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RESEARCH ARTICLE

Global research trends and emerging frontiers of *Clitoria ternatea* in veterinary and animal sciences: A bibliometric analysis (1973–2026)

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ABSTRACT

Background and Aim: *Clitoria ternatea* L. (butterfly pea) has attracted increasing research interest in veterinary and animal sciences because of its applications in livestock nutrition, animal-model pharmacology, and intelligent packaging for animal-origin foods. However, the geographical distribution, collaborative structure, thematic organization, and evolution of this research remain insufficiently characterized. This study aimed to map global publication trends, leading contributors, research networks, and emerging scientific frontiers of *C. ternatea* in veterinary and animal sciences.

Materials and Methods: A bibliometric analysis was conducted using Scopus records retrieved on March 18, 2026. Publications addressing *C. ternatea* in veterinary and animal sciences were identified through predefined search terms and eligibility criteria. Of the 1,466 retrieved records, we excluded 1,148 after screening, leaving 318 publications from 1973 to March 2026. Publication trends, citation indicators, geographical contributions, institutional productivity, international collaboration, and keyword co-occurrence were analyzed using Microsoft Excel, Python, and VOSviewer. Thematic communities were identified through weighted modularity-based network analysis, and temporal keyword mapping was used to characterize changing research priorities.

Results: Annual publication output increased by approximately 14% during 2000–2025 (R^2 = 0.88), reaching 45 publications in 2024. Of the 318 publications, 170 (53.5%) appeared during 2021–March 2026. The publications accumulated 4,991 citations, averaging 15.7 citations per document, with an h-index of 34. India (91 publications) and Indonesia (66) were the leading contributors, followed by Australia (32), Thailand (26), Brazil (25), and Malaysia (25). International collaboration accounted for only 19.8% of publications. Analysis of 112 keywords identified five thematic clusters (modularity Q = 0.33): animal-model pharmacology and toxicology, anthocyanin-based intelligent packaging, tropical forage and ruminant nutrition, phytochemistry and bioactive characterization, and antidiabetic and metabolic animal models. Temporal mapping indicated increasing emphasis on intelligent packaging during 2020–2024.

Conclusion: Research on *C. ternatea* is expanding but remains geographically concentrated and internationally fragmented. The identified research fronts highlight opportunities for coordinated investigations into livestock nutrition, animal-origin food quality, and veterinary applications. Broader collaboration and controlled translational studies are needed to strengthen veterinary and One Health relevance.

Keywords: animal nutrition, anthocyanins, bibliometric analysis, *Clitoria ternatea*, intelligent food packaging, research trends, tropical forage, veterinary science.

INTRODUCTION

Clitoria ternatea L. (Fabaceae), commonly known as butterfly pea, telang, or Asian pigeonwings, is a perennial tropical legume widely distributed across South and Southeast Asia, northern Australia, the Americas, and parts of Africa [1–3]. Traditionally recognized for its ethnomedicinal applications, including memory

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enhancement, anxiolytic effects, and metabolic support [1, 2], this species has attracted increasing scientific interest because of its nutritional, phytochemical, and functional properties. Beyond its applications in human health, *C. ternatea* has considerable relevance to veterinary medicine, animal nutrition, and animal-origin food safety. As a protein-rich forage legume, it can be used in ruminant and monogastric nutrition, particularly in tropical production systems [4]. Its flowers contain acylated anthocyanins, commonly known as ternatins, which have attracted attention as natural colorimetric indicators in intelligent packaging materials designed to monitor the freshness of meat, fish, and dairy products. Researchers have also investigated its diverse phytochemical constituents in experimental animal models of hepatotoxicity, diabetes, cognitive impairment, and inflammation [5–8].

These applications demonstrate the interdisciplinary relevance of *C. ternatea* across animal production, veterinary pharmacology, food technology, and environmental sustainability. In livestock systems, forage legumes may contribute to nutritional management, pasture diversification, and sustainable feed production. Phytochemical investigations using animal models provide experimental evidence of biological activities and potential therapeutic applications but translating them into veterinary clinical practice requires further validation. Similarly, anthocyanin-based intelligent packaging represents an emerging approach to monitoring the quality and freshness of animal-origin foods. Collectively, these research directions are relevant to the One Health framework, which recognizes the interconnectedness of animal, human, and environmental health. However, the available literature encompasses distinct research communities, methodologies, and applications, making it difficult to assess the overall development of *C. ternatea* research from a specifically veterinary and animal science perspective.

Bibliometric analysis provides a quantitative approach to evaluating the development, structure, and thematic characteristics of a scientific field. By systematically examining publication output, citation patterns, geographical contributions, institutional productivity, scientific collaboration, and keyword relationships, bibliometric methods can identify influential research contributors and characterize the evolution of scientific interests [9–11]. Unlike conventional narrative reviews, which primarily synthesize experimental findings and biological mechanisms, bibliometric analysis examines the organization and development of the published literature. Keyword co-occurrence analysis can reveal relationships among research topics, whereas temporal mapping can identify changes in thematic emphasis across publication periods. These approaches are particularly relevant to interdisciplinary subjects such as *C. ternatea*, where research on animal nutrition, experimental pharmacology, phytochemistry, and intelligent food packaging may develop within partially distinct scientific communities.

Previous reviews of *C. ternatea* have predominantly focused on its phytochemical composition, traditional medicinal applications, and experimentally reported pharmacological activities, particularly in relation to human health [2, 12, 13]. Although these reviews provide valuable information on bioactive constituents and their biological properties, they do not systematically characterize the publication landscape of *C. ternatea* within veterinary medicine and animal sciences. Consequently, the geographical distribution of research activities, the contributions of leading institutions and authors, and the extent of international collaboration in this specific field remain insufficiently documented. Furthermore, existing narrative syntheses provide limited information regarding how research on tropical forage, animal-model pharmacology, and intelligent packaging for animal-origin foods is organized within the broader scientific literature.

An additional research gap concerns the thematic structure and temporal development of *C. ternatea* investigations relevant to veterinary and animal sciences. Although studies have addressed its nutritional applications, phytochemical characteristics, biological activities, and food packaging potential, the relationships among these research directions have not been systematically quantified within a clearly defined veterinary and animal science publication dataset. In particular, it remains unclear which themes dominate the literature, which research areas exhibit greater thematic connectivity, and how scientific attention has shifted between established applications and emerging technologies. Without such information, identifying research concentrations, collaboration gaps, and potentially underexplored areas remains challenging.

Bibliometric studies on herb-induced liver injury, Fabaceae-derived phytochemicals, and feed additives have shown the value of quantitative literature mapping for identifying publication trends, research networks, and thematic developments [10, 14, 15]. However, these investigations address broader or different scientific domains and do not provide a dedicated assessment of *C. ternatea* research within veterinary and animal sciences. A focused bibliometric investigation is therefore needed to distinguish animal-relevant research from the broader human-oriented literature and to examine the development of this interdisciplinary field using reproducible quantitative indicators. Such an assessment may help identify research priorities, strengthen scientific

collaboration, and guide future investigations relevant to animal health, livestock nutrition, and animal-origin food safety.

This study aimed to systematically characterize the global scientific landscape of *C. ternatea* research within veterinary medicine and animal sciences through bibliometric analysis. Specifically, the study examined annual and cumulative publication trends, characterized document types and leading publication outlets, and identified the countries, institutions, and authors contributing most prominently to the field. It also aimed to evaluate patterns of international scientific collaboration and determine the extent to which research activities are geographically concentrated or distributed across participating countries.

A further objective was to identify and characterize the principal research themes through keyword co-occurrence analysis, with particular attention to animal-model pharmacology, tropical forage and livestock nutrition, phytochemical investigations, and intelligent packaging applications involving animal-origin foods. Temporal keyword mapping examined shifts in thematic emphasis and distinguished comparatively recent research interests from established areas of investigation. By integrating publication indicators, collaboration patterns, thematic clustering, and temporal analysis, the study aimed to provide a quantitative overview of how *C. ternatea* research is organized and has developed within the selected disciplinary boundaries.

The findings are intended to provide veterinary researchers, animal nutritionists, food scientists, and research institutions with an evidence-based overview of publication activity, collaborative relationships, and thematic developments. This information may help identify opportunities for interdisciplinary collaboration, prioritize underexplored research areas, and inform future investigations relevant to animal production, veterinary applications, food safety, and One Health. The study characterizes patterns within the published literature rather than directly evaluating the clinical efficacy, nutritional effectiveness, or practical performance of *C. ternatea*-derived interventions.

MATERIALS AND METHODS

Ethical approval

This study was conducted exclusively as a bibliometric analysis of previously published scientific literature and bibliographic metadata retrieved from the Scopus database. It did not involve the recruitment of human participants, experimentation on animals, collection of biological samples, or access to identifiable personal or confidential clinical information. All analyses were based on existing publication records, including bibliographic details, author affiliations, citation information, and keywords. Therefore, institutional ethical approval for research involving human or animal subjects was not required. The study was conducted using published information and bibliographic records within the scope of the database retrieval and analytical procedures described below.

