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LAPORAN PENELITIAN DOSEN

MAPPING GLOBAL WATER BUFFALO RESEARCH FROM 2000 TO 2024: PUBLICATION TRENDS, COLLABORATION NETWORKS, AND RESEARCH THEMES

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RINGKASAN

This study maps the global landscape of water buffalo research between 2000 and 2024 using bibliometric approaches. The analysis covers scientific output, collaboration patterns, and the evolution of research themes within the field. Overall, the findings indicate a steady and marked increase in publication volume, reflecting growing scientific attention to buffalo production systems. India emerged as the most prolific contributor, whereas Italy showed the highest citation impact, suggesting differences between research quantity and influence.

Analysis of keyword co-occurrence and thematic clusters indicates a clear shift in research priorities. Earlier studies were largely centered on genetics and basic physiology, while more recent work increasingly emphasizes reproductive biotechnology, molecular techniques, and lactation-related research. In contrast, topics related to nutrition, feed resources, and feeding innovation remain relatively underrepresented. Collaboration network analysis shows that internationally co-authored publications tend to achieve higher citation impact; however, several major buffalo-producing countries continue to demonstrate limited participation in global research networks.

Conceptual structure mapping reveals three dominant research domains: milk production and lactation biology, molecular and genetic studies, and reproductive physiology and biotechnology. Based on these patterns, future buffalo research would benefit from greater attention to sustainable nutrition, rumen microbiome studies, and locally available feed.

resources, as well as from stronger international collaboration and the adoption of emerging technologies such as genomics, artificial intelligence, and climate-smart approaches. These insights provide a basis for shaping future research directions and improving the sustainability of buffalo production systems

Kata kunci: buffalo, bibliometric, citation, reproduction, trends, sustainability

SUMMARY

Keywords: buffalo, bibliometric, citation, reproduction, trends, sustainability

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PENDAHULUAN

Latar Belakang

The water buffalo (Bubalus bubalis) plays a vital role in livestock production systems across tropical and subtropical regions, particularly as a source of milk, meat, and draft power (Zhang et al., 2020). An estimated 97% of the global buffalo population is found in Asia, where the species remains closely linked to rural livelihoods and smallholder-based farming systems (Kurihara et al., 2012). In many of these regions, buffalo production is not only an economic

activity but also an integral component of social and cultural practices.

Despite this importance, buffalo research has long received less scientific attention than cattle-oriented studies. As a result, progress in key areas such as genetic improvement, reproductive biotechnology, precision feeding strategies, animal health management, and overall production efficiency has been relatively slow (Wanapat & Rowlinson, 2007). This imbalance is becoming increasingly problematic as buffalo production systems are now exposed to multiple pressures, including climate variability, disease risks, competition for feed resources, and growing global demand for high-quality animal protein (Pehan et al., 2025).

In recent decades, advances in reproductive physiology, genomics, and molecular biology have stimulated renewed interest in buffalo research (Liao et al., 2025). Empirical studies have highlighted the species' capacity for high milk fat yield, resilience under harsh environmental conditions, and efficient utilization of fibrous feeds, reinforcing its relevance for sustainable livestock development (Nakao et al., 2003). Nevertheless, existing research efforts remain unevenly distributed across regions and disciplines. Buffalo studies are often concentrated in a limited number of countries, with relatively weak international collaboration and insufficient integration across research themes (Mulianda et al., 2025). Such fragmentation constrains the identification of coherent research priorities and may limit the ability of buffalo production systems to compete and adapt within rapidly evolving global livestock sectors.

Bibliometric analysis has increasingly been used to examine the structure and dynamics of scientific research by mapping publication outputs, collaboration patterns, and the evolution of research themes (Aria & Cuccurullo, 2017). Within animal science, this approach has been applied to various topics, including dairy production systems, feed additives, and rumen microbiome research, providing insights into research concentration and emerging directions. However, despite the economic and ecological importance of water buffalo, a systematic bibliometric evaluation of buffalo-focused research remains lacking. The absence of such an analysis limits the ability to assess how research efforts are distributed, which topics dominate the field, and where critical knowledge gaps persist.

In response to this gap, the present study investigates global trends in buffalo research between 2000 and 2024, with particular attention to dominant themes, collaboration networks, and evolving research priorities. Bibliometric methods

were applied to publications retrieved from the Web of Science database, complemented by visualization techniques to explore structural and thematic patterns. By synthesizing long-term publication data, this study aims to provide a clearer understanding of the development of buffalo science and to inform future research strategies, policy formulation, and efforts to enhance the productivity and sustainability of buffalo production systems.

Materials and Methods

Materi and methods

The bibliometric analysis was conducted through several iterative steps, including keyword refinement, data extraction from academic databases, and science-mapping analyses. The bibliometric review was initiated by surveying the existing global literature on water buffalo research in order to obtain an overview of major topics and influential publications. This initial exploration helped identify recurring themes and informed the refinement of the analytical framework. The methodological approach was adapted from established bibliometric and science-mapping procedures reported in previous studies (Mulianda et al., 2025), with adjustments made to suit the scope of buffalo-focused research.

