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RESEARCH

Bibliometric and visual analysis of wasp research progress based on ITGInsight

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Abstract

Attention was drawn to wasps primarily in the fields of biological control and medicine. Bibliometric analysis and visual mining were performed on 9,436 publications in the field of wasp research from 2014 to 2024 using the ITGInsight platform based on the Web of Science Core Collection database to research dynamics, hotspot evolution and future trends were examined. The results from the study showed that: (a) The number of global research literatures on wasps has grown exponentially (R^2=0.9309), with the United States (25.06%), China (15.57%) and Brazil (11.31%) as core contributors; (b) Chinese Academy of Sciences (489) achieved the highest publication count; (c) The author with the largest number of published articles was James M. Carpenter; (d) Research hotspots were centered on "Hymenoptera", "Transcriptome" and "Biological Control"; (e) The themes "new species" and "parasitoid wasp" gained prominence in recent years. Future research was recommended to integrate ecological, molecular biological, and interdisciplinary methodologies to advance the application value of wasps in agricultural systems, medical innovations, and biodiversity conservation efforts. By deciphering how the field organizes itself around key challenges, this study provides a diagnostic, evidence-based framework to guide future research toward solving the most pressing problems in sustainable agriculture, biomedicine, and conservation.

Keywords Wasp · Bibliometrics · Visual analysis · ITGInsight

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Introduction

Approximately 5,000 wasp species (Hymenoptera: Wasp family) were documented worldwide. In ecological systems, chemical insecticides were adopted globally due to cost effectiveness and demonstrated efficacy in pest population control. However, these practices were found to affect multiple organisms including wasps, resulting in reduced natural biological control efficiency(Theenoor et al. 2024). Accordingly, wasps were proposed as synthetic pesticide alternatives for integrated pest management(Fei et al. 2023), with its environmental sustainability being acknowledged in agricultural applications(Hambäck et al. 2024; Khamis and Ajene 2024). In addition, this finding motivated explorations of biopesticides derived from wasp venom(da Silva Santana et al. 2023), along with sustainable agricultural approaches(Rehman et al. 2022).

Medicinal applications were researched through wasp derivatives including venom, larval components(Zedan et al. 2021), honeycomb extracts, and adult body substances(Dongol et al. 2014), all of which were demonstrated to have therapeutic potential(Rajkhowa and Deka 2016). First, the whole insect was used as medicine to treat sores and bites, to make amino acid supplements and to develop traditional Chinese medicine(Li et al. 2021). Subsequently, biologically active compounds in larvae and pupae were used for the evaluation of cosmetic applications(Chilicka et al. 2022; Mortari et al. 2023). Venom constituents including phospholipase A2 and antigen 5 were confirmed to exhibit anticancer, antibacterial, and anti-inflammatory properties(Abd El-Wahed et al. 2021), while antimicrobial peptides (Anoplin, Mastoparan) were shown to display dual anti-biofilm and anti-inflammatory functions(Bhattacharya et al. 2024; Dongol et al. 2016). In addition, Neurological applications were identified for peptide Ppnp7 and Neuropolybin in anti-epileptic treatment(e Silva et al. 2020), polybia-CP derivatives in anti-malarial, anti-cancer interventions(Torres et al. 2020) and the copolymer of venom and human albumin was used in immunotherapy(Gewurz et al. 1986). Understanding of the allergic mechanism and development of new treatments were achieved through investigation of venom-immune system interactions(Gao et al. 2020). Simultaneously, genetic and behavioral studies were conducted to reveal immune mechanisms and biomimetic technology applications(Shimasaki et al. 2020; Ye et al. 2024). Its complex social structure, behavior and medicinal value make it an interesting research topic in entomology, ecology and medicine, which effective controlled and management of it was beneficial to research(Lester 2025). Additionally, wasps have been explored as a source of food and high-protein ingredients(Adamczyk et al. 2023), and its larvae were widely used in the food industry as high-protein ingredients and its derivative products(Nonaka 2010; Wang et al. 2024).

In this study, bibliometric methods were employed to evaluate scientific publications. It could be used to examine research priorities and hotspots within the field, as well as to assess the scientific productivity of countries, institutions, and researchers. ITGInsight was utilized as a text mining and visualization tool dedicated to bibliometric analysis, with demonstrated capability to analyze patent and paper data(Wang et al. 2022). Through this tool, three types of analyses could be conducted: cooperative relationship analysis, co-occurrence relationship analysis, and evolution analysis. Subsequently, various intuitive charts were generated, including network diagrams, heat maps, world maps, and evolution diagrams. It was identified as its support of multi-source data fusion processing, efficient data cleaning, and flexible report generation. These features made it particularly suitable for meeting the complex analysis requirements of interdisciplinary research.