Study period and location

The bibliographic search was conducted on March 18, 2026, and data extraction, screening, processing, and bibliometric analyses were performed between March and April 2026. The study covered publications indexed in Scopus from 1973, the earliest year represented in the eligible dataset, through March 18, 2026. As this investigation was based on an international bibliographic database, it was not restricted to a specific geographical study location. Geographical analyses were conducted using the institutional affiliations of authors contributing to the included publications. All citation counts, indexing information, and other database-dependent indicators corresponded to the retrieval date of March 18, 2026, and may differ in subsequent database searches because of continuing publication indexing and citation updates.

Study design

This study employed a retrospective, descriptive, and quantitative bibliometric design to characterize the global research landscape of *C. ternatea* within veterinary medicine and animal sciences. The analytical framework included identification and screening of relevant publications, extraction and standardization of bibliographic metadata, descriptive analysis of publication and citation indicators, assessment of geographical and institutional contributions, evaluation of international scientific collaboration, and construction of keyword co-occurrence networks.

The study population comprised English-language publications indexed in Scopus that addressed *C. ternatea* in relation to animal nutrition, veterinary applications, experimental animal models, animal reproduction, or animal-origin food quality and safety. Publications were selected using predefined inclusion and

exclusion criteria. Bibliometric indicators were used to describe research productivity, scientific influence, collaborative relationships, and thematic organization. Temporal analysis was undertaken to identify changes in the relative emphasis of research topics over the study period. The investigation was designed to characterize patterns within the published literature rather than to evaluate the biological efficacy or clinical effectiveness of *C. ternatea*-derived interventions.

Data source and search strategy

Bibliographic records were retrieved from the Scopus database (Elsevier B.V., Amsterdam, The Netherlands) on March 18, 2026. Scopus was selected because of its multidisciplinary coverage of veterinary medicine, animal science, food science, agricultural research, and related disciplines, together with its capacity to export standardized bibliographic metadata for quantitative analysis [16]. Although reliance on a single database may limit literature coverage, Scopus provides access to journals addressing tropical forage production, experimental animal pharmacology, and food packaging technologies, including agricultural and food technology publications that may not be comprehensively represented in biomedical databases.

The search strategy combined the scientific and common names of *C. ternatea* with descriptors associated with veterinary medicine, livestock production, animal nutrition, experimental animal research, and animal-origin food products. The following search string was applied:

(TITLE-ABS-KEY ("clitoria ternatea") OR TITLE-ABS-KEY ("butterfly pea")) AND (TITLE-ABS-KEY (forage OR legume OR pasture OR fodder OR silage OR ruminant OR livestock OR veterinar* OR poultry OR broiler OR chicken OR cattle OR bovine OR dairy OR cow OR buffalo OR goat OR sheep OR ovine OR caprine OR pig OR swine OR porcine OR rabbit OR fish OR aquaculture OR shrimp OR prawn OR meat OR beef OR pork OR carcass OR "egg yolk" OR milk OR sperm OR semen OR cryopreservation OR "animal model" OR rat OR rats OR mouse OR mice OR rumen OR "animal feed" OR "animal nutrition")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ch"))

The search strategy was pilot-tested against a reference set of 20 previously identified publications relevant to animal-oriented *C. ternatea* research, encompassing forage production, experimental pharmacology, and food packaging. All 20 publications were retrieved, supporting the sensitivity of the search strategy within this reference set.

Additional species-specific descriptors, including equine, horse, canine, dog, feline, cat, calf, lamb, kid, and duck, were not included in the primary search string because broader descriptors such as veterinary, livestock, poultry, "animal model", "animal feed", and "animal nutrition" were considered sufficient to capture relevant publications. A supplementary search incorporating these additional terms did not identify further eligible records (Supplementary Table S5).

No publication date restriction was applied during database retrieval. The earliest eligible publication identified was from 1973. Bibliographic records were exported in comma-separated values (CSV) format and included publication titles, author names, Scopus Author IDs, institutional affiliations, abstracts, author keywords, indexed keywords, source titles, document types, publication years, citation counts, digital object identifiers (DOIs), and funding information.

Inclusion, exclusion, and screening

Publications were eligible for inclusion when they met the following criteria: (i) the title, abstract, or keywords contained *C. ternatea* or its common name, butterfly pea; (ii) the publication addressed a topic relevant to veterinary medicine or animal sciences, including forage and animal feed research, production-animal or laboratory-animal investigations, animal reproduction, animal-model pharmacology, or animal-origin food quality and safety; and (iii) the publication was available in English.

Research on intelligent packaging materials was considered eligible when the application specifically involved animal-origin foods, including meat, fish, dairy products, or eggs. Publications were excluded if they were retracted articles, notes, errata, or editorials, or if their primary focus was plant biology, plant pathology, human clinical research, or materials science without a relevant connection to animal-origin products. Publications that mentioned *C. ternatea* without addressing an eligible veterinary or animal science topic were also excluded.

The initial Scopus retrieval yielded 1,466 records after applying the predefined language and document-type restrictions. No duplicate records were identified by Scopus. Titles and abstracts of all 1,466 records were screened against the eligibility criteria, resulting in the exclusion of 1,148 records. The remaining 318 publications were included in the bibliometric analysis.

Records with uncertain eligibility, including publications mentioning *C. ternatea* only as an example of the Fabaceae family or studies primarily addressing peptide engineering without a relevant animal science application, were independently evaluated by two reviewers. Disagreements were resolved through discussion. Inter-reviewer agreement for the ambiguous subset was high, and any disagreements were resolved through discussion.

The publication identification, screening, and inclusion process is presented in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram (Figure 1) [17, 18]. The screened bibliographic dataset is provided in Supplementary Data S1.

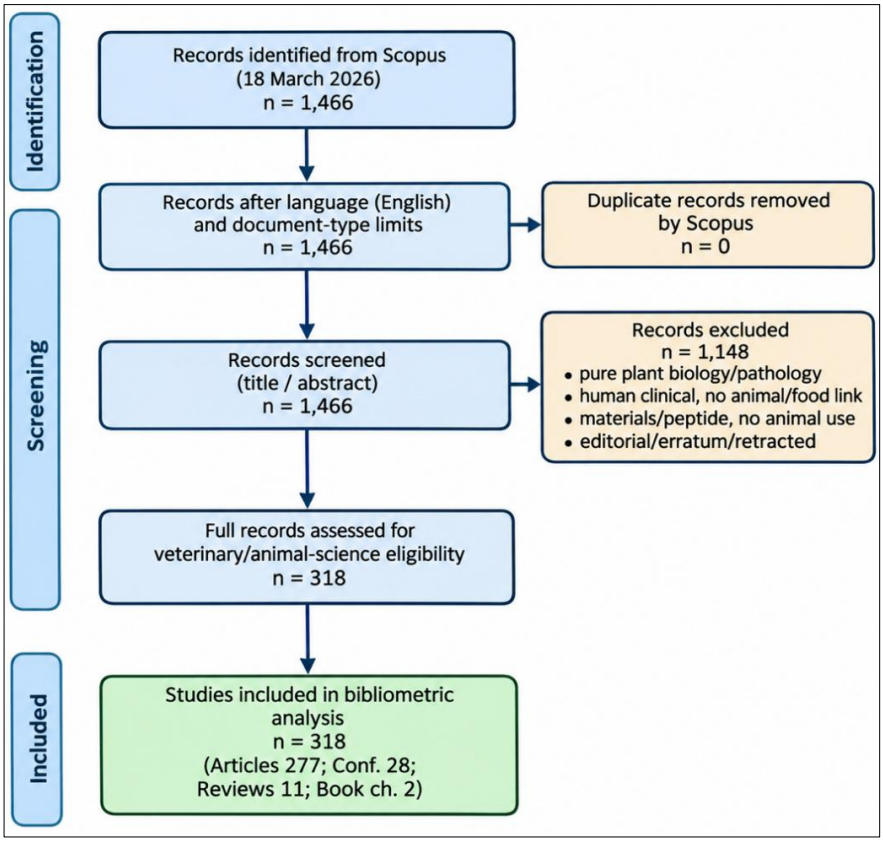


Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram illustrating the identification, screening, and inclusion of publications.

Bibliometric and statistical analysis

Data processing and analytical software: The final dataset comprised 318 publications. Descriptive bibliometric analyses were performed using Microsoft Excel 365 (Microsoft Corporation, Redmond, WA, USA) and Python 3.11.15 (Python Software Foundation), incorporating pandas 3.0.2, numpy 2.4.4, matplotlib 3.10.9, and networkx 3.6.1. The web addresses of the software and libraries used are as follows: Microsoft Excel (https://www.microsoft.com/microsoft-365/excel), Python (https://www.python.org), pandas (https://pandas.pydata.org), NumPy (https://numpy.org), Matplotlib (https://matplotlib.org), and NetworkX (https://networkx.org). A reproducible computational environment file containing the software dependencies and versions is provided in Supplementary Data S4.