The analytical workflow was implemented in six main steps. These included the definition and refinement of search terms, the application of inclusion and exclusion criteria, and the selection of publications relevant to the objectives of the study. An initial performance analysis was then conducted, followed by data cleaning and standardization using Refine software. Finally, detailed bibliometric, thematic, and network analyses were performed to explore publication patterns, research themes, and collaboration structures, as summarized in Figure 1. All bibliographic records were retrieved from the Scopus database on 16 July 2025.

Scopus was selected as the primary data source because of its broad coverage of peer-reviewed journals in agriculture, veterinary medicine, and the life sciences. Its long-standing indexing, which extends back to 1966, allows for the examination of publication trends, citation patterns, international collaboration, and thematic development over time. For these reasons, Scopus has been widely used in bibliometric studies to map the evolution of research fields (Coman et al., 2024; Simeão et al., 2021). In this study, the search strategy was based on domain-specific terms relevant to buffalo research, including “buffalo,” “water buffalo,” and Bubalus bubalis. These terms were applied in the initial search to retrieve potentially relevant publications prior to the screening processstage.

Eligibility Criteria

Scopus was used as the primary data source for this study because of its wide coverage of international journals and its structured metadata, which are well suited for bibliometric analysis using tools such as VOSviewer and Bibliometrix. Although alternative databases, including Web of Science and PubMed, were considered during the study design stage, Scopus was selected as it provides more extensive indexing for livestock- and animal science–related publications,

particularly those focusing on buffalo production systems. The time span from 2000 to 2024 was chosen to represent the contemporary phase of buffalo research, during which substantial developments have occurred in areas such as genetics, reproductive biotechnology, nutrition, animal health, and sustainable production.

Article selection was carried out in several steps. Publications were screened based on the relevance of their titles, abstracts, and author-provided keywords to the buffalo research topic, following predefined inclusion and exclusion criteria. Only documents published within the 2000–2024 period were retained to maintain consistency across the dataset. This screening strategy is consistent with bibliometric and systematic mapping approaches applied in earlier studies (Fahimnia et al., 2015; Djalal et al., 2022). An overview of the selection and screening process is provided in Figure 1.

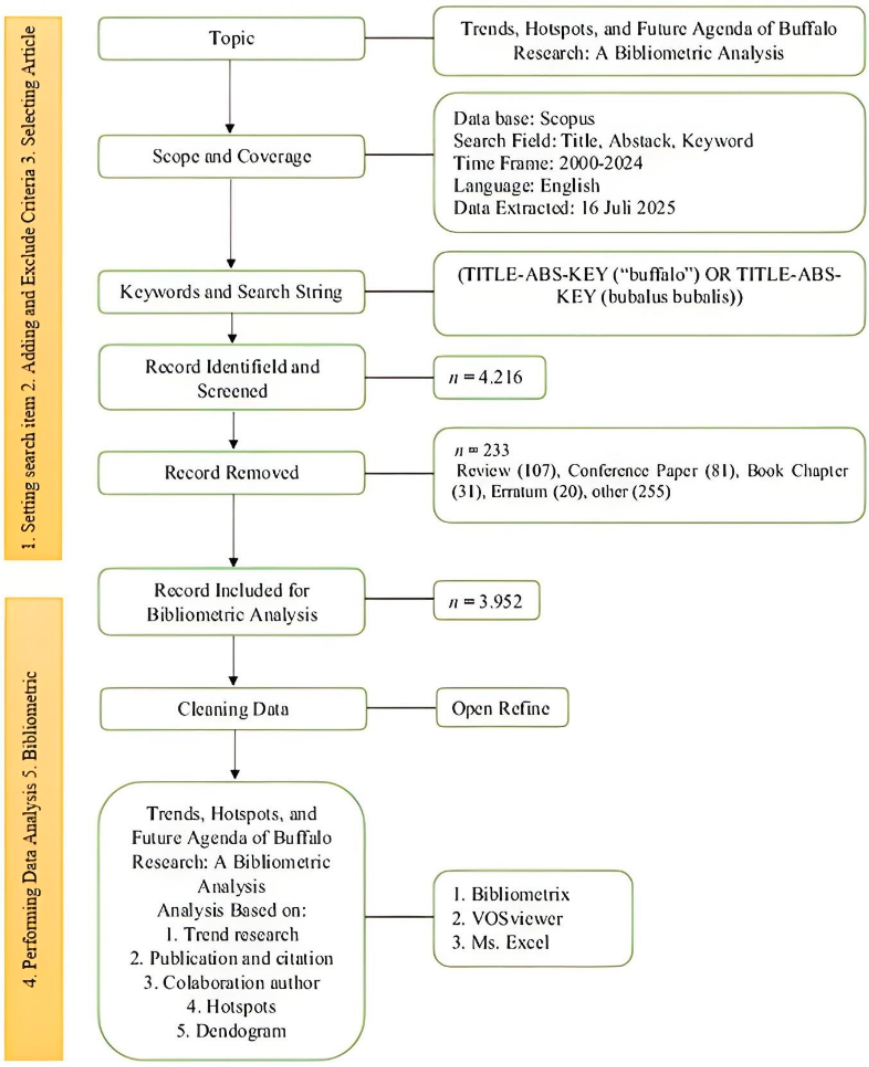

Figure 1. Bibliometric method (Prihambodo *et al*., 2025)

