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Review Article

Trends in *Indigofera* research (2016-2025): A bibliometric analysis

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Abstract

This work offers a comprehensive bibliometric review of global *Indigofera* research published from 2016-2025, analyzing 2,001 documents indexed in Scopus, including journal articles, review papers, book chapters, and conference proceedings. It investigates the evolution of research themes, collaboration trends, and knowledge paradigms over the decade. The study finds a noticeable shift in research focus: earlier studies emphasized ecological and agronomic issues (such as forage quality, nitrogen fixation, species diversity), while recent work highlights phytochemical profiling, antioxidant capabilities, and pharmacological prospects. Collaboration network mapping shows a globally dispersed but highly interconnected institutional dominance, with many contributors remaining fairly isolated. Factorial and cluster analyses underline the interdisciplinary nature of the field, bridging agriculture, ecology, veterinary, and biomedical sciences. Keyword co-occurrence analysis reveals a chronological evolution of topics from traditional fodder and ecological studies to more sophisticated biochemical and pharmacological research. These findings suggest *Indigofera* plays a dual role in sustainable agriculture and natural product discovery, offering significant implications for food security and human health, with potential applications in livestock productivity, ecological restoration, and pharmaceutical innovation. This review not only maps the current research landscape but also offers a roadmap for future studies, advocating for enhanced interdisciplinary collaboration, advanced biochemical evaluations, and translational research to fully harness *Indigofera's* scientific and practical potential.

Keywords: *Indigofera*, Bibliometric analysis, Research trends, Review

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Introduction

The *Indigofera* genus has been historically significant in agriculture and medicine. Traditionally, *Indigofera* species have been valued for their ecological contribution as nitrogen-fixing legumes that improve soil fertility, enhancing sustainable agriculture (Selvarajah et al., 2017; Mapfumo and Tauro, 2009; Mpepereki et al., 2005). They have also been cherished across cultures for natural dyes, livestock fodder, and medicinal uses (Patel et al., 2023). Over the past decade, global research interest in *Indigofera* has surged, fueled by its diverse applications in pharmacology, ecology, and biotechnology. Recognizing *Indigofera* as a versatile plant has driven studies into its phytochemical composition, pharmacological activities, and potential as a sustainable agricultural input. Recent findings of antioxidant and antimicrobial activities in certain *Indigofera* species underscore their potential therapeutic value (Vijayan et al., 2012; Mohammad et al., 2019; Rehman et al., 2024). Concurrently, *Indigofera* continues to hold a crucial role in tropical and subtropical agroecosystems, key for livestock nutrition and soil fertility programs (Selvarajah et al., 2017; Choudhary et al., 2025). Amid global challenges like climate change, food insecurity, and increased demand for natural products, *Indigofera* emerges as a vital multifaceted resource at the intersection of agriculture, ecology, and human health. Examining the body of scholarly work on *Indigofera* is essential, spotlighting influential authors and institutions, and highlighting emerging knowledge domains. A bibliometric approach affords a robust method to map these trends, offering strategic insights to guide future research.

Previous research and knowledge gaps

While multiple prior reviews have delved into the agricultural and pharmacological properties of *Indigofera*, a comprehensive bibliometric analysis systematically mapping global research trends on this genus has been absent. Most prior works were descriptive, focusing narrowly on species-specific agronomic or phytochemical traits without examining the broader research landscape. This fragmented approach obstructs the identification of overarching patterns or knowledge progression in *Indigofera* research. Furthermore, although individual studies have detailed medicinal properties of Indigofera extracts (like anti-inflammatory, antimicrobial, and antioxidant effects), efforts to synthesize these findings into a holistic research framework were limited (Taj Ur Rahman et al., 2017). Similarly, ecological studies on benefits such as soil fertility enhancement and erosion control remained largely detached from biomedical inquiries. Therefore, a bibliometric synthesis is vital to capture Indigofera research's full interdisciplinarity and showcase how its various themes interconnect. The rapid expansion of Indigofera literature compounds this issue. According to Scopus, over 2,001 related publications emerged between 2016 and 2025, spanning journal articles, book chapters, conference papers, and reviews. Without a structured analysis, navigating this growing body of work becomes daunting, risking the loss of strategic research direction opportunities.

Objectives and research questions

To bridge this gap, the current study executed a comprehensive bibliometric analysis of Indigofera-related research published from 2016 to 2025. Sourcing data from Scopus, this review assesses the growth of scholarly output, identifies leading contributors, and traces the evolution of research themes and concepts. The analysis addresses the following research questions:

- How has the volume of *Indigofera* research output evolved from 2016 to 2025?
- Which source titles featured the highest number of *Indigofera* studies during this period?
- Who were the most prominent authors shaping *Indigofera* research in this time frame?
- Which countries were the leading contributors to *Indigofera* literature?
- What are the most relevant keywords reflecting thematic developments in *Indigofera* research?
- What characterizes the overarching Indigofera research landscape, including collaboration networks and thematic clusters?