Keyword co-occurrence networks were additionally visualized using VOSviewer 1.6.20 (Leiden University, Leiden, The Netherlands; https://www.vosviewer.com), with the full counting method applied to keyword relationships [19]. The analyses included publication trends, citation indicators, geographical and institutional productivity, author contributions, international collaboration, thematic clustering, and temporal changes in research emphasis.

Publication trends and citation indicators: Annual publication counts were calculated for the period 1973–2026. Because the database search was conducted on March 18, 2026, publication records for 2026 represented an incomplete year. Consequently, 2026 was excluded from publication trend modeling and identified separately in the corresponding figures.

Linear, exponential, and polynomial models were evaluated to describe changes in annual publication

output. An exponential model provided a balance between goodness of fit and interpretability for the period 2000–2025, yielding an estimated annual growth rate of approximately 14% and a coefficient of determination (R^2) of 0.88. A higher-order polynomial model of degree six produced a slightly higher R^2 of approximately 0.92 but was considered less interpretable and potentially unstable for extrapolation.

Accordingly, the exponential model was used to characterize historical publication growth, while a lower-order polynomial was retained only as a descriptive visual smoother. No forecasts of future publication output were derived from these models. Cumulative publication counts were presented descriptively rather than fitted using a linear cumulative model because the observed trajectory showed accelerating growth (Figure 2).

Citation indicators included the total number of citations, mean citations per publication, and the h-index of the included publication corpus. For the most frequently cited publications, both total citations and citations per year were reported to facilitate comparison across publication periods and reduce the influence of differences in citation accumulation time. Citations per year were calculated as the total number of citations divided by the number of years since publication, defined as (2026 − publication year + 1).

Geographical distribution and international collaboration: Country information was extracted from institutional affiliation metadata. The country of affiliation was initially identified using the final comma-separated component of each affiliation record, followed by manual verification against the complete affiliation information. Country names were standardized to reconcile spelling variants and alternative geographical designations, including "USA" and "United States" and "Viet Nam" and "Vietnam."

Country-level publication productivity was calculated using full counting. Under this approach, each country received one publication count when at least one author of a publication was affiliated with an institution in that country. Publications involving authors from multiple countries therefore contributed to the publication totals of all participating countries.

Internationally collaborative publications were defined as those involving authors affiliated with institutions in at least two different countries. Country co-authorship relationships were examined to characterize the geographical structure of scientific collaboration and identify frequently occurring international research partnerships.

Institutional and author productivity: Author productivity was assessed using Scopus Author IDs to distinguish researchers with similar names or initials and reduce errors associated with author-name ambiguity. Author-level publication counts were calculated after disambiguation using these identifiers.

Institutional affiliations were standardized to account for variations in institutional names, abbreviations, spelling conventions, organizational changes, and campus designations. Publication counts were subsequently aggregated to identify institutions contributing most frequently to the included research literature.

Keyword normalization and co-occurrence analysis: Author keywords and indexed keywords were combined to construct the keyword dataset. All keywords were converted to lowercase, and terminology was standardized using a custom thesaurus to reconcile singular and plural forms, spelling variants, and synonymous expressions. Examples included anthocyanin/anthocyanins, flavonoid/flavonoids, legume/legumes/Fabaceae, rat/rats, and mouse/mice.

Because author keywords and indexed keywords originate from different indexing processes, an additional analysis was conducted using author keywords alone. This analysis reproduced the same five broad thematic categories, allowing comparison with the network constructed from the combined keyword dataset.

Generic indexing and methodological descriptors, including article, nonhuman, animal experiment, controlled study, male, and female, were removed to reduce the influence of nonspecific terms. The complete keyword thesaurus, excluded-term list, and standardized keyword dataset are provided in Supplementary Data S2–S3.

Keywords occurring at least eight times were retained for network construction, resulting in 112 terms. Co-occurrence relationships were retained when the edge weight was at least three. These thresholds were selected to balance thematic coverage with network interpretability.

A sensitivity analysis was performed by varying the minimum keyword occurrence threshold from 6 to 10 and the minimum edge weight threshold from 2 to 4. The resulting networks produced solutions containing four or five thematic clusters, indicating that the broad thematic structure was relatively stable across the evaluated parameter settings (Supplementary Table S6).

Thematic clustering and network analysis: Thematic communities were identified using weighted greedy modularity-based community detection based on the Clauset–Newman–Moore algorithm [20]. The analysis was

implemented in NetworkX using the networkx.algorithms.community.greedy_modularity_communities function on an undirected, edge-weighted keyword co-occurrence graph with a resolution parameter of 1.

The algorithm was applied deterministically, and no random seed was required. The resulting network partition comprised five thematic communities, with an overall modularity value of Q = 0.33.

Thematic labels were assigned by consensus between two authors after examining the most frequently occurring keywords within each community. These labels were independently cross-checked, and ambiguous terms were assigned according to their strongest co-occurrence relationships within the identified communities.

Temporal evolution of research themes: Temporal changes in research emphasis were examined using keyword overlay analysis. The mean publication year was calculated for each retained keyword based on the publication years of the documents in which the keyword occurred.

These mean publication years were incorporated into the keyword co-occurrence network to visualize the relative temporal distribution of research topics [10, 19]. The resulting overlay was used to distinguish comparatively recent research interests from established themes and to describe changes in the relative prominence of different research areas over time.

The temporal analysis was interpreted descriptively. A more recent mean publication year was considered indicative of comparatively recent research activity rather than evidence that earlier research themes had ceased or been replaced.

RESULTS

Publication trends

A total of 318 publications on *C. ternatea* relevant to veterinary and animal sciences, published between 1973 and March 2026, met the inclusion criteria. Research articles constituted the largest proportion of the dataset (277/318; 87.1%), followed by conference papers (28/318; 8.8%), review articles (11/318; 3.5%), and book chapters (2/318; 0.6%).

Annual publication output remained relatively low until the mid-2000s, followed by an acceleration after 2010, reaching a peak of 45 publications in 2024 (Figure 2). Publication growth during 2000–2025 was approximately exponential, with an estimated annual growth rate of 14% and a coefficient of determination of R^2 = 0.88. Because the database search was conducted on March 18, 2026, the 14 publications indexed for 2026 represented an incomplete year and were excluded from the growth model.

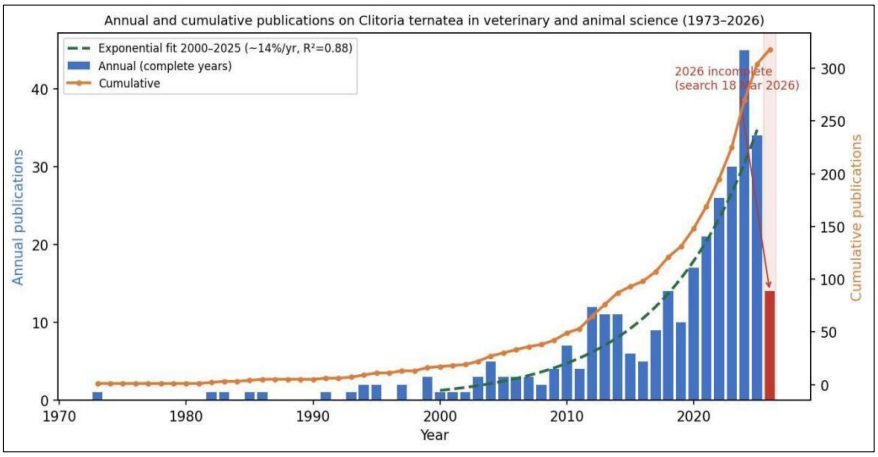


Figure 2: Annual and cumulative publication trends for *Clitoria ternatea* research in veterinary and animal sciences from 1973 to 2026 (n = 318). Bars represent annual publication counts, and the orange line indicates cumulative publications. The dashed green line represents the exponential growth model fitted to complete publication years (2000–2025). The red bar and shaded region identify 2026 as an incomplete publication year. Publications indexed in 2026 were excluded from growth modeling.

Of the 318 publications, 170 (53.5%) appeared between 2021 and March 2026, indicating a substantial concentration of research activity in recent years. The included publications accumulated 4,991 citations, with a mean of 15.7 citations per publication, a median of 6 citations, and a corpus h-index of 34. In addition, 142 publications (44.7%) were open access, and 146 (45.9%) included funding information.

Geographic distribution and international collaboration

The included publications involved contributions from 51 countries across five continents (Figure 3). India

was the leading contributor, with 91 publications (28.6%), followed by Indonesia (66; 20.8%), Australia (32; 10.1%), Thailand (26; 8.2%), Brazil (25; 7.9%), Malaysia (25; 7.9%), China (16; 5.0%), and the United States (12; 3.8%).