For each eligible publication, bibliographic information was extracted, including authorship, publication year, institutional affiliations, keywords, funding information, country of origin, and citation data. These data were compiled in CSV format and used for subsequent analyses. Descriptive indicators, such as annual

publication trends, journal distribution, and general patterns of research productivity, were first examined to characterize the overall development of buffalo-related research. Analysis of publication trends provided insights into growth dynamics over time, while journal distribution helped identify the most influential publication outlets in this field.

In the final analytical stage, bibliometric and network analyses were conducted using VOSviewer (Van Eck & Waltman, 2018), the Bibliometrix R package (Aria & Cuccurullo, 2017), and Microsoft Excel. The combined use of these tools enabled the examination of authorship and institutional contributions, country-level productivity, funding patterns, and citation networks, as well as the visualization of thematic clusters, collaboration structures, and the conceptual evolution of global buffalo research.

Result

Analysis of publication and citations

As shown in Figure 2, the volume of buffalo-related publications increased markedly between 2000 and 2024, although this growth did not occur uniformly over time. During the early 2000s, annual publication output remained relatively modest, averaging around 50–60 articles per year. A noticeable acceleration began after 2005, followed by a sustained increase that culminated in a peak in 2021, when more than 200 publications were recorded. Despite some year-to-year variation, the overall pattern reflects a long-term expansion of research activity, suggesting growing global interest in buffalo science, particularly in areas related to nutrition, health, genetics, and production management.

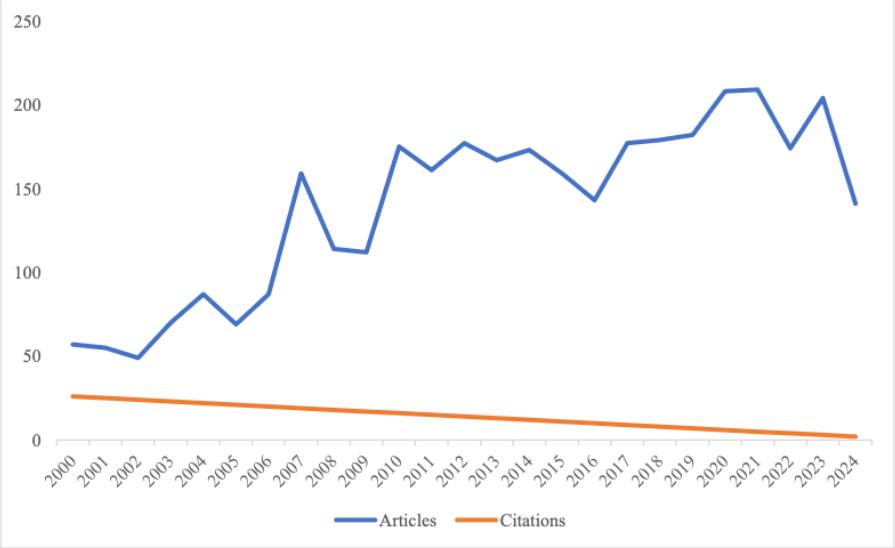

Figure 2. Annual statistics on published studies and citation frequency (2000-2024)

In contrast to publication output, citation trends display a different temporal pattern. Figure 2 indicates a gradual decline in annual citation counts over the same

period. This trend is largely influenced by the citation time-lag effect, as recently published articles have had limited time to accumulate citations. In addition, the rapid increase in publication volume has not been accompanied by a proportional rise in citations within individual years. Taken together, these observations suggest that while research output in buffalo studies continues to expand, citation impact typically emerges over a longer timeframe.

Authorship analysis (Figure 3) reveals a high level of concentration in research productivity. A small group of researchers accounts for a substantial proportion of total publications in the field. Kumar S emerged as the most prolific author, with 116 publications, followed by Kumar A and Palta P, each contributing 90 publications. This pattern indicates the presence of a core group of highly active researchers who have consistently shaped buffalo research over the past two decades. In addition, authors such as Chauhan MS, Singla SK, Manik RS, and Sharma A form a secondary tier of contributors, with publication outputs ranging from 60 to 82 documents, and continue to influence the development of research topics, methodological approaches, and collaborative networks.