By answering these questions, the study not only quantifies the productivity of *Indigofera* research but also offers interpretive insights into the structural and thematic dynamics of the field.

Research scope and methodological considerations

This review hinges on a bibliometric analysis of literature indexed in Scopus, targeting publications from 2016 through 2025. This recent timeframe reflects the surge of interest in *Indigofera* over the past

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decade and the need to capture its current research trajectory. Only peer-reviewed documents (journal articles, review papers, book chapters, and conference papers) were included, excluding non-peer-reviewed materials to preserve dataset reliability and quality. The bibliometric analysis employed several complementary methods. Trend analysis was used to examine the growth of research output over time (Figure 2). Collaboration network analysis identified key institutions and evaluated scholarly interconnectedness in the field (Figure 3). Factorial analysis delineated major thematic clusters, revealing the interdisciplinary nature of *Indigofera* research (Figure 4). Finally, a keyword co-occurrence mapping (Figure 5) provided insights into the field's conceptual structure and temporal evolution of research themes. These techniques collectively enabled a thorough mapping of the *Indigofera* research landscape.

Significance of the study

The significance of this bibliometric study lies in its ability to distill an extensive body of literature into meaningful insights that enhance scholarly understanding of Indigofera. By documenting research output growth and identifying prolific sources, authors, and contributing countries, the study pinpoints areas of concentrated scholarly effort and identifies critical gaps. This information is crucial for directing future research funding and encouraging strategic collaborations. Second, thematic findings illuminate field evolution, revealing a shift from traditional agricultural applications to more modern pharmacological and biotechnological interests. Keyword co-occurrence mapping demonstrates continuity of core themes (like forage quality, nitrogen fixation) and the emergence of new research frontiers, including studies on bioactive compounds and the use of high-performance analytical techniques. Third, this study contributes to plant-derived resource literature by positing *Indigofera* as a model genus for dual-use applications traversing sustainable agriculture and natural product discovery. By highlighting *Indigofera's* inherently interdisciplinary role, the study underscores its potential to address global challenges in food security, ecological resilience, and human health. Lastly, the bibliometric approach used ensures high objectivity and reproducibility, allowing future researchers to update and extend the analysis as the field evolves. Consequently, the study provides both a baseline assessment and a roadmap for continued *Indigofera* research exploration.

Material and Methods

Research design

This study employed a bibliometric mapping approach to analyze *Indigofera* research trends over the period 2016–2025. Bibliometric methods are increasingly embraced to evaluate the structure and dynamics of scholarly fields, providing a systematic way to assess publication output, collaboration patterns, and thematic evolution (Aria and Cuccurullo, 2017; Aria et al., 2024). These methods serve as valuable tools for multidisciplinary domains like *Indigofera* research, where agricultural, ecological, and pharmacological perspectives intersect.

Bibliometric mapping allows researchers to identify influential sources, authors, and countries, while also uncovering conceptual linkages through co-citation and co-occurrence analyses. The present study builds on previous bibliometric applications in plant science and environmental studies by using advanced visualization tools to comprehensively map the intellectual framework of *Indigofera* research (Bancong, 2024; Nanda et al., 2025).

Data sources and retrieval

Data for this analysis were exclusively acquired from the Scopus database, known for its extensive coverage of peer-reviewed journals across multiple disciplines and robust metadata suitable for bibliometric studies (Visser et al., 2021). Compared to other indexing services (such as Web of Science, Dimensions, or CrossRef), Scopus offers a balanced coverage of both established and emerging journals, making it suitable for capturing global research trends (Visser et al., 2021). The bibliographic search was conducted on August 21, 2025. The query was limited to publications that contained the keyword "*Indigofera*" in the title, abstract, or keywords fields, ensuring all retrieved documents pertained explicitly to the genus. This search yielded an initial dataset of 2,001 documents, comprising journal articles, review papers, book chapters, and conference papers.

Inclusion and exclusion criteria

The dataset was refined by applying specific inclusion and exclusion criteria, culminating in a final selection of 663 documents for analysis. The screening and selection process followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and

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reproducibility. A PRISMA flow diagram (Figure 1) outlines the inclusion and exclusion steps in detail, documenting the records removed at each filtering stage. The criteria included:

Document type: Only journal articles, review papers, and book chapters were retained, while excluding editorials, letters, and other non-research documents. This refinement reduced the dataset to 964 documents.