To ensure methodological rigor, this study is grounded in established bibliometric research frameworks (Öztürk et al. 2024) and leverages the specialized capabilities of the ITGInsight platform(Wang et al. 2022). The successful application of this platform in prior field-specific analyses(Afrane et al. 2022), including a recent bibliometric study in cultural neuroscience(Xu et al. 2022), supports its suitability for the present study. Our approach also aligns with discussions on the application and robust analysis of bibliometric data(De Battisti and Salini 2013; Ellegaard 2018).

Despite the clear importance of wasps in ecology, biocontrol, and biomedicine, the overall research landscape remains fragmented. To the best of our knowledge, a comprehensive bibliometric analysis that captures the entire scope of global wasp research—encompassing its diverse subfields from taxonomy to applied medicine—has not been previously conducted. While valuable focused studies exist on specific applications, such as hymenoptera venom immunotherapy(Luo et al. 2025), they cannot provide the holistic perspective needed to understand field-wide dynamics. This study was designed to address this critical gap by moving beyond mapping to identify how the field organizes itself to solve problems. By applying the advanced bibliometric platform ITGInsight to analyze 9,436 publications (2014–2024), we provide the first comprehensive, field-wide analysis of wasp research. Our analysis not only quantifies collaboration and growth but, more importantly, deciphers the core knowledge structures and evolving hotspots that reveal the field's prioritized challenges and solution pathways. The findings are intended to synthesize existing knowledge into a diagnostic, data-driven framework that can guide future research toward the most pressing scientific and applied problems in this multifaceted field.

To achieve this, the study was designed to address three specific research questions: first, how the global collaborative structure among countries, institutions, and authors has evolved over the past decade; second, what the core knowledge clusters, persistent hotspots, and emerging frontiers are that define the field's trajectory; and third, how the trajectories of basic research align with or enable applied developments, and what critical scientific challenges remain at their intersection.

Methodology

Data collection and processing

In this study, the Web of Science (WoS) core database was adopted as the principal data source for literature and patent retrieval. Recognized as an authoritative scientific repository, WoS was characterized by rigorous journal selection protocols and multidisciplinary coverage, encompassing 8,618 high impact journals across 176 subject categories. All indexed publications were equipped with complete citation metrics to establish a robust foundation for disciplinary evolution analysis.

To ensure the relevance and accuracy of literature screening, our research team included members with expertise in entomology. The analysis covered publications from 1 January 2014 to 29 November 2024 (the date the search was executed). This timeframe captures over a decade of recent research activity while providing a substantial dataset for trend analysis. We acknowledge that publications from December 2024 are not included, as they may not have been fully indexed at the time of our search.

From 18 to 30 November 2024, the WoS Core Collection was searched using the following keywords based on the "Topic" field: "((((TS = wasp))ORTS=(vespid)) ORTS=(vespa))ORTS=(vespidae))ORTS(Vespoidea))". The search results for wasp research publications from the WoS core collection attained a total of all types: research articles, review articles, books, meetings, patents, editorials materials, case reports, unspecified, etc. Firstly, the results were further refined by limiting the search to only research articles, and secondly, research articles published only in the English language. The research team obtained 12,757 publications, and extracted publication information from each article including title, author(s), institution/organization, source (journal title), funding, author keywords, cited reference count, publisher information, page count, ISSN, and subject category, among other sourced data. Subsequently, the literature unrelated to wasp was screened out manually. Publication information of 9554 papers was acquired and downloaded as .txt files to export into ITGInsight for data cleaning, refinement and further analysis. ITGInsight were powerful text mining, data cleaning, and visualization tools. Research publications were cleaned by checking the columns or fields and identifying incomplete details and wrong entries. In addition, ensured that fields contained data that were consistent with the field title. During the data processing and refinery, incorrect, duplicate, and missing entries were deleted to ensure accuracy in results. Finally, 9,436 articles were obtained for visual analysis. The comprehensive workflow was depicted in Fig. 1.