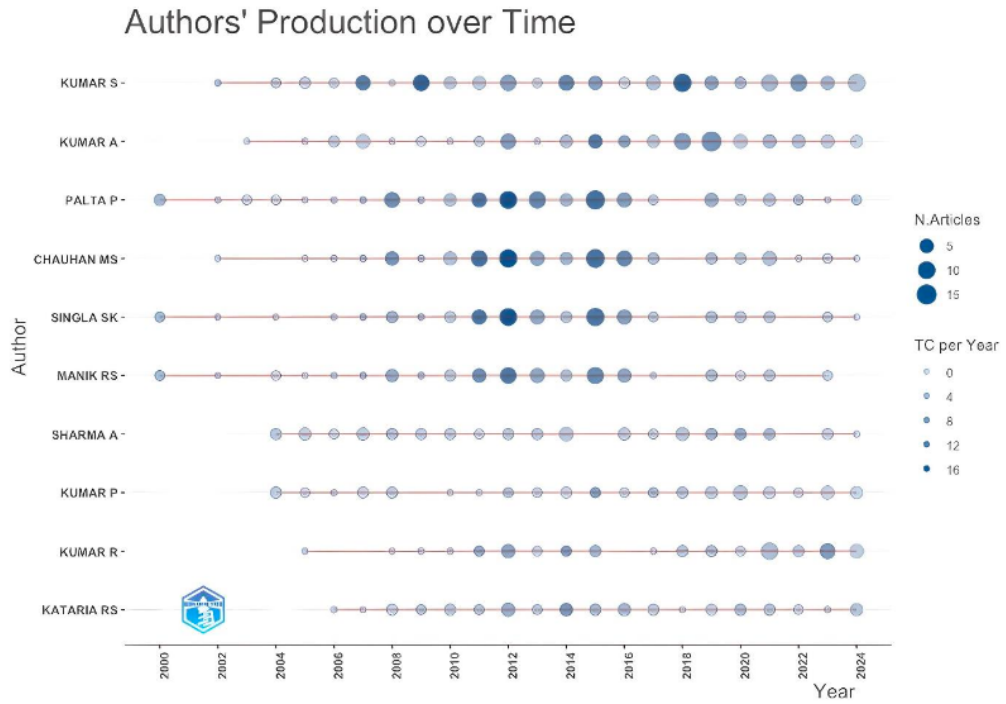

Figure 3. Top Contributing Authors in Buffalo-Related Publications (2000–2024)

Overall, these results point to an author-centric research landscape, where scientific output is concentrated among a limited number of key contributors. While this concentration has likely supported continuity and depth within the field, it also highlights the potential to broaden participation through increased international collaboration and the inclusion of a more diverse group of researchers, thereby fostering a more balanced and inclusive development of buffalo research.

Core Journals Identified Through Bradford's Law

The application of Bradford's Law reveals a highly uneven distribution of journals publishing buffalo-related research (Figure 4). A relatively small group of journals accounts for a substantial share of total publications, indicating a clear core set of outlets within this research field. Among these, Buffalo Bulletin, Journal of Animal Production, and Tropical Animal Health and Production emerge as the most prominent sources of buffalo-focused studies. Beyond this core group, the number of publications decreases rapidly, with a much larger number of journals contributing only a limited number of articles. This extended peripheral zone reflects the broad dissemination of buffalo research across diverse publication outlets, albeit with lower individual productivity. Overall, the observed pattern confirms a strong concentration of research output within a small number of specialized journals, which play a central role in shaping the dissemination and visibility of buffalo research.journals.