Language: Only documents published in English were included, ensuring consistency and accessibility, further trimming the dataset to 663 documents.

Final dataset: After removing duplicates and conducting consistency checks, a total of 663 documents remained for bibliometric mapping.

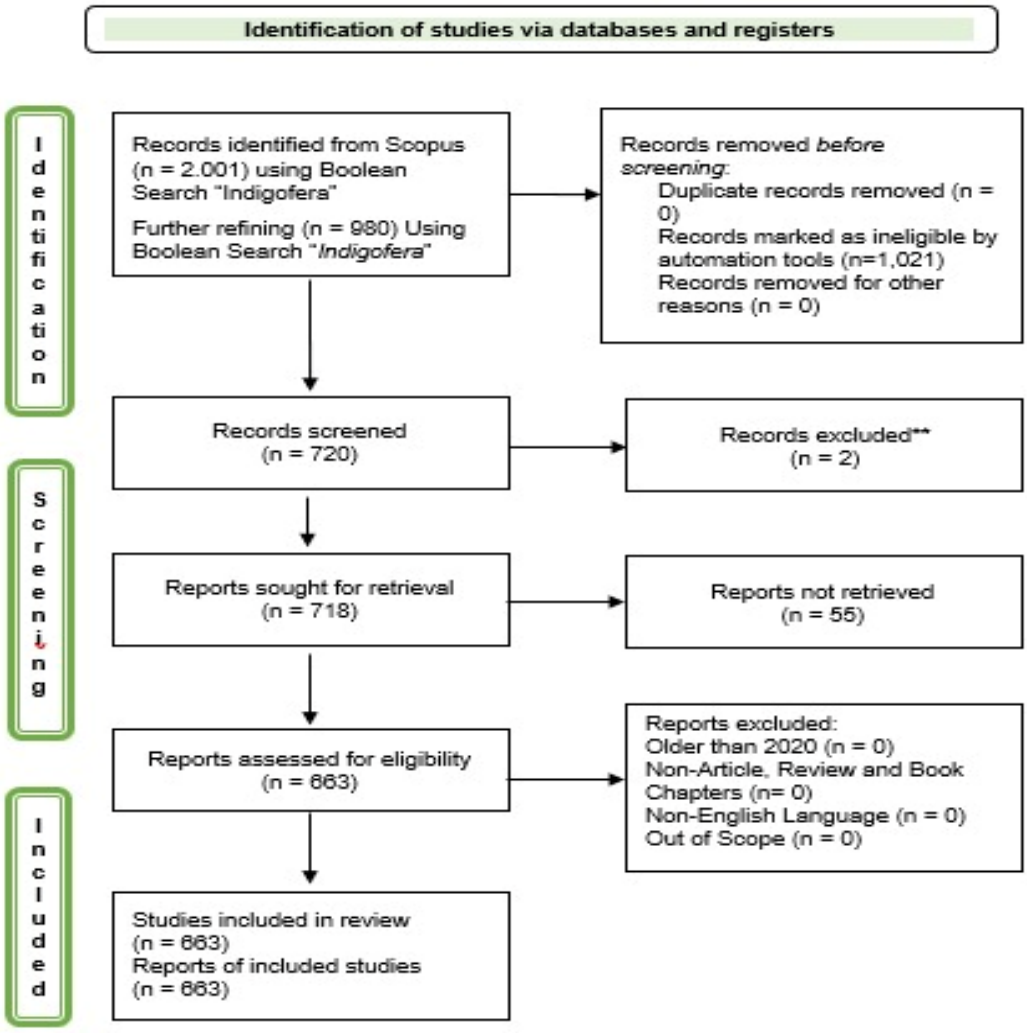

Figure-1. PRISMA flow diagram illustrating the literature screening and selection process, from an initial retrieval of 2,001 records to a final sample of 663 documents.

Data extraction and processing

The bibliographic data were exported from Scopus in both comma-separated values (CSV) and Research Information System (RIS) formats, chosen for their compatibility with bibliometric software. Extracting data in these formats provided the necessary flexibility for subsequent analyses and ensured interoperability across different analytical tools. Several data preprocessing steps were undertaken to correct inconsistencies in author names, institutional affiliations, and journal titles. This step was critical to prevent distortions in the network analysis results, as bibliometric mapping is highly sensitive to metadata inaccuracies (van Eck and Waltman, 2017). After data cleaning and standardization, the dataset was primed for visualization and advanced analysis. This study

utilized a combination of software tools for data analysis and visualization.