Data analysis

Refined data from 9,436 research publications were obtained from 2014 to 2024 for structured and unstructured analysis. This study focuses on investigating the research and development of wasp through bibliometric analysis of research articles within this scope of the study. This analysis contributors concerning country, journal and authors. Simultaneously, collaborations exist among countries, authors, and institutions in this field of study. Additionally, identifying trends, key issues, and hotspots in the field of wasp research directed attention to critical areas. Given this, analytical tools such as ITGInsight were used for data processing, analysis, and visualization of results.

Results

The number of literature and its growth trend analysis

The results revealed a steady increase in the cumulative number of publications on wasp research, rising from 750 in 2014 to 9,436 in 2024 (Fig. 2A). Although annual publication numbers fluctuated between 2021 and 2024, the overall trend was upward, with the cumulative total showing consistent growth (Fig. 2A). An exponential growth function ($y = 8 \times 10^{-200} e^{0.2312x}$) was fitted to the cumulative publication data, revealing a strong correlation with publication year (R^2=0.9309). This robust correlation indicates that wasp research has expanded considerably over this period. Consequently, a growing interest in wasp research is evident over the preceding decade.

Analysis of national publications and collaborations

Geospatial analysis revealed productivity patterns in wasp research across countries. The United States was recognized as the primary contributor, with 2,365 papers published, representing 25.06% of the total. China produced 1,469 papers,