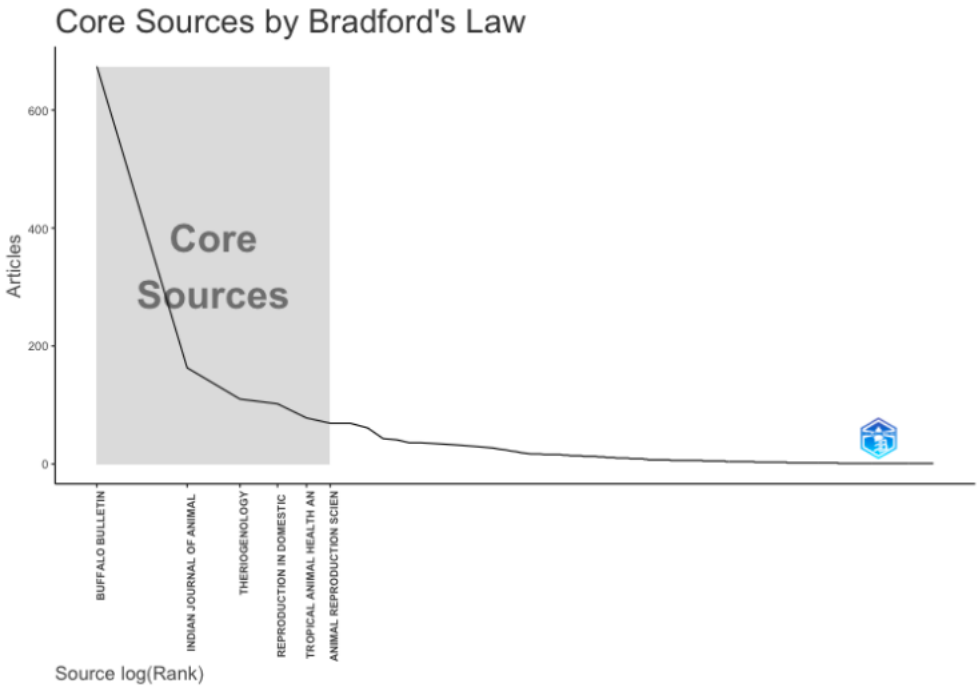

Figure 4. Sources by Bradford's law.

Most influential journals in buffalo research

Figure 5 presents journal productivity in buffalo research using a bubble chart, highlighting substantial differences in publication output among journals. Buffalo Bulletin stands out as thenmost prolific outlet, with 674 published articles, far exceeding other journals in the field. The Indian Journal of Animal Sciences ranks second, contributing 163 publications.

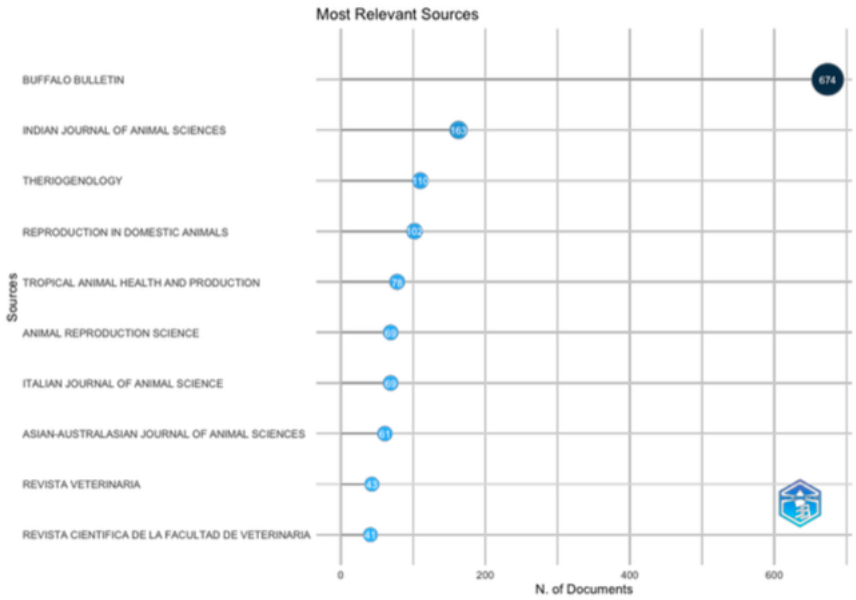

Figure 5. Most productive journals in buffalo research

Several international journals also play an important role in disseminating buffalo research. Theriogenology (110 articles) and Reproduction in Domestic Animals (102 articles) are particularly prominent, reflecting the strong focus on reproductive biology and biotechnology within buffalo studies. Additional contributions are provided by Tropical Animal Health and Production, Animal Reproduction Science, and the Italian Journal of Animal Science, which together cover a broad range of topics related to health, production, and reproduction.

The presence of regional journals, such as the Asian-Australasian Journal of Animal Sciences and Revista Veterinaria, further illustrates the geographically diverse nature of buffalo research. This distribution suggests that while a small number of journals dominate publication output, buffalo-related studies are disseminated across a wide range of international and regional outlets.

Conceptual Structure and Thematic Clustering of Buffalo Research

The conceptual structure map shown in Figure 6 illustrates how buffalo research is organized into several closely related thematic areas. One prominent cluster is centered on milk production, encompassing keywords such as milk yield, lactation, water buffalo, and Bubalus bubalis. The concentration of these terms highlights the dominant role of milk productivity as a core research focus within buffalo science.