Microsoft Excel was employed for basic descriptive analyses, such as tracking annual publication output and identifying prolific source titles and contributing countries. Biblioshiny (the web-based interface of the Bibliometrix R package) was utilized for factorial analysis, thematic mapping, and conceptual structure analysis (Aria and Cuccurullo, 2017; Aria et al., 2024). This tool has gained wide acceptance in recent bibliometric studies due to its interactive and reproducible features (Aria et al., 2023). VOSviewer (version X.X) was used to generate visual maps of co-authorship networks, keyword co-occurrence patterns, and citation relationships. VOSviewer excels at bibliometric mapping due to its optimized layout algorithms and robust clustering techniques (van Eck and Waltman, 2017).

The key visualizations presented in the Results section—including the trend topic timeline (Figure 2), the collaboration network map (Figure 3), the factorial analysis diagram (Figure 4), and the keyword co-occurrence map (Figure 5)—were all produced using these tools.

Results

Overview of analyzed publications

A total of 2,001 *Indigofera*-related documents were identified in Scopus from 2016–2025. These publications encompass journal articles, review papers, book chapters, and conference proceedings. This sizeable array of literature reflects the sustained and growing academic interest in *Indigofera*, a genus recognized for its ecological, medicinal, and agricultural significance.

Research trends and emerging topics

As depicted in Figure 2 (Trend Topics), the most prominent themes during this timeframe include *Indigofera* tinctoria, *Indigofera* suffruticosa, indigenous fodder, and medicinal plant applications. Topics like high-performance liquid chromatography (HPLC), bioactive compounds, and antioxidant activity began gaining traction post-2019, signaling a shift towards deeper biochemical and pharmacological explorations. Meanwhile, themes of ecological and agronomic importance (e.g., forage quality, animal feed, nitrogen fixation) persistently prevail, emphasizing the genus's dual role in environmental sustainability and livestock nutrition.

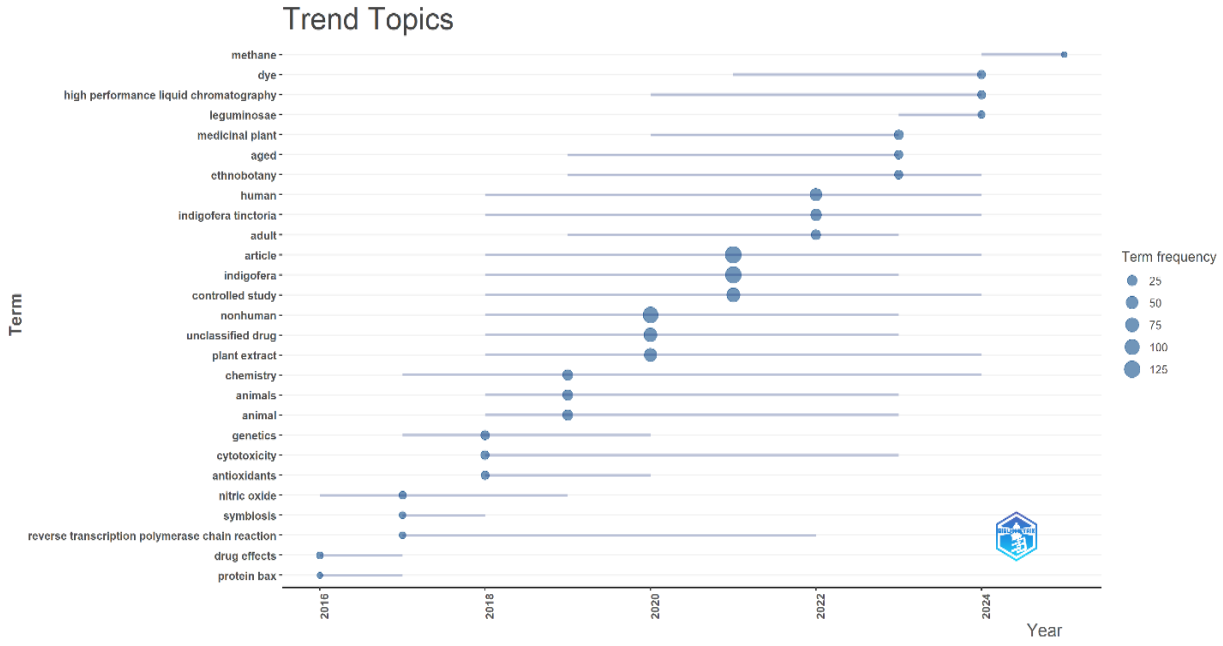

Figure-2. Temporal analysis of trending topics in *Indigofera* research (2016–2025).

Collaboration patterns

Collaboration network analysis (Figure 3) illustrates that a handful of well-connected institutions and

researchers carry a significant portion of research activities, while a long list of smaller, less-integrated contributors exists. This structure suggests that while *Indigofera* research is globally dispersed, strategic collaborations are concentrated around academic hubs, which could steer the overall trajectory of exploration and innovation.