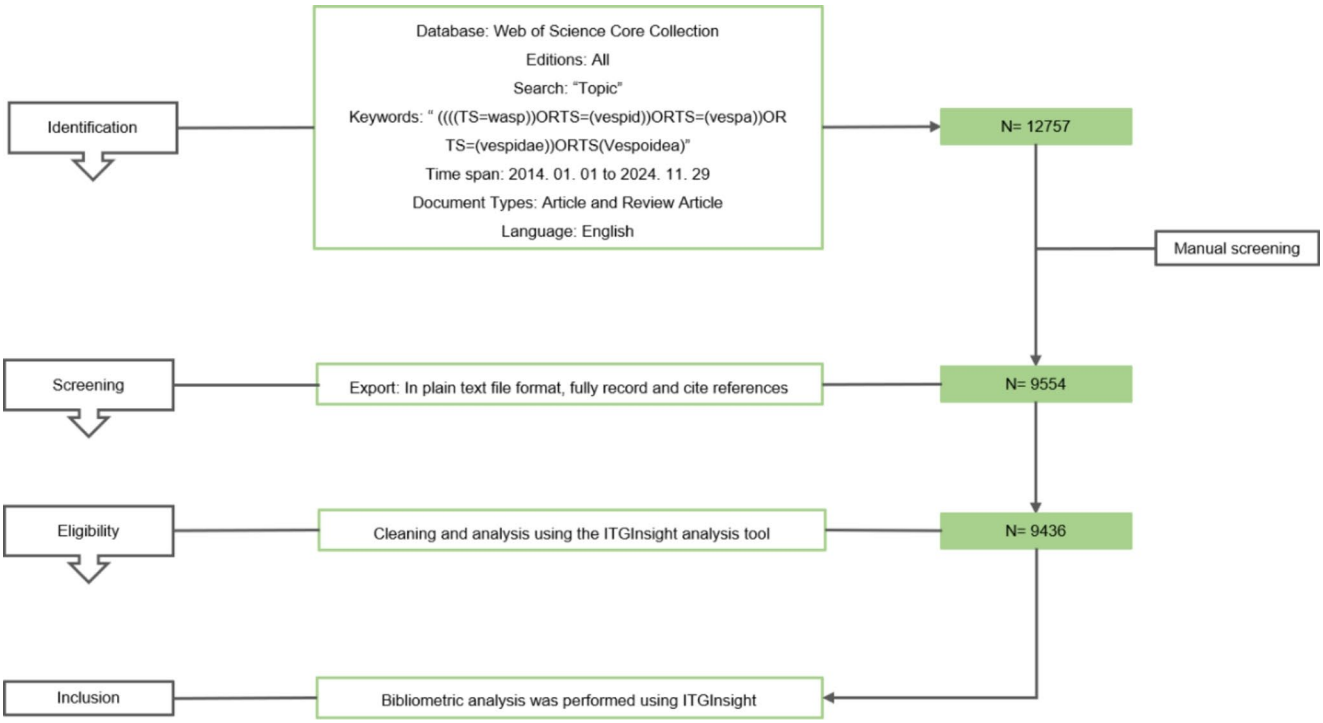

Fig. 1 Flowchart of publication selection process

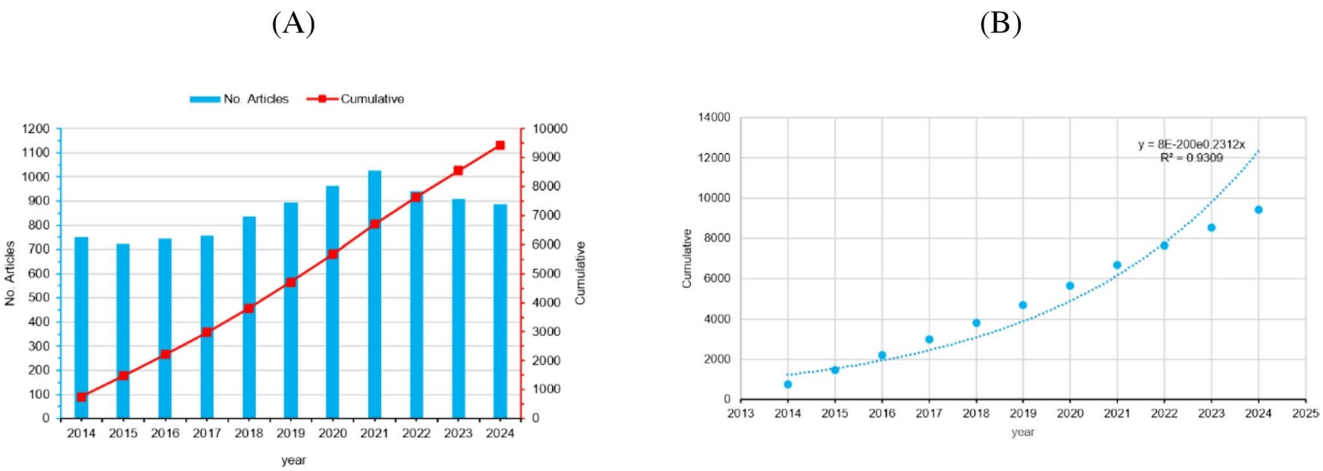

Fig. 2 (**A**) Annual and cumulative number of articles for wasps. Note: the red curve represents the cumulative number of articles for each year. (**B**) Correlation between cumulative number of publications and year of publication

constituting 15.57% of the total. Brazil's output (1,068) was exceeded by that of the United States and China. Additionally, significant contributions to wasp research were made by countries including Germany (698), France (687), the United Kingdom (638), and Italy (566) (Fig. 3A, B).

Cooperation patterns among various countries were revealed through geospatial mapping visualization (Fig. 3C) and network topology analysis (Fig. 3D). Each country was represented by a node of a specific color; the direction and size of arrows between nodes were used to indicate existing regional cooperation. The directional arrows were employed to show initiator-receiver relationships, while arrow thickness was utilized to reveal collaboration volume between regions. In the top ten research collaborations, the United States was identified as the leader with the largest number of published papers. The highest cooperation volume was recorded between the United States and China (259 articles). This was followed by U.S. collaborations with Brazil (152 articles), Germany (132 articles), France (132 articles), and England (115 articles).