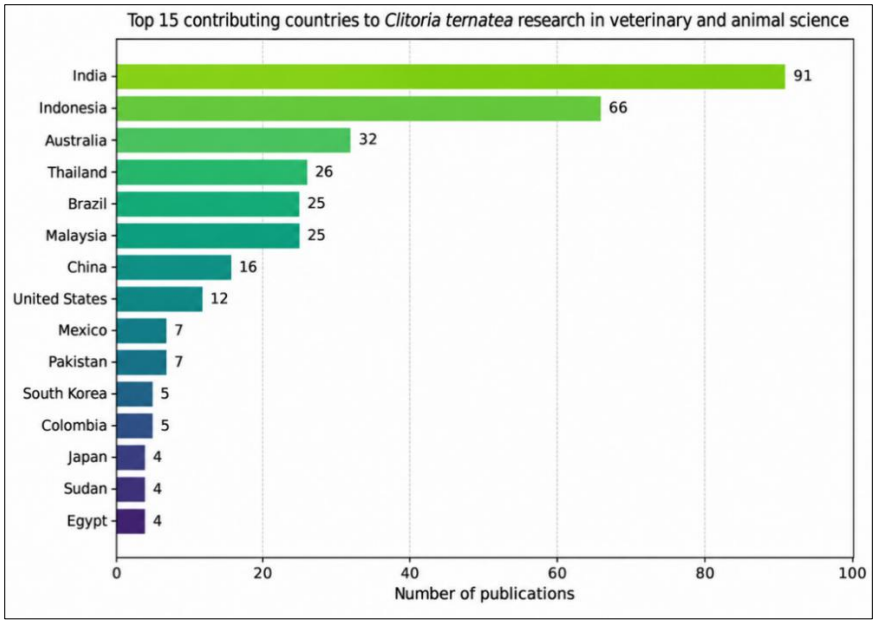


Figure 3: Fifteen leading contributing countries to *Clitoria ternatea* research in veterinary and animal sciences. Country-level publication counts were calculated using full counting of all author affiliations. Each country received one publication count for every document involving at least one author affiliated with an institution in that country. Consequently, publications involving multiple countries contributed to the totals of all participating countries.

Country-level productivity was calculated using full counting of author affiliations, whereby each country represented in a publication received one publication count. Consequently, internationally coauthored publications contributed to the totals of all participating countries, and the combined country-level counts could exceed the total number of included publications.

The geographical distribution showed substantial research contributions from South and Southeast Asia, together with notable contributions from Australia and Brazil. Publications associated with African institutions were comparatively limited, with approximately 17 documents involving affiliations from countries such as Egypt, Nigeria, Kenya, Ethiopia, and Tanzania. None of these countries ranked among the leading contributors.

International collaboration appeared in 63 of 318 publications (19.8%), indicating that most publications involved authors affiliated with institutions within a single country. The country coauthorship network showed a relatively sparse distribution of international collaborative relationships, with several prominent bilateral connections (Figure 4).

The strongest collaborative relationship was between Australia and Pakistan, involving six jointly authored publications, followed by Australia and Indonesia, with three publications. Additional bilateral collaborations, each represented by two publications, included Australia–India, India–United States, Japan–Thailand, and South Korea–Thailand. Overall, international collaboration was concentrated among a limited number of country pairs, whereas broader cross-continental connections were less frequently represented.

Institutional and author productivity

After standardizing institutional affiliations, Khon Kaen University, Thailand, was the most productive institution, contributing eight publications. Jiangsu University, China, and Universiti Sains Malaysia each contributed seven publications, followed by the Indian Grassland and Fodder Research Institute of the Indian Council of Agricultural Research (ICAR), India, and The University of Queensland, Australia, with six publications each. The Research Center for Animal Husbandry and Universitas Gadjah Mada, both in Indonesia, contributed five publications each.

The leading institutions represented several research areas within the dataset. Jiangsu University was associated with intelligent food packaging research, whereas Universiti Sains Malaysia and Khon Kaen University contributed to animal-model pharmacology. The Indian Grassland and Fodder Research Institute and The University of Queensland were associated with tropical forage and pasture research.

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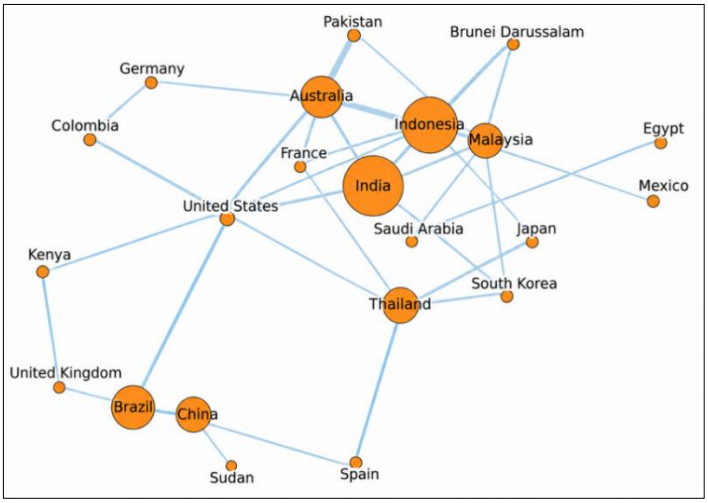


Figure 4: Country coauthorship collaboration network for *Clitoria ternatea* research in veterinary and animal sciences, including countries contributing at least three publications. Node size is proportional to the number of publications associated with each country, while edge width represents the number of jointly authored publications between countries. Internationally collaborative publications accounted for 19.8% of the analyzed dataset. Detailed bilateral collaboration counts and total link strengths are provided in Supplementary Data S7.

The 20 most productive authors contributed between four and seven publications each after author-name disambiguation using Scopus Author IDs (Figure 5). Asad Shabbir (Scopus Author ID: 13604877500) was the most productive author, contributing seven publications, primarily associated with Australian tropical pasture research.

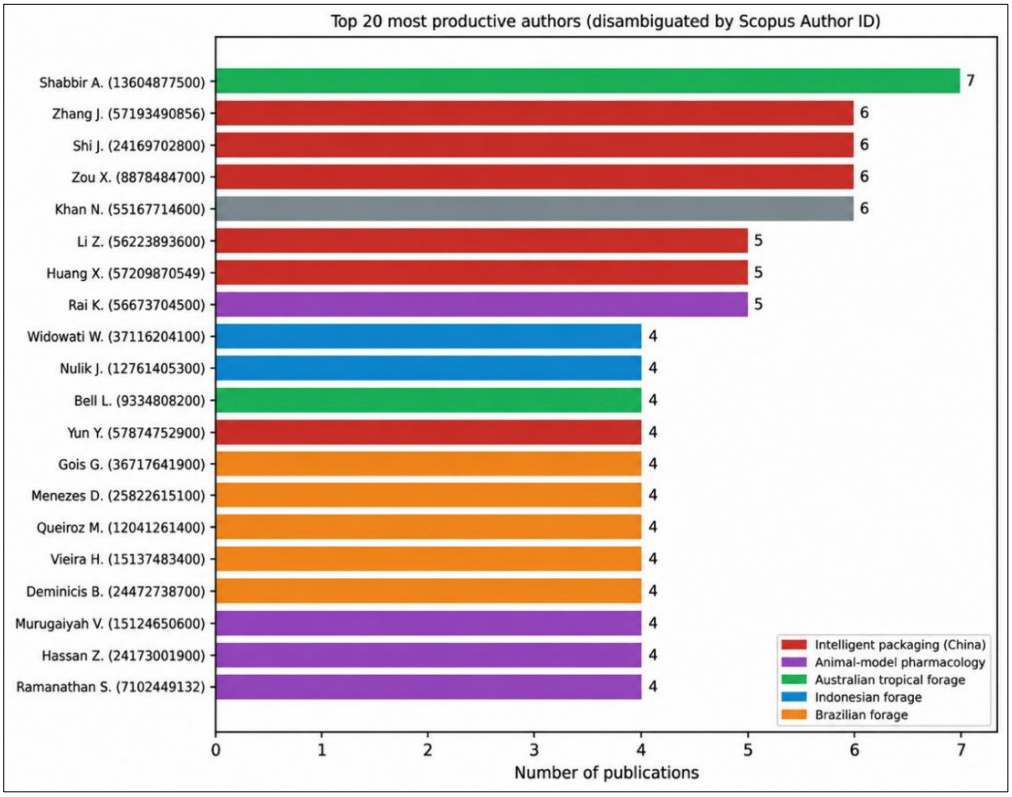


Figure 5: Twenty most productive authors contributing to *Clitoria ternatea* research in veterinary and animal sciences. Author identities were disambiguated using Scopus Author IDs, which are displayed in parentheses. Author productivity is represented by publication counts, while colors distinguish the research communities associated with the authors.

Junjun Zhang (Scopus Author ID: 57193490856), Jiyong Shi (24169702800), and Xiaobo Zou (8878484700) each contributed six publications and were associated with research on intelligent packaging technologies. Other contributing researchers included Kiranmai S. Rai and Vikneswaran Murugaiyah in animal-model pharmacology; Wahyu Widowati and Jacob Nulik in Indonesian forage-related research; and B.B. Deminicis and H.D. Vieira in Brazilian forage research.

No individual author contributed more than seven publications to the included dataset. Author productivity

was therefore distributed across multiple research groups rather than concentrated among a small number of highly prolific researchers.