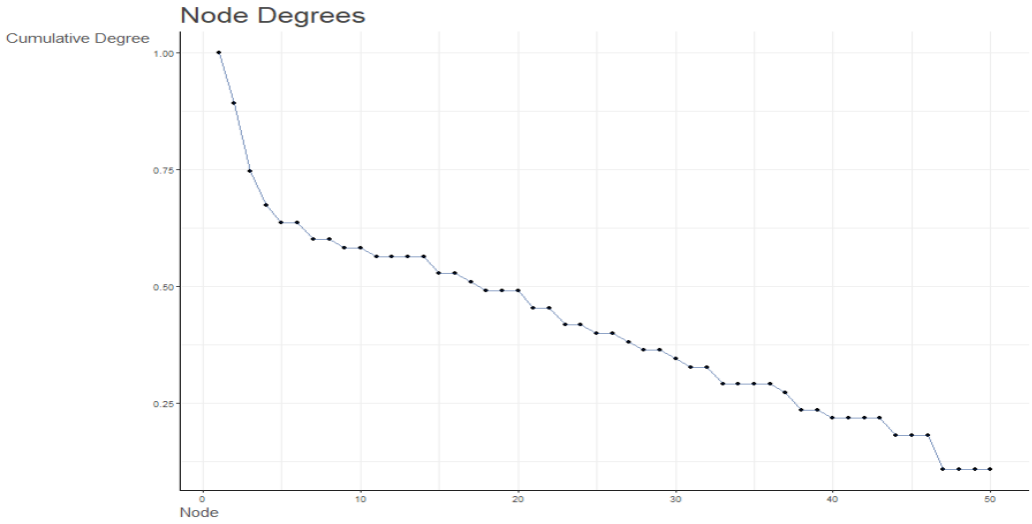

Figure-3. The collaboration network within the academic community.

Factorial and cluster analysis

Factorial analysis (Figure 4) reveals the thematic clustering of research topics across disciplines. The clusters signify overlapping domains like phytochemistry, veterinary science, and sustainable agriculture. The resultant dendrogram displays that studies on phytochemical composition and bioactivity are closely linked to pharmacological and biomedical research, whereas themes like fodder utilization and species diversity align with ecological and agronomic research.

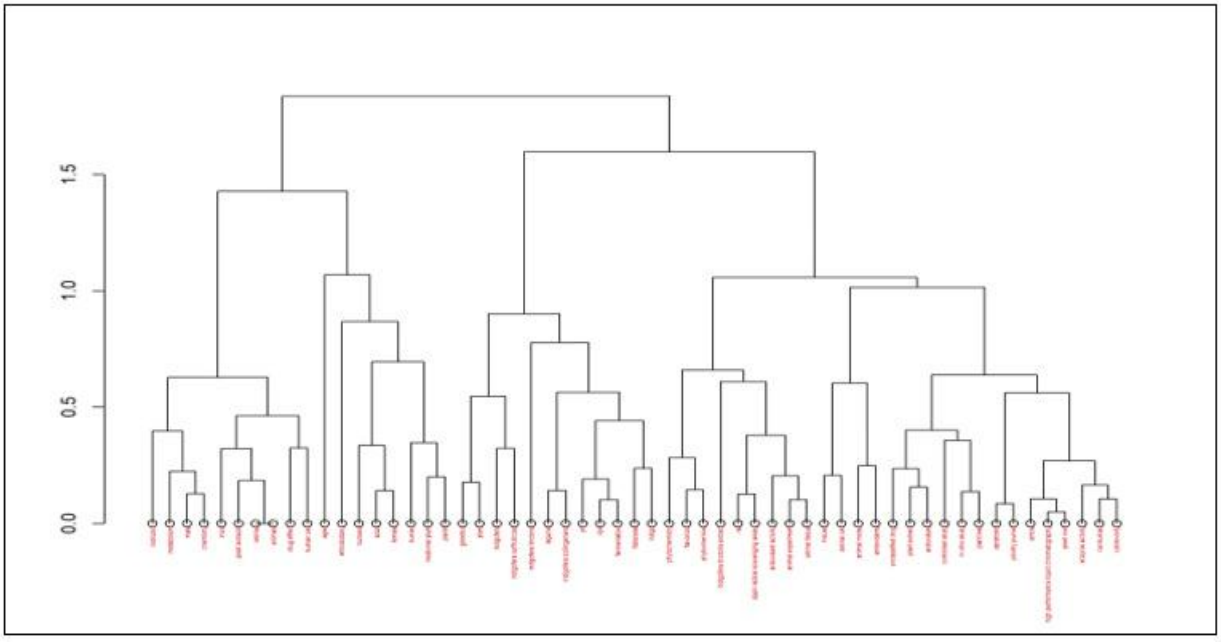

Figure-4. The factorial analysis highlights the multifaceted nature of *Indigofera* research.