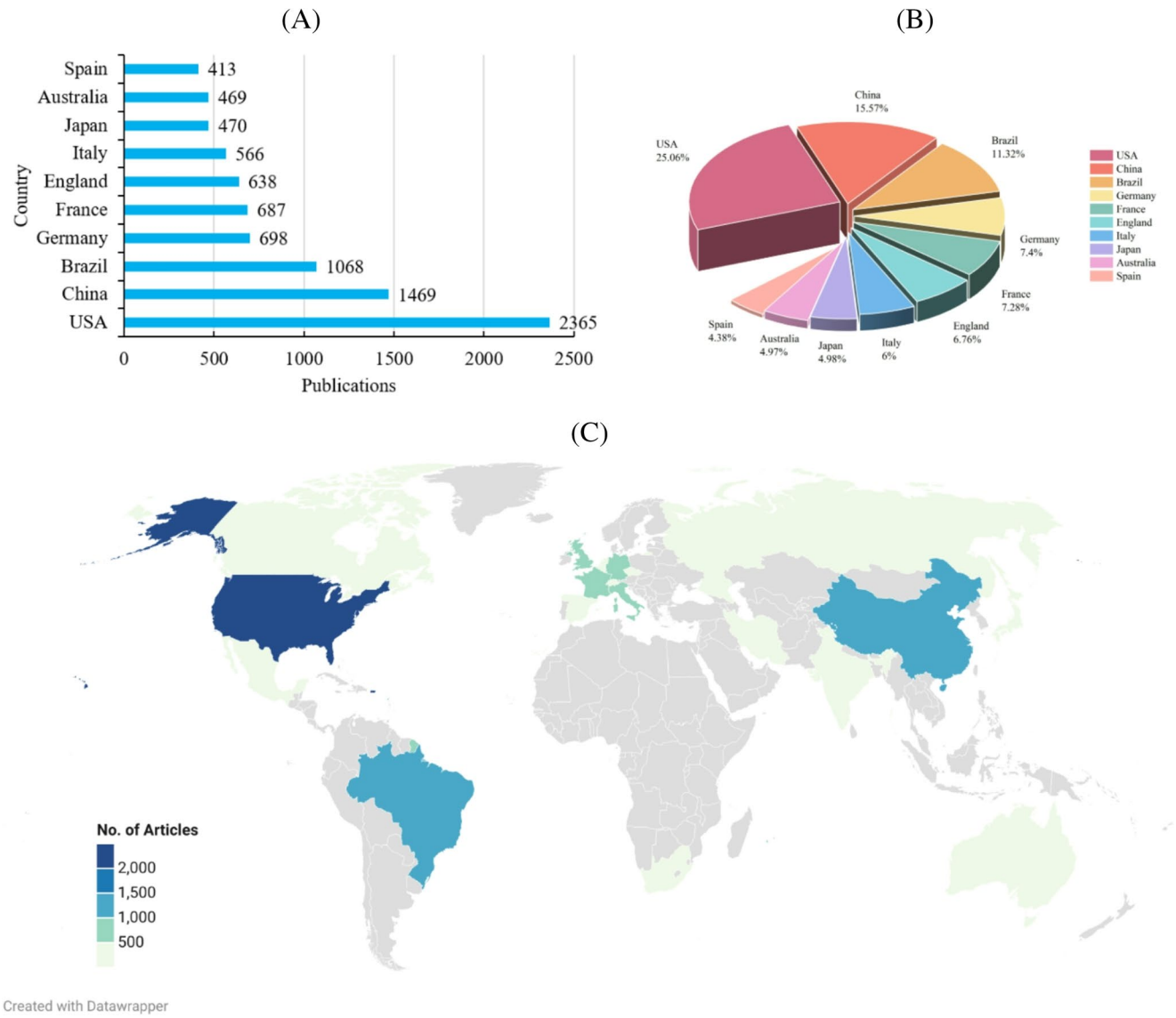

Fig. 3 The contribution of each country to wasps. (**A**) The top 10 countries in terms of the number of publications; (**B**) Chart of the proportion of publications of the top 10 countries; (**C**) A world map of the distribution of wasp research publications in the top 20 countries globally from 2014 to 2024; (D) The top 10 countries co-authored the string chart

Analysis of institutional publications and collaborations

Differences were observed among institutions in wasp research productivity (Fig. 4A, B). The Chinese Academy of Sciences (CAS) was considered the most productive contributor, with 321 papers published. It was followed by the University of Sao Paulo (237, Brazil), the Russian Academy of Sciences (216, Russia), and Zhejiang University (168, China). Output from other institutions had the American Museum of Natural History (135, USA), the Chinese Academy of Agricultural Sciences (135, China), Agricultural Research Service (135, USA), Natural History Museum (133, England), University of California (113, USA) and Wageningen University (103, Netherlands). In the collaborative network (Fig. 4C), node size was determined by the intensity of institutional participation, where larger nodes (e.g., CAS) were recognized as representing core roles in cross-border partnerships and knowledge dissemination. Interconnection nodes across countries were highlighted to demonstrate the universality of international cooperation.