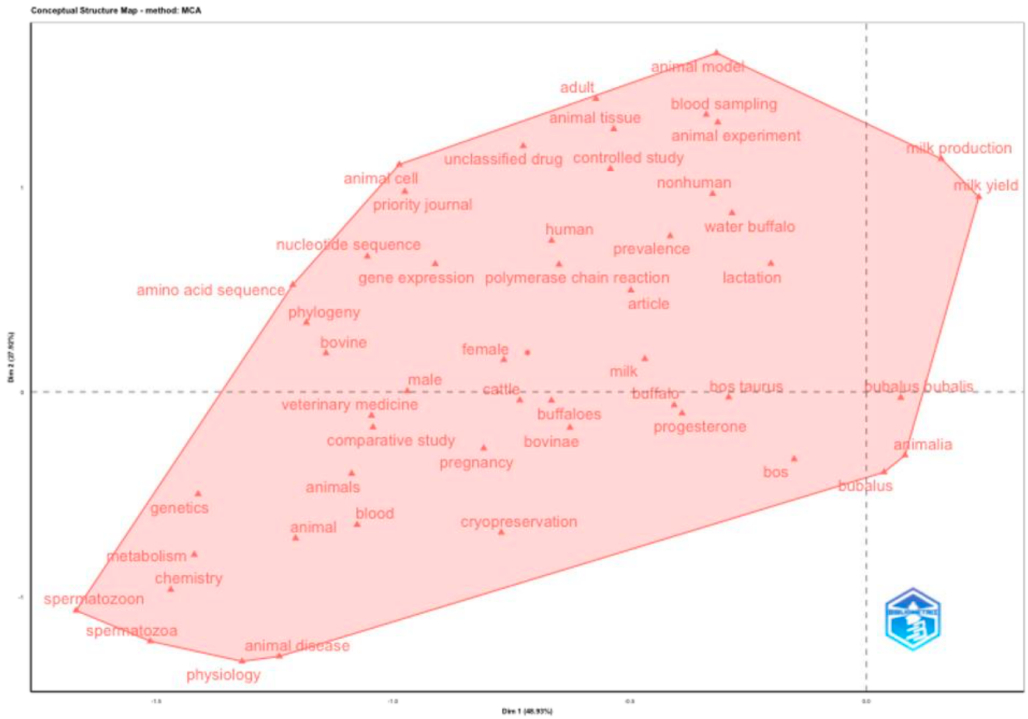

Figure 6. Conceptual structure map about cow bufallo

A second major cluster is characterized by molecular and genetic terminology, including gene expression, polymerase chain reaction, nucleotide sequence, and phylogeny. The presence of these keywords reflects the growing application of molecular techniques to address questions related to genetic variation, population structure, and biological function in buffalo.

In addition, a separate thematic group emerges around reproductive and physiological research. This cluster includes keywords such as spermatozoa, cryopreservation, metabolism, physiology, and genetics, indicating sustained scientific interest in reproductive performance, fertility preservation, and physiological mechanisms. Together, these clusters suggest that buffalo research has evolved into a multidisciplinary field, with strong emphasis on milk production supported by expanding molecular and reproductive research frameworks.

Global research productivity and collaboration dynamics in buffalo studies

From Table 1 and Figure 7, investigation of publication productivity shows that global buffalo research from 2000 to 2024 has an imbalanced distribution among countries. India is the most productive country, with 1,183 papers (33.9% of global output). This dominance can be attributed to the significance of buffalo in India's animal husbandry and continued provision for buffalo research. Also to consider as large contributors are Italy, Brazil, Pakistan and Egypt with publication volumes much lower than India.

Tabel 1. Top 10 corresponding autho"s countris

No	Country	Articles	% Articles	SCP	MCP	MCP rasio	TC
1	India	1183	33.92	1131	52	4.4	10925
2	Italy	272	7.80	209	63	23.2	5977
3	Brazil	194	5.56	154	40	20.6	2224
4	Pakistan	177	5.07	151	26	14.7	2396
5	Egypt	148	4.24	112	36	24.3	1509
6	China	103	2.95	83	20	19.4	1804
7	Thailand	72	2.06	51	21	29.2	1049
8	Iran	67	1.92	58	9	13.4	600
9	Philippines	62	1.78	50	12	19.4	270
10	Turkey	55	1.58	51	4	7.3	329

Note: SCP = singel-country piblication; MCP = multi-country piblication; TC = total citation

Differences are also evident in patterns of international collaboration. Research output from India is largely characterized by single-country publications, suggesting a strong domestik research base with relatively limited reliance on international co-authorship. In contrast, countries such as Italy and Thailand display higher proportions of multi-country publications, indicating more active engagement in international research partnerships.