Keyword co-occurrence and knowledge mapping

The keyword co-occurrence map (Figure 5) illustrates the interconnectedness of various research directions within the field. Distinct keyword clusters form thematic areas like compound bioactivity, extract characterization, livestock production, and species diversity. A conspicuous temporal gradient emerges as earlier studies stressed species identification and forage potential, whereas recent publications (particularly post-2020) focus on bioactive compounds, quality assessments, and biotechnological applications. This trend signifies an evolving focus, transitioning from *Indigofera's* traditional usages to contemporary pharmacological and industrial applications.

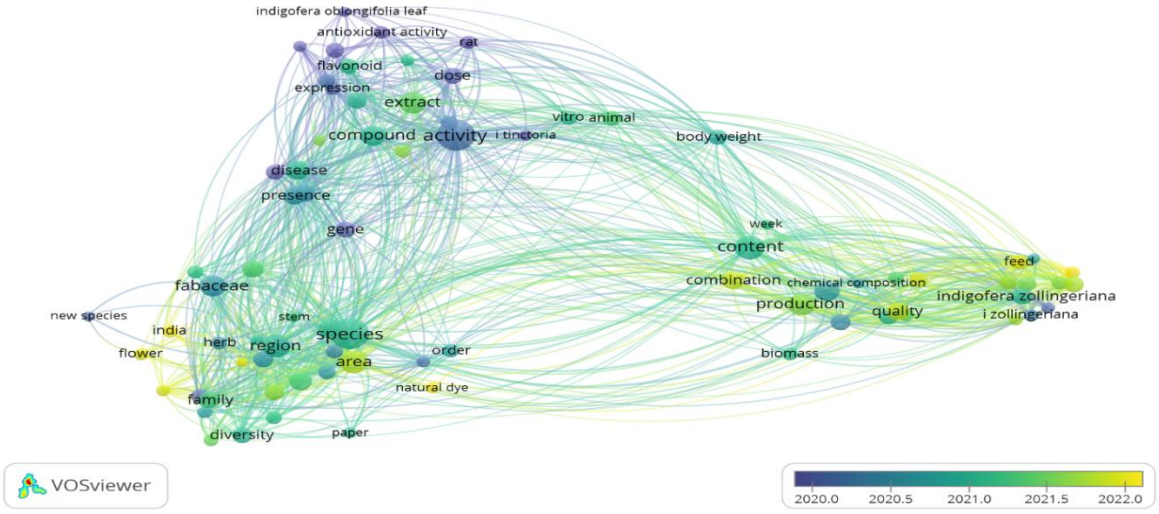

Figure-5. The keyword co-occurrence map further bolsters the narrative of disciplinary convergence.

Discussion

This bibliometric review scrutinized 2,001 publications on *Indigofera* (2016–2025) from Scopus to discern major research trends, collaboration patterns, thematic clusters, and new frontiers in this rapidly growing field. The discoveries underscore *Indigofera's* dual importance: it persists as a traditional resource for fodder and medicine while emerging as a modern subject of biotechnological, pharmacological, and ecological investigation. In the discussion ahead, we dissect the broader significance of these results against the study's objectives, compare emergent patterns with insights from prior research, and outline implications for future research directions.

Research trends and knowledge evolution

The temporal analysis of trending topics (Figure 2) lucidly demonstrates that *Indigofera* research priorities have considerably shifted over the past decade. Early publications predominantly concentrated on agronomic themes like forage quality, nitrogen fixation, and species diversity, echoing long-standing interests in sustainable livestock systems and ecological resilience. These findings align with previous reports identifying *Indigofera* as an underutilized legume with immense potential to boost soil fertility and feed quality in tropical and subtropical agroecosystems (Rahman et al., 2016; Abdullah et al., 2017). Around 2019, however, publications reflect a growing interest in phytochemistry, antioxidant activity, and HPLC-based plant compound analyses. This transition resonates with a global surge in natural products research, where leguminous plants are increasingly explored for bioactive compounds with pharmaceutical potential (Nguyen et al., 2019; Kumar et al., 2020; Ali et al., 2021).