Leading journals and most-cited publications

The 318 publications were distributed across more than 200 publication outlets, reflecting the multi-disciplinary scope of *C. ternatea* research relevant to veterinary and animal sciences. The 10 most productive journals and publication outlets are presented in Table 1.

Table 1: Ten most productive publication outlets for *Clitoria ternatea* research in veterinary and animal sciences (n = 318).

Rank	Publication outlet	Publisher	Publications (n)
1	IOP Conference Series: Earth and Environmental Science	IOP Publishing	12
2	International Journal of Biological Macromolecules	Elsevier	10
3	Journal of Ethnopharmacology	Elsevier	7
4	Asian Journal of Pharmaceutical and Clinical Research	Innovare Academic Sciences	5
5	Current Research in Food Science	Elsevier	4
5	Tropical Grasslands-Forrajes Tropicales	CIAT	4
5	AIP Conference Proceedings	AIP Publishing	4
5	Livestock Research for Rural Development	CIPAV	4
5	Food Chemistry	Elsevier	4
5	Food Research	Rynnye Lyan Resources	4

CIAT = Centro Internacional de Agricultura Tropical; CIPAV = Centro para la Investigación en Sistemas Sostenibles de Producción Agropecuaria; n = Number of publications. Rankings are based on publication counts using competition ranking, with equal ranks assigned to outlets having identical publication counts. The dataset comprised 318 eligible publications, and the table presents the 10 most productive outlets.

These outlets represented three principal publication categories: veterinary and animal science journals, food science and technology journals, and multidisciplinary or conference-based outlets. Animal science publications appeared in journals such as *Tropical Grasslands-Forrajes Tropicales* and *Livestock Research for Rural Development*. Research involving anthocyanin-based intelligent packaging was represented in journals including *International Journal of Biological Macromolecules*, *Food Chemistry*, *Current Research in Food Science*, and *Food Research*.

The 10 most-cited publications are presented in Table 2, together with their total citation counts and citations per year to facilitate comparisons across publication periods. These publications comprised five studies on intelligent packaging technologies published during 2021–2024, two animal-model pharmacology investigations published in 2003, one study on cyclotide-bearing C. ternatea published in 2019, one review of Australian pasture legumes published in 2007, and one study on the silage quality of tropical forage legumes published in 2012.

Table 2: Ten most-cited publications on *Clitoria ternatea* research in veterinary and animal sciences, with citation counts and annual citation rates as of March 18, 2026.

Research topic	Publication source	Citations (n)	Citations/year	Reference
Gelatin/agar colorimetric indicator film	Food Hydrocolloids	215	43.0	[6]
Effects of *C. ternatea* on the central nervous system	Pharmacology Biochemistry and Behavior	186	7.8	[5]
Cyclotide-containing *C. ternatea*	Frontiers in Plant Science	180	22.5	[7]
Review of Australian pasture legumes	Field Crops Research	180	9.0	[22]
pH-sensitive starch/carbon dot film	Food Control	169	28.2	[36]
Sugarcane wax/agar-based pH-sensitive film	Food Chemistry	118	23.6	[31]
Chitosan/gelatin-based freshness indicator film	Food Hydrocolloids	116	38.7	[35]
Sodium alginate-based active and intelligent film	International Journal of Biological Macromolecules	110	22.0	[32]
Anti-inflammatory activity of *C. ternatea* root	Fitoterapia	109	4.5	[38]
Silage quality of tropical legumes	Animal Feed Science and Technology	99	6.6	[25]

n = Number of citations. Citation counts correspond to the Scopus retrieval date of March 18, 2026. Annual citation rates are presented to facilitate comparisons among publications of different ages. Publication source titles are written in full. The citation counts and annual citation rates have been retained as reported in the original dataset.

Recent publications on intelligent packaging showed particularly high annual citation rates, with two leading studies receiving 43.0 and 38.7 citations per year, respectively. In comparison, the older animal-model pharmacology publications accumulated approximately 3.8–7.8 citations per year. These findings indicate

differences in citation accumulation rates among the represented research themes and publication periods.

Keyword co-occurrence and thematic clusters

A total of 112 keywords met the minimum occurrence threshold of eight and were retained for keyword co-occurrence analysis. Weighted greedy modularity-based community detection identified five thematic clusters, with an overall network modularity of Q = 0.33 (Figure 6 and Table 3).

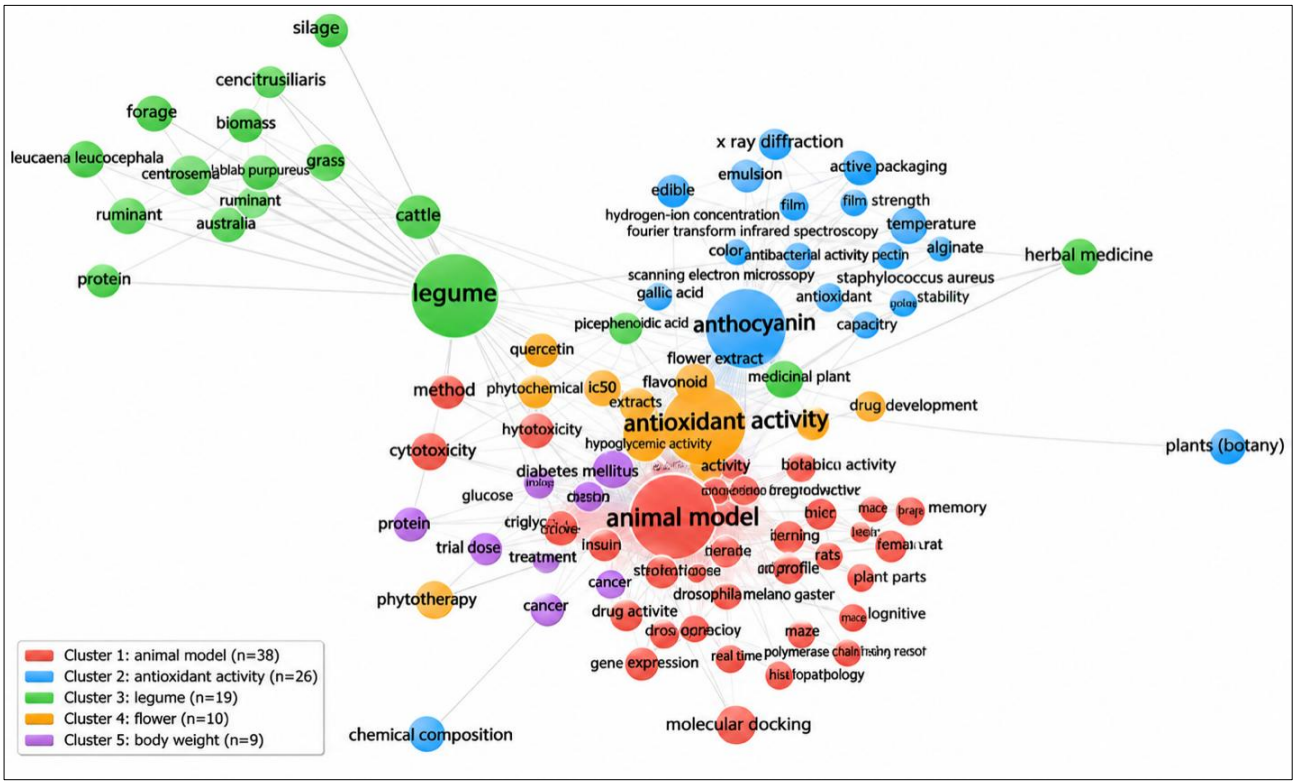


Figure 6: Keyword co-occurrence network of *Clitoria ternatea* research in veterinary and animal sciences. Keywords occurring at least eight times were retained for network analysis. Node size is proportional to keyword occurrence frequency, while node colors represent the five thematic clusters identified through weighted modularity-based community detection (Q = 0.33). For visual clarity, labels are displayed only for frequently occurring keywords, although all retained nodes were included in the network analysis.

Table 3: Thematic clusters identified through modularity-based community detection of the keyword co-occurrence network for *Clitoria ternatea* research in veterinary and animal sciences (five communities; overall network modularity Q = 0.33).

Cluster	Research theme	Representative keywords	Terms (n)
1	Animal-model pharmacology and toxicology	Animal model; rat; animal tissue; oxidative stress; plant root; histopathology; superoxide dismutase; Sprague-Dawley; neuroprotective agent	47
2	Anthocyanin-based intelligent packaging and antimicrobial activity	Anthocyanin; colorimetry; pH; Fourier-transform infrared spectroscopy; food packaging; antibacterial activity; *Escherichia coli*; color; scanning electron microscopy	27
3	Tropical forage legume and ruminant nutrition	Legume; pasture; *Centrosema*; *Lablab purpureus*; *Leucaena leucocephala*; cattle; grass; forage; biomass	21
4	Phytochemistry and bioactive characterization	Flower; flavonoid; phytochemistry; IC_{50}; ascorbic acid; alkaloid; quercetin; phenol derivative	9
5	Antidiabetic and metabolic animal models	Diabetes mellitus; body weight; antidiabetic activity; glucose; cholesterol; triacylglycerol; streptozotocin	8

IC_{50} = Half-maximal inhibitory concentration; n = Number of keywords assigned to each cluster; pH = Potential of hydrogen; Q = Network modularity. The five thematic clusters were identified using weighted greedy modularity-based community detection. The term counts represent the number of retained keywords assigned to each cluster (total = 112). Representative keywords are shown for each community. Keyword normalization was performed using the predefined thesaurus and stop list described in Supplementary Data S2–S3.