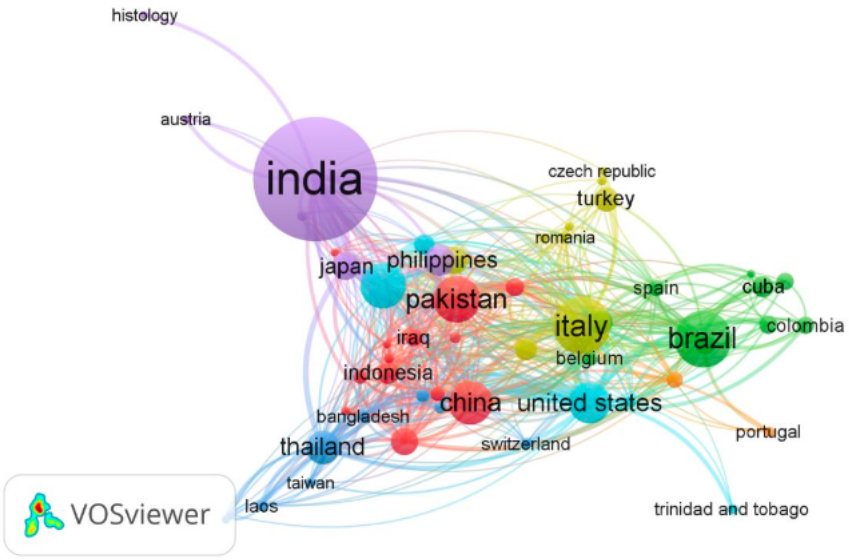

Figure 7. Co-authorship between countries

The co-authorship network analysis further illustrates these patterns of collaboration. As shown in Figure 7, dense collaboration clusters connect researchers across Asia, Europe, and the Americas, highlighting the global nature of buffalo research. Within this network, India appears as the largest and most influential node, reflecting both its high publication output and its central role in linking different regional research communities.

Analysis of research trends and conceptual structure

Figure 8 illustrates the temporal evolution of research topics in buffalo studies between 2000 and 2024. The use of the terms buffalo and Bubalus bubalis shows a clear increase after 2011, suggesting a growing consolidation of species-specific research during this period. This shift likely reflects improved data availability, methodological advances, and increasing recognition of buffalo as a distinct research focus within animal science.

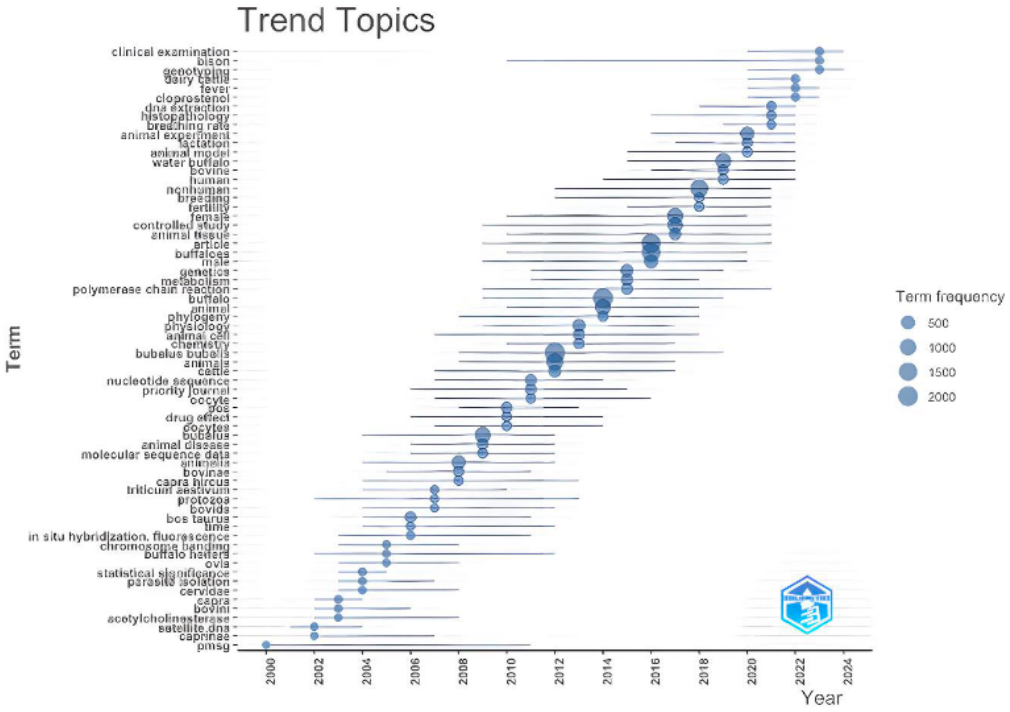

Figure 8. Trending research topics in Buffalo global.

Over the past decade, keywords associated with animal experimentation, breeding, nutrition, and production management have expanded substantially. The rising prominence of these terms indicates a gradual movement away from purely descriptive studies toward more applied and production-oriented research. Collectively, these trends highlight an increasing emphasis on practical outcomes, with research efforts increasingly aligned with productivity, efficiency, and management improvements in buffalo production systems.

Discussion

Research methodology framework and strategic research agenda

The bibliometric findings suggest that buffalo research has been shaped by a relatively narrow set of methodological approaches, with strong emphasis on experimental and laboratory-based studies. While such approaches have generated important advancesparticularly in reproduction and molecular biology they may not fully capture the complexity of buffalo production systems, which are often

embedded in smallholder, resource-limited, and climate-sensitive contexts. Broader methodological integration, including mixed and interdisciplinary approaches, could therefore enhance the relevance and applicability of future buffalo research, especially in areas such as nutrition management, sustainability, and socio-economic performance.

Experiences from other livestock sectors illustrate the value of coordinated research planning. For example, collaborative initiatives involving government agencies and producer organizations in the United States have successfully identified priority research areas related to nutrition, food safety, and sustainability (Miller *et al*., 2020). Similar stakeholder-driven frameworks could be adapted to buffalo-producing regions to align scientific research more closely with production challenges and development goals.