The shift suggests that *Indigofera* has effectively transitioned into a multidisciplinary research subject, melding elements of agricultural science, pharmacognosy, and biotechnology. Notably,

prominence has been given to studies reporting bioactive secondary metabolites (such as flavonoids, alkaloids, and tannins) in recent years. These findings support *Indigofera's* traditional ethnomedicinal uses documented earlier (Sari et al., 2015; Kumar and Bhat, 2017; Ali et al., 2018) and point towards modern drug discovery routes. Thus, the theme evolution provides a valuable case of how *Indigofera* studies have expanded from mostly an agricultural focus to significant biomedical relevance.

Collaboration patterns and research hubs

The collaboration network (Figure 3) uncovers a noticeable stratification within the *Indigofera* research community. A few institutions and research collectives dominate the field through extensive co-authorship networks, whereas a longer list of less-connected contributors signifies a broad yet scattered research base. This structure typifies emerging interdisciplinary fields: pioneering groups establish leading expertise hubs that attract collaborations worldwide (Wagner and Leydesdorff, 2005; Cummings and Kiesler, 2007; Katz and Martin, 1997). The geographical clustering of collaborations is also noteworthy. Previous bibliometric studies in plant science indicate that countries in the global South, especially Asia and Africa, tend to lead research on regionally vital crops and forage species (Mohapatra et al., 2018; Pouris et al., 2020). Thus, the notable presence of *Indigofera* research in these regions is not surprising, given the genus's adaptability to marginal lands and its role in traditional farming systems.

Nevertheless, limited participation from Western institutions (aside from some pharmacological collaborations) suggests untapped opportunities for more global research partnerships. These collaborations could enhance methodological rigor, facilitate access to advanced analytical tools, and broaden the translational impact of *Indigofera* research findings.

Thematic clustering and factorial insights

The factorial analysis (Figure 4) underscores the multifaceted character of *Indigofera* research. Distinct thematic clusters emerge, grouping studies on phytochemistry, pharmacological bioactivity, veterinary applications, and ecological functions. This clustering pattern embodies the broad interdisciplinary appeal of *Indigofera*, as it addresses global challenges in food security, sustainable agriculture, and human health simultaneously.

The close association of phytochemical research topics with pharmacological outcomes is especially striking. It reveals a trajectory from merely descriptive phytochemical studies towards applied biomedical testing, hence reducing the gap between traditional ethnobotanical knowledge and modern clinical validation. This trend aligns with broader calls in medicinal plant research to integrate ethnomedicine with evidence-supported pharmacology (Fabricant and Farnsworth, 2001; Heinrich et al., 2012; Ekor, 2014).

Conversely, the clustering of topics related to fodder utilization alongside those on species diversity and ecological functions reaffirms the enduring importance of *Indigofera* for sustainable agriculture. These themes are crucial given global pressures to diminish reliance on synthetic feeds and nitrogen fertilizers, aligning directly with international sustainability objectives.

Knowledge mapping and keyword dynamics

The keyword co-occurrence analysis (Figure 5) offers enhanced evidence of disciplinary convergence. Keyword clusters centered on topics such as bioactive compound activity, extract characterization, and production quality underscore the increasing complexity of research questions in the field. Importantly, a temporal gradient appears in the keyword map: terms transition from taxonomic and forage-oriented concepts in the earlier years to pharmacological and biotechnological heuristics after 2020, reflecting the evolving research community priorities.

This temporal progression echoes developmental trajectories seen in other underutilized legume genera, like Sesbania and Crotalaria, which progressed from being primarily explored as green manure and fodder species to being identified as bioactive metabolite sources (Kumar et al., 2015; Akinmoladun et al., 2018; Gupta and Singh, 2020). These parallels suggest *Indigofera's* research trajectory forms part of a broader global trend in legume science, where historically agricultural species are being re-examined for their hidden pharmacological potential.

Significance of findings and theoretical implications

This review's findings carry several crucial theoretical and practical implications. First, the convergence of agricultural and pharmacological research streams in

Indigofera underscores the genus's remarkable versatility as an interdisciplinary research model. Unlike numerous plant genera confined to either agronomic or biomedical domains, *Indigofera* simultaneously contributes to food system resilience, environmental sustainability, and drug discovery. Its multifaceted relevance strongly advocates for sustained research investment in *Indigofera.*

Second, observed collaboration disparities highlight the need to cultivate more inclusive research networks. Stronger integration of scientists from traditionally underrepresented regions could expedite knowledge transfer and diminish research effort redundancies. For instance, while pharmacological studies often employ advanced chemical and molecular techniques, local agronomic research contributes essential ecological and ethnobotanical insights. Bridging these complementary perspectives can cultivate a more comprehensive knowledge foundation that supports both localized applications and global innovations.