The identified clusters were characterized as follows:

1. Animal-model pharmacology and toxicology: This cluster included keywords associated with experimental animal models, oxidative stress, histopathology, superoxide dismutase, and neuroprotective activity. Representative terms included animal model, rat, Sprague-Dawley, oxidative stress, histopathology, and neuroprotective agent.

2. Anthocyanin-based intelligent packaging and antimicrobial activity: This cluster comprised terms related to anthocyanins, colorimetric indicators, packaging materials, and antimicrobial investigations. Representative keywords included anthocyanin, colorimetry, pH, Fourier-transform infrared spectroscopy, scanning electron microscopy, intelligent packaging, *Escherichia coli*, and *Staphylococcus aureus*.
3. Tropical forage legume and ruminant nutrition: This cluster included keywords associated with pasture development, forage biomass, and livestock nutrition. Representative terms included legume, pasture, *Centrosema*, *Lablab purpureus*, *Leucaena leucocephala*, cattle, forage, and biomass.
4. Phytochemistry and bioactive characterization: This cluster was characterized by keywords related to phytochemical composition and bioactive constituents, including flavonoid, phytochemistry, half-maximal inhibitory concentration (IC_{50}), ascorbic acid, alkaloid, and quercetin.
5. Antidiabetic and metabolic animal models: This cluster included keywords associated with experimental metabolic disorders and related biochemical outcomes, including diabetes mellitus, antidiabetic activity, streptozotocin, glucose, and cholesterol.

The overall modularity value of Q = 0.33 indicated a detectable community structure within the keyword co-occurrence network, with thematic differentiation alongside connections among research areas. The five identified clusters collectively represented the principal research directions within the included publication dataset.

Temporal shift in relative research emphasis

Temporal overlay analysis of the keyword co-occurrence network identified differences in the mean publication years of keywords associated with the five thematic clusters (Figure 7).

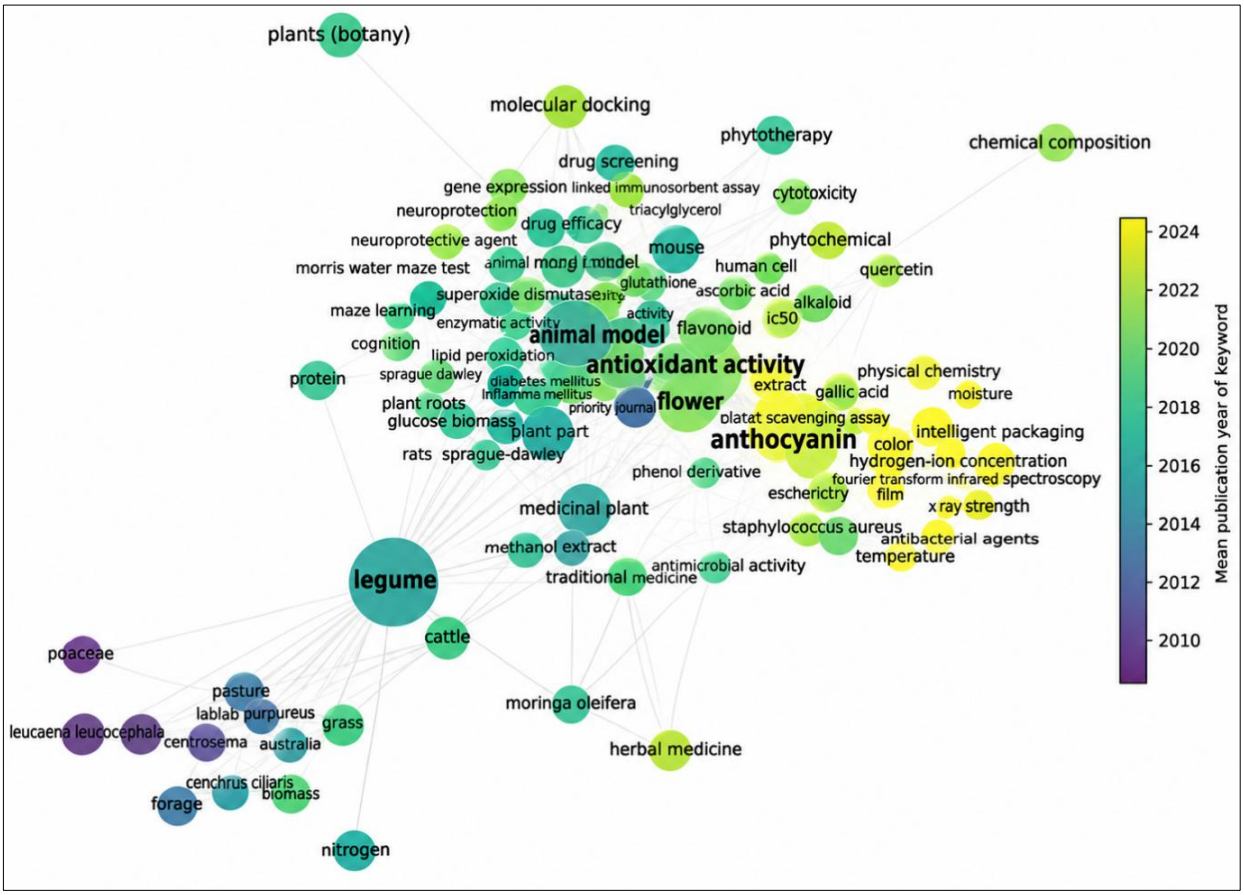


Figure 7: Temporal overlay visualization of the keyword co-occurrence network for *Clitoria ternatea* research in veterinary and animal sciences. Node colors represent the mean publication year of documents containing each keyword. Earlier mean publication years are indicated by dark blue to purple, whereas more recent mean publication years are represented by bright yellow. The mean publication year was calculated as the unweighted arithmetic mean of the publication years of all documents containing the corresponding keyword. The overlay illustrates changes in the relative temporal distribution of research topics.

Keywords related to tropical forage research, including *Centrosema*, *L. leucocephala*, pasture, biomass, and forage, were associated with comparatively earlier mean publication years, approximately 2008–2012. These

findings indicated that tropical forage and pasture research represented an established component of the *C. ternatea* literature.

Keywords associated with animal-model pharmacology, including Wistar rat, Sprague-Dawley, Morris water maze, and streptozotocin, were concentrated around mean publication years of approximately 2014–2018. This distribution indicated relatively later research activity in experimental pharmacology and related animal-model investigations.

More recent mean publication years, approximately 2020–2024, were associated with keywords related to anthocyanin chemistry, colorimetric indicators, and intelligent packaging. These findings indicated that intelligent packaging and related food technology applications were comparatively recent research emphases in the analyzed dataset.

Overall, the temporal overlay showed a shift in research emphasis from tropical forage and pasture studies to experimental animal pharmacology and, more recently, anthocyanin-based intelligent packaging applications. However, the temporal distribution reflected differences in the mean publication years of keywords rather than the discontinuation or replacement of earlier research areas. Forage-related investigations and animal-model pharmacology remained represented alongside the more recent packaging-oriented research.

DISCUSSION

The present bibliometric analysis provides a systematic overview of the development, geographical distribution, collaborative structure, and thematic evolution of *C. ternatea* research relevant to veterinary medicine and animal sciences. Three principal findings emerged. First, publication activity increased substantially, particularly during the most recent five years of the study period, with research contributions concentrated in tropical and subtropical countries. Second, the literature was organized into five interconnected thematic clusters, with animal-model pharmacology, tropical forage and livestock nutrition, and anthocyanin-based intelligent packaging representing prominent research directions. Third, temporal keyword analysis indicated a shift in relative research emphasis from forage and pasture investigations toward experimental pharmacology and, more recently, intelligent packaging applications involving animal-origin foods.

These findings characterize the organization and development of the existing scientific literature rather than directly establishing the biological efficacy, nutritional benefits, clinical effectiveness, or food safety performance of *C. ternatea*-derived interventions. Accordingly, the implications discussed below distinguish bibliometric observations from findings reported in individual experimental studies and recommendations for future research.

Expansion of research activity and geographical concentration

The substantial increase in publication output demonstrates growing scientific interest in *C. ternatea* across veterinary and animal-oriented disciplines. More than half of the included publications (53.5%) appeared between 2021 and March 2026, while annual publication output increased by approximately 14% during 2000–2025. This pattern is consistent with the broader expansion of research on medicinal plants, phytochemicals, and related biological applications reported in previous bibliometric investigations [10, 21]. Nevertheless, publication growth should be interpreted as an indicator of increasing research activity rather than direct evidence of improvements in scientific quality, experimental rigor, or practical applicability.