Influence of core journals on research direction

The Bradford distribution analysis demonstrates that buffalo research output is highly concentrated in a small number of core journals, which serve as the main platforms for knowledge dissemination. This concentration aligns with classical bibliometric patterns (Alves, 2019) and indicates that editorial focus and journal scope play a critical role in shaping the visibility and perceived importance of research topics. As a result, research themes that align closely with the priorities of these journals are more likely to gain prominence within the field.

Journals such as Buffalo Bulletin and Theriogenology have emerged as key publication outlets, particularly for studies related to productivity improvement, reproductive biotechnology, adaptive nutrition, and animal health (Neglia *et al*., 2020; Khan *et al*., 2025). Their central position suggests that they not only disseminate research findings but also influence the thematic orientation of buffalo science. While this concentration supports efficient knowledge exchange, it may also limit exposure for interdisciplinary or emerging topics that fall outside traditional editorial scopes.

Conceptual structure and thematic evolution

Conceptual structure mapping indicates that buffalo research is currently organized around three dominant domains: milk production and lactation biology; molecular and genetic studies; and reproductive physiology and biotechnology. The growing frequency of molecular and genomic keywords over time reflects a clear shift toward technology-intensive research approaches. This trend mirrors broader developments in livestock science, where genomic selection, molecular diagnostics, and systems biology are increasingly used to improve productivity and resilience (Simeão et al., 2021; Ravi Kumar *et al*., 2023).

However, the relative dominance of these domains also highlights thematic imbalances. Topics related to nutrition, feed innovation, and rumen function appear less integrated into the core conceptual structure, despite their importance for sustainable buffalo production. Addressing this imbalance may require deliberate efforts to expand research agendas beyond laboratory-based innovation toward system-level challenges, particularly in regions where buffalo production plays a critical role in food security and rural livelihoods.

Government support and policy frameworks

The bibliometric patterns observed in this study indicate that sustained progress in buffalo research and production cannot rely solely on scientific innovation but also requires consistent institutional and policy support. Multi-sectoral government involvement, particularly across agriculture, food security, and rural development programs, has been shown to play an important role in improving the productivity and long-term viability of buffalo farming systems (Molossi et al., 2023). In several buffalo-producing regions, fragmented policy implementation and limited coordination across programs remain major constraints.

Future buffalo development strategies would benefit from a more integrated policy framework that links research outcomes with food security initiatives, community-based livestock development, and environmental conservation objectives (Glotko et al., 2020). Without sustained and coherent policy support, the potential of buffalo as a strategic local livestock resource is unlikely to be fully realized, particularly in smallholder-dominated production systems.

Limitations

This study is subject to several limitations that should be considered when interpreting the results. First, the bibliometric analysis was restricted to English-language publications indexed in the Scopus database. While this approach ensures data consistency, it may exclude relevant studies published in local or regional journals, particularly from countries with long-standing buffalo research traditions. As a result, some regional research contributions may be underrepresented.

Second, reliance on a single bibliographic database introduces potential coverage bias, as Scopus primarily indexes journals from major international publishers and selected regions. Consequently, the global distribution of buffalo research identified in this study may not fully capture scientific outputs from developing countries. In addition, citation-based indicators are influenced by time-dependent effects; publications from the most recent years (2023–2024) have had limited opportunity to accumulate citations. Future bibliometric studies could address these limitations by integrating multiple databases, such as Web of Science

or CAB Abstracts, to provide a more comprehensive and balanced overview of global buffalo research.

Conclusion

The present bibliometric analysis, covering a 25-year period, shows that global research on water buffalo has expanded steadily, although its development has been uneven across regions and research themes. India accounts for the largest share of publications, reflecting its strong research capacity and production base, whereas Italy demonstrates higher citation impact, suggesting greater international visibility and influence. Over time, buffalo research has shifted from a primary focus on genetics and basic physiology toward reproductive biotechnology and molecular-oriented studies. In contrast, research on nutrition, feed resources, and feeding strategies remains relatively limited despite its central importance for production sustainability.

The analysis also indicates that international collaboration is closely associated with higher citation impact, highlighting the value of cross-border partnerships in enhancing research quality and visibility. However, several countries with large buffalo populations remain weakly connected to global research networks, which may constrain knowledge exchange and innovation. Addressing this imbalance will be critical for strengthening the global buffalo research community. Based on these findings, future buffalo research should place greater emphasis on improving feed innovation and sustainable nutrition, including studies on rumen microbiome dynamics and locally available feed resources. At the same time, expanding international collaboration and adopting emerging technologies such as genomics, artificial intelligence, and climate-smart approaches will be essential for improving productivity, resilience, and adaptability of buffalo production systems. Together, these directions provide a practical foundation for advancing buffalo science and supporting its contribution to global food security under changing climatic conditions.

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