Third, the thematic evolution observed suggests that *Indigofera* can serve as a case study for the transition of traditional ethnobotanical knowledge into validated biomedical science. Similar trajectories have been documented in other medicinal plants such as Curcuma longa and Moringa oleifera (Aggarwal et al., 2013; Anwar et al., 2007; Gupta et al., 2020). Yet the distinctive dual role of *Indigofera* in both fodder systems and pharmacology renders its case unique. Theoretically, this underscores the potential of "dual-use" species in shaping integrated research agendas.

Comparison with previous studies

The patterns identified in this review broadly align with findings from preceding bibliometric and content analyses in related areas. For instance, previous global reviews of forage legumes highlighted the underrepresentation of tropical species in mainstream scientific literature (Tarawali et al., 2011). The notable increase in *Indigofera*-related studies since 2016 indicates that this specific gap is gradually being bridged in *Indigofera*.

Similarly, earlier pharmacological surveys showcased *Indigofera* species as promising bioactive compound sources but remarked on inadequate biochemical and toxicological investigations (Ali et al., 2018). The intensified focus on HPLC-based compound screenings and antioxidant assays in recent works suggests that the field is beginning to address these shortcomings, albeit comprehensive toxicological studies remain scarce.

Furthermore, while older research highlighted *Indigofera's* ecological roles in nitrogen fixation and erosion control, current results demonstrate the sustained relevance of these themes, now viewed within wider sustainability and resilience frameworks. This shift reflects a conceptual change from perceiving *Indigofera* merely as a supportive legume to recognizing it as a strategic resource for climate-resilient agriculture.

Contribution of this research

This study contributes significantly to *Indigofera* research in three primary aspects. First, by delivering the most comprehensive bibliometric analysis of *Indigofera* literature to date, it establishes a baseline for tracking the knowledge production trajectory across almost a decade. Second, it integrates agricultural, ecological, and pharmacological perspectives, highlighting *Indigofera's* multifaceted relevance and spurring greater interdisciplinary collaboration. Third, this work identifies strengths and gaps within the existing literature, assisting in forging a clearer roadmap for future exploration.

Implications for future research and practice

Looking forward, several clear recommendations surface from this study's findings. On the research forefront, future work should prioritize melding advanced biochemical assessments with field-based agronomic evaluations of *Indigofera*. This integration will bridge the gap between laboratory discoveries and real-world applications. For example, long-term field trials are essential for assessing the agronomic performance of *Indigofera* species under varied climatic conditions while concurrently monitoring the stability of their phytochemical profiles.

In terms of pharmacological inquiry, there exists an urgent need for extensive toxicological assessments and eventual clinical trials to substantiate the safety and efficacy of bioactive compounds extracted from *Indigofera*. These investigations are pivotal in translating laboratory discoveries into viable therapeutic applications. Additionally, developing standardized extraction processes and quality control protocols for *Indigofera* phytochemicals would heighten reproducibility and facilitate prospective regulatory approvals.

From a practical perspective, the results emphasize *Indigofera's* potential contribution to sustainable agriculture and the natural products industry. Agricultural policymakers and practitioners, for

example, might facilitate the integration of *Indigofera* into livestock fodder systems to enhance productivity and diminish synthetic feed reliance. Concurrently, pharmaceutical firms could partner with academic institutions in systematically screening *Indigofera* metabolites for drug development prospects.

Lastly, building stronger international research networks will be crucial for further progress. Initiatives fostering North–South collaborations, capacity-building programs, and shared access to advanced technologies could accelerate advancements in *Indigofera* research. Such partnerships would not only improve scientific outcomes but also ensure the benefits of *Indigofera*-related innovations are equitably distributed across regions.

Conclusion

In conclusion, this bibliometric analysis of *Indigofera* research trends (2016–2025) uncovers a vibrant and evolving field bridging agriculture, ecology, and pharmacology. Findings reveal significant thematic shifts and highlight the key collaborative hubs, underscoring this genus's interdisciplinary charm. By contextualizing results within broader scientific and societal frames, this review significantly contributes to understanding *Indigofera's* role in contemporary research.

The study's implications provide guidance for future research projects and practical applications, highlighting Indigofera's growing significance in addressing global challenges related to food security, environmental sustainability, and human health. They can inform policy-making in these areas. Over this decade, *Indigofera* research has progressed from traditional agricultural inquiries to pioneering biomedical applications, rendering the genus an exemplar of a dual-use species supporting sustainable farming systems and natural product discovery.

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Contribution of Authors

Kadir MJ: Conceived idea, designed research methodology, collected and analyzed the data and manuscript write up

Natsir A & Mustabi J: Literature review, analyzed and interepreted data, manuscript write up and editing.

Dagong MIA & Syahrullah: Critically reviewed the manuscript for write up and editing.

All authors read and approved final draft of the manuscript.

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