The geographical distribution revealed a concentration of research contributions in India, Indonesia, Australia, Thailand, Brazil, and Malaysia. The prominent contributions of India and Indonesia are consistent with the geographical distribution and traditional applications of *C. ternatea*, whereas research activity in Australia and Brazil coincides with established investigations of tropical forage legumes and pasture systems [22, 23]. These relationships provide relevant geographical and disciplinary context but do not establish causal explanations for differences in national research productivity.

International collaboration was comparatively limited, with only 19.8% of publications involving authors affiliated with institutions in two or more countries. This proportion was lower than the approximately 35%–50% reported for some established veterinary research fields [24]. The country coauthorship network also showed relatively few international connections, with collaborative relationships concentrated among a limited number of participating countries. Together, these findings suggest opportunities to strengthen international research partnerships and improve the integration of geographically dispersed research communities.

The relatively limited representation of African institutions is noteworthy because tropical forage legumes may be relevant to livestock production systems facing seasonal feed shortages and climatic variability. However,

the observed geographical distribution may also reflect differences in database coverage, publication language, research infrastructure, and indexing practices. Consequently, low publication counts should not be interpreted as evidence of limited scientific activity or research capacity without additional information.

Greater collaboration among research institutions in Southeast Asia, Africa, Australia, and Latin America could facilitate comparative investigations under different agroecological conditions. In particular, coordinated research programs could support the harmonization of forage evaluation methods, nutritional assessment procedures, rumen fermentation measurements, and animal feeding trials. These opportunities represent recommendations informed by the geographical and collaborative patterns identified in the bibliometric analysis rather than outcomes directly demonstrated by the present study.

Tropical forage potential and climate resilience in livestock production

The tropical forage and ruminant nutrition cluster represents an established component of *C. ternatea* research, reflecting the longstanding interest in this species as a forage legume for livestock production. Previous studies have reported crude protein concentrations of approximately 16%–25% of dry matter and evaluated its suitability for cattle, goats, and sheep in forage systems, including hay and silage production [22, 25, 26]. These findings provide a biological and agricultural context for the prominence of forage-related keywords in the bibliometric network.

The potential contribution of *C. ternatea* to climate-resilient livestock production is particularly relevant in tropical regions where seasonal rainfall variability and fluctuations in forage availability may constrain animal nutrition. Its reported tolerance to heat and moisture limitations, together with its capacity for biological nitrogen fixation as a legume, supports continued investigation of its suitability for diversified forage systems. However, the magnitude and consistency of these advantages depend on environmental conditions, management practices, and the characteristics of individual production systems.

Improved forage quality may support more efficient nutrient use and higher livestock productivity. Nevertheless, potential effects on enteric methane emissions should be evaluated through controlled experimental investigations rather than inferred from forage composition or bibliometric trends alone. Previous assessments of livestock greenhouse gas mitigation provide a broader context for evaluating dietary interventions, but they do not independently establish methane mitigation by *C. ternatea* [27].

Research involving *C. ternatea* has also extended beyond ruminant production to applications in monogastric animals, including investigations involving butterfly pea supplementation in broiler diets [28, 29]. Such studies indicate an expansion in the range of animal production systems represented in the literature. However, the relevance of these applications should be evaluated using species-specific nutritional requirements, inclusion levels, feed composition, and experimentally measured production outcomes.

The geographical and thematic distribution of forage research reflects contributions from Australian, Indonesian, and Brazilian research groups investigating tropical pasture and livestock production systems [23, 30]. Further progress would benefit from standardized reporting of forage composition, antinutritional factors, digestibility, feed intake, and animal performance. Long-term feeding trials, particularly in dairy and other production-animal systems, are also needed to clarify the nutritional value, practical feasibility, and consistency of responses to *C. ternatea*-based feeding strategies.

Additional investigations of rumen fermentation, nutrient utilization, and methane production under controlled *in vivo* conditions would help establish whether the species provides measurable environmental benefits beyond its potential nutritional contribution. These priorities arise from identified research themes and gaps in the broader literature, not from direct experimental findings from the present bibliometric study.

Anthocyanin-based intelligent packaging and animal-origin food quality

Anthocyanin-based intelligent packaging emerged as one of the most recent and citation-intensive research areas in the analyzed literature. This thematic cluster reflects growing interest in natural colorimetric indicators derived from *C. ternatea* flowers for monitoring the freshness and quality of animal-origin foods.

The flowers contain acylated anthocyanins, particularly ternatins, that change color in response to pH variations. Researchers have investigated these properties to develop indicator materials that respond to chemical changes associated with food deterioration [6, 31–34]. These applications are primarily in food science and technology, although they also relate to veterinary public health and animal-origin food quality.

Experimental studies have incorporated *C. ternatea* anthocyanins into packaging matrices containing chitosan, gelatin, starch, alginate, and cellulose-based materials. Researchers have investigated these systems for

monitoring freshness changes in products such as chicken, beef, fish, shrimp, and milk [6, 32, 35, 36]. The diversity of packaging materials and food products represented in the literature illustrates the multidisciplinary nature of this research cluster.

The comparatively high annual citation rates of recent intelligent packaging studies indicate substantial scientific attention to this research direction. However, citation frequency is influenced by publication age, disciplinary citation practices, and research visibility. It should not be interpreted as direct evidence of superior technological performance, commercial feasibility, regulatory acceptance, or practical implementation.

Despite the growing literature, several issues require further investigation before these technologies can be widely applied to animal-origin food monitoring. Many experimental studies have evaluated packaging performance under laboratory conditions, whereas evidence from commercial processing, transportation, retail storage, and integrated cold-chain environments remains comparatively limited.

Another important consideration is the relationship between colorimetric responses and microbiological food safety. Changes in packaging indicator color may reflect chemical or biochemical alterations associated with spoilage, but they do not necessarily provide direct evidence of pathogen contamination or establish microbiological safety. Accordingly, future investigations should evaluate indicator responses alongside quantitative microbiological measurements, including aerobic plate counts and assessments of relevant foodborne pathogens such as *Salmonella* spp. and *Listeria monocytogenes*.

The migration of anthocyanins and other packaging constituents into food products, material stability, reproducibility of color responses, and performance under variable storage conditions also require systematic assessment. These factors are particularly relevant when considering the translation of experimental packaging prototypes into practical food monitoring systems.

From a One Health perspective, the potential relevance of this research lies in its connection to animal-origin food quality, food loss prevention, and consumer protection. Nevertheless, the present bibliometric findings highlight the prominence and growth of intelligent packaging research but do not confirm its effectiveness in reducing foodborne disease or improving public health outcomes.

Animal-model pharmacology and veterinary translation

Animal-model pharmacology and toxicology was the largest thematic cluster by keyword count, indicating substantial research activity investigating *C. ternatea*-derived preparations and their biological effects. Previous studies have examined outcomes associated with hepatoprotection, antidiabetic activity, neuroprotection, inflammation, and oxidative stress, primarily using rodent and fish models [5, 37–39].

The prominence of experimental animal models demonstrates the importance of preclinical investigations within the broader *C. ternatea* literature. However, laboratory animal studies should be distinguished from studies that directly evaluate therapeutic efficacy, safety, or clinical outcomes in veterinary patients.

The bibliometric analysis identified comparatively limited representation of controlled clinical or field investigations involving production animals and companion animals. This observation suggests a gap between experimental pharmacological research and its potential translation into veterinary applications. Nevertheless, the presence or absence of specific study types in the analyzed dataset should be interpreted in light of the database coverage and eligibility criteria used in this investigation.

Experimental findings on antioxidant, anti-inflammatory, neuroprotective, or metabolic outcomes may support further veterinary research. However, biological responses observed in laboratory models cannot be assumed to occur consistently in other animal species because of differences in physiology, metabolism, exposure, disease mechanisms, and treatment conditions.

Similarly, findings from individual toxicological studies cannot establish a general safety profile for all *C. ternatea* preparations, extracts, or administration routes. Veterinary applications would require appropriate characterization of plant materials, standardization of bioactive constituents, dose-response evaluation, species-specific safety assessment, and controlled investigations of clinically relevant outcomes.

Future investigations could include metabolic disorders in companion animals, inflammatory conditions in livestock, and other veterinary health problems for which existing experimental evidence supports a biologically plausible rationale. However, specific applications, such as poultry coccidiosis or bovine mastitis, should be considered exploratory rather than as demonstrated indications for *C. ternatea*-based interventions.

A structured translational research approach would involve initial characterization of extracts and formulations, followed by appropriate *in vitro* assessments, controlled *in vivo* studies, pharmacokinetic and

toxicological investigations, and, when justified by preliminary evidence, well-designed clinical or field trials. Such investigations would help determine whether biological activities reported in experimental models translate into safe, effective veterinary applications.

