficacy and sustainability of supplementation strategies in poultry production.

Study limitations

This study presents the methodological limitations inherent to bibliometric analyses. First, the analyzed corpus relies exclusively on the Scopus and Web of Science databases. These databases are known to favor anglophone publications and generally privilege internationally indexed journals with high visibility. Although this methodological choice guarantees data quality and standardization, it induces a selection bias. It underrepresents works published in other languages and excludes grey literature as well as research arising from local contexts. As a result, the obtained findings more closely reflect visible and indexed scientific output, but do not represent the entirety of knowledge actually produced in the field. Furthermore, the analysis relies primarily on bibliometric metadata, and no in-depth qualitative evaluation of article content was conducted. In addition, the methodological choice regarding the search strategy directly influences the composition of the corpus. The use of broad keywords aimed at maximum coverage leads to the inclusion of peripheral articles. Conversely, certain relevant works may be excluded. Similarly, the application of a minimum threshold of 10 occurrences for the keyword co-occurrence analysis has certainly excluded emerging themes that are still underrepresented. Finally, temporal limitations must also be highlighted. The study focuses on the period from 2000 to 2025, thus excluding earlier pioneering works. Despite these limitations, this study provides a rigorous and systematic mapping of the field.

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