Integration of research themes and One Health implications

The identification of five thematic clusters demonstrates that *C. ternatea* research relevant to veterinary and animal sciences encompasses several interconnected but methodologically distinct disciplines. The principal research directions include forage and livestock nutrition, experimental animal pharmacology, phytochemical characterization, metabolic animal models, and intelligent packaging for animal-origin foods.

Although these themes share a common plant species, their research objectives, experimental methods, and practical applications differ considerably. Forage investigations primarily address feed resources and livestock production, pharmacological studies examine biological responses in experimental models, and intelligent packaging research focuses on developing and evaluating materials for food quality monitoring.

The keyword co-occurrence network indicates relationships among these research topics, but these relationships do not necessarily reflect direct scientific collaboration, methodological integration, or the transfer of experimental findings between disciplines. Similarly, the observed temporal shift toward intelligent packaging should not be interpreted as evidence that forage or pharmacological research has become less relevant.

The interdisciplinary nature of the literature nevertheless provides opportunities for coordinated research. For example, phytochemical characterization may support the standardization of plant-derived materials used in experimental pharmacology, while research on forage production and animal-origin food quality may contribute to broader discussions of sustainable livestock systems.

Within a One Health framework, these connections relate to animal production, food quality, environmental sustainability, and human health. However, practical One Health benefits would need to be demonstrated through appropriate experimental, epidemiological, or implementation studies. The present bibliometric analysis identifies research directions and potential connections but does not establish direct health or environmental outcomes.

Limitations

Several limitations should be considered when interpreting the findings of this study.

First, bibliographic records were retrieved exclusively from Scopus. Although this database provides multidisciplinary coverage, relevant publications indexed only in Web of Science, PubMed, CAB Abstracts, AGRIS, Google Scholar, or regional databases may not have been included. Consequently, the analyzed dataset represents the literature retrieved under the specified search strategy rather than an exhaustive inventory of all research on *C. ternatea*.

Second, the restriction to English-language publications may have excluded relevant studies published in other languages. This limitation may be particularly important for research conducted in countries where agricultural, veterinary, or ethnobotanical findings are frequently disseminated through regional publication outlets.

Third, publication selection depended on predefined search terms and eligibility criteria. Although the search strategy was pilot-tested and supplementary searches were conducted, some relevant studies may not have contained the selected descriptors in their titles, abstracts, or keywords. Conversely, the inclusion of animal-model pharmacology and intelligent packaging studies broadens the disciplinary scope beyond clinical veterinary medicine.

Fourth, bibliometric indicators measure characteristics of scientific publications and their relationships but do not directly assess methodological quality, reproducibility, biological efficacy, or clinical relevance. The findings therefore cannot substitute for systematic reviews or meta-analyses of experimental outcomes.

Fifth, author disambiguation using Scopus Author IDs may not eliminate all identification errors. Similarly, institutional and country-level analyses may be affected by incomplete affiliation information, variations in institutional naming, and changes in organizational structures.

Sixth, keyword normalization and thematic labeling involve methodological decisions that may influence the resulting network structure. Although we used a standardized thesaurus, an excluded-term list, and sensitivity analyses to improve reproducibility, identifying and interpreting thematic clusters still depends partly on analytical choices.

Seventh, citation indicators are influenced by publication age and differences in citation behavior among disciplines. Reporting citations per year provides an additional comparative measure but does not eliminate these sources of variation or establish research quality.

Eighth, the 2026 publication data were incomplete because the database search was conducted on March 18, 2026. Although this year was excluded from publication growth modeling, the included records reflect only the portion of 2026 available at the retrieval date.

Finally, the temporal keyword overlay was based on mean publication years and therefore provides a descriptive representation of changes in research emphasis. It does not independently establish the emergence, maturity, or discontinuation of individual research areas.

Despite these limitations, predefined eligibility criteria, standardized bibliographic processing, author disambiguation, keyword normalization, network analysis, and sensitivity testing provide a structured, reproducible framework for examining the development of *C. ternatea* research within the selected veterinary and animal science boundaries.

CONCLUSION

This bibliometric analysis characterized the global development, geographical distribution, scientific collaboration, and thematic evolution of *C. ternatea* research relevant to veterinary medicine and animal sciences from 1973 to March 2026. The analysis included 318 publications, with more than half (53.5%) published between 2021 and March 2026, demonstrating a substantial increase in recent research activity. India and Indonesia were the leading contributors, while international collaboration appeared in only 19.8% of publications. Keyword co-occurrence analysis identified five thematic clusters: animal-model pharmacology and toxicology; anthocyanin-based intelligent packaging and antimicrobial activity; tropical forage and ruminant nutrition; phytochemistry and bioactive characterization; and antidiabetic and metabolic animal models. Temporal mapping indicated a shift in relative research emphasis from established forage investigations toward experimental pharmacology and, more recently, intelligent packaging applications. These findings demonstrate the multidisciplinary development of the field while highlighting its geographical concentration and relatively limited international collaboration.

The findings provide a quantitative overview of research priorities and collaborative patterns that may help veterinary researchers, animal nutritionists, food scientists, and research institutions identify opportunities for interdisciplinary investigation. The prominence of forage-related research supports continued evaluation of *C. ternatea* in tropical livestock feeding systems, particularly regarding nutritional quality, animal performance, and environmental adaptability. Growing research attention on anthocyanin-based intelligent packaging highlights opportunities to investigate freshness-monitoring technologies for animal-origin foods. Similarly, the substantial body of animal-model pharmacological research provides a basis for identifying biological activities that may warrant further veterinary investigation. However, the practical effectiveness, safety, and feasibility of these applications must be established through appropriately designed experimental and field studies rather than inferred from bibliometric indicators.

A principal strength of this study was its focused examination of *C. ternatea* research within clearly defined veterinary and animal science boundaries. The analysis integrated publication trends, citation indicators, geographical and institutional productivity, author contributions, international collaboration, keyword co-occurrence, and temporal mapping. The use of predefined eligibility criteria, standardized bibliographic metadata, author disambiguation, keyword normalization, and sensitivity analyses strengthened the methodological transparency of the investigation. Furthermore, the identification of five thematic clusters provided a structured overview of research directions that are otherwise distributed across several scientific disciplines.

Future research should prioritize stronger international and interdisciplinary collaboration, particularly among institutions in Asia, Africa, Australia, and Latin America. In livestock nutrition, standardized investigations of forage composition, antinutritional factors, digestibility, animal performance, and rumen fermentation are needed to clarify the suitability of *C. ternatea* under different production conditions. Controlled *in vivo* studies should also evaluate potential effects on nutrient utilization and enteric methane production where biologically justified.

For intelligent packaging applications, future investigations should emphasize validation under practical storage and cold-chain conditions, reproducibility of colorimetric responses, packaging material stability, migration safety, and relationships between indicator performance and quantitative microbiological measurements. In

veterinary pharmacology, further progress requires standardized phytochemical characterization, species-specific toxicological assessment, dose-response investigations, and controlled clinical or field studies before therapeutic applications can be recommended.

Future bibliometric investigations could integrate additional databases, include non-English publications, and evaluate changes in collaboration networks and research themes over longer periods. Such approaches may provide a more comprehensive understanding of emerging research directions and the translation of experimental findings into practical applications.

Research on *C. ternatea* has developed into an increasingly active and multidisciplinary field encompassing livestock nutrition, experimental pharmacology, phytochemistry, and animal-origin food quality. Although publication activity has expanded substantially, the geographical concentration of research contributions and limited international collaboration indicate opportunities for greater scientific integration. The identified thematic clusters and temporal patterns provide a foundation for prioritizing future investigations and strengthening connections among veterinary medicine, animal production, food technology, and One Health. Translating these research directions into practical benefits will require coordinated, methodologically rigorous studies that establish biological efficacy, safety, and applicability under relevant veterinary and production conditions.

DATA AVAILABILITY

The bibliographic dataset analyzed in this study was retrieved from Scopus using the search strategy described in the Materials and Methods section. To facilitate reproducibility, the screened bibliographic dataset, including document identifiers, digital object identifiers, and screening decisions where permitted by Scopus licensing conditions, together with the keyword thesaurus and stop list, cleaned keyword dataset, network node and edge tables, Python and NetworkX analysis scripts, and a reproducible computational environment file specifying software dependencies and package versions, have been deposited in the Zenodo repository (DOI: 10.5281/zenodo.22782667). These materials are also identified as Supplementary Data S1–S7.

GENERATIVE AI DECLARATION

Generative AI tools were used solely to support language refinement and formatting. All scientific content, data analysis and interpretation, conclusions, and reference verification were independently conducted by the authors. The authors remain fully responsible for the accuracy, integrity, and overall content of the work.

AUTHORS' CONTRIBUTIONS

IR and AK: Conceptualization and study design. IR, AK, and YD: Developed the search strategy, retrieved bibliographic data, and screened publications. AK and MSAF: Bibliometric and network analyses using Python, NetworkX, and VOSviewer, and figure preparation. WAP: Botanical and phytochemical interpretation. ASRA and HK: Veterinary and animal nutrition interpretation. IR and YD: Manuscript drafting. All authors critically reviewed and edited the manuscript and approved the final version.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

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