Analysis of publications and cooperation among authors

As shown in Fig. 5A, B, significant differences in academic productivity were revealed among authors. The most prolific author was identified as James M. Carpenter

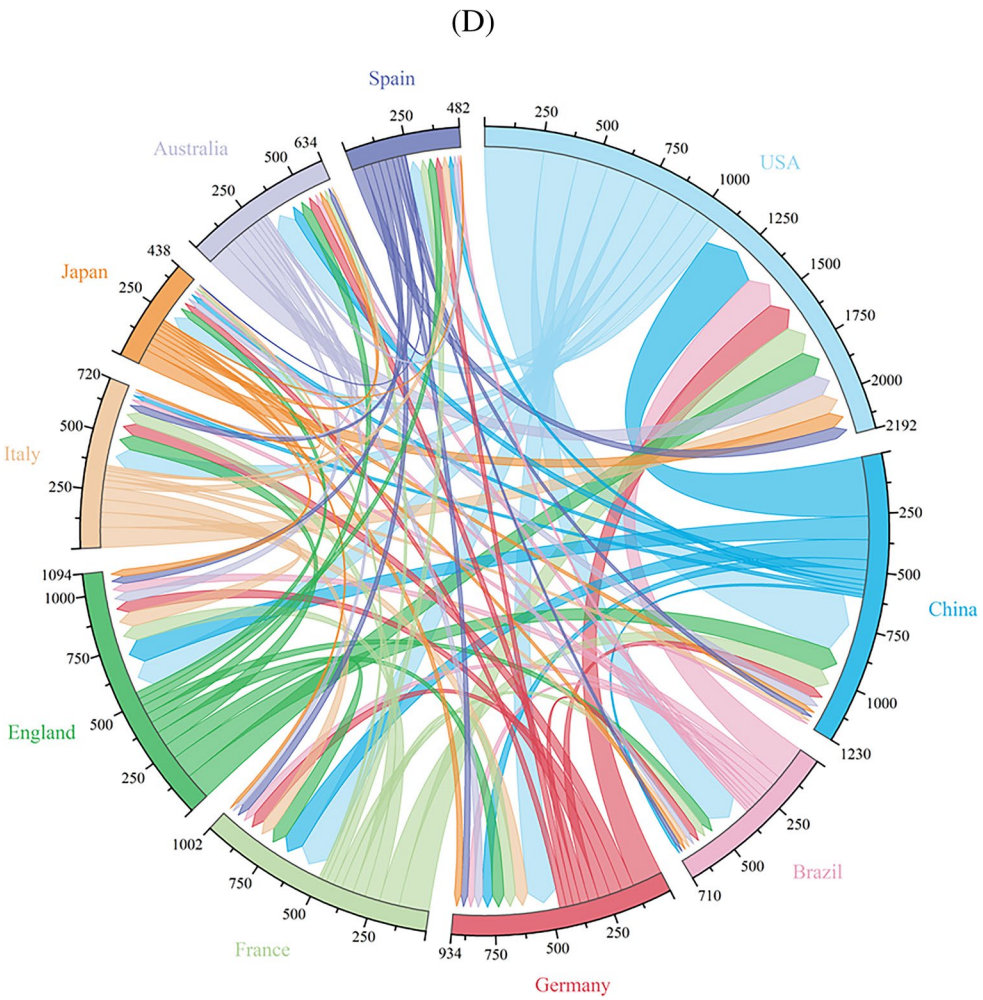

Fig. 3 (continued)

(75 publications). Other leading contributors were noted to include Juli Pujade-Villar (56), Cornelis van Achterberg (51), Qi Fang (50), and Stephen G. Compton (50). Additional highly productive authors were recorded, such as Petr Bogusch and Sergey A. Belokobylskij, with publication counts ranging from 42 to 50.

To enrich the collaboration perspective, the primary institutional affiliations and countries of these prolific authors were identified based on the publication data. This linkage revealed that these leading authors were predominantly affiliated with institutions in the United States, China, Spain, and the Czech Republic—countries which were also recognized as the most productive in the global analysis (Sect. 3.2). This alignment suggested a concentration of expertise and output within these key regions.

The co-authorship network was visualized in Fig. 5C. Node size was determined by an author's publication count, while link thickness was utilized to indicate the strength of co-authorship. Distinct collaborative patterns were observed within the network. Authors such as Carpenter, J.M. were found to have fewer connections, suggesting a more independent research profile. In contrast, authors like van Achterberg, C. and Belokobylskij, S.A. were identified as major hubs with extensive connections, indicating their central role in fostering broader collaborative research endeavors, which may underpin the strong international cooperation links identified in Sect. 3.2 (e.g., between the United States and European nations).

Cross-analysis of the issuing institution and the journal

The frequency at which research institutions published papers in specific journals was analyzed using a cross-matrix visualization (Fig. 6). In this matrix, rows represent research institutions, columns correspond to academic journals, and intersecting nodes (with numerical values) indicate the publication frequency of each institution in each journal. The frequency at which papers were published by each institution through specific journals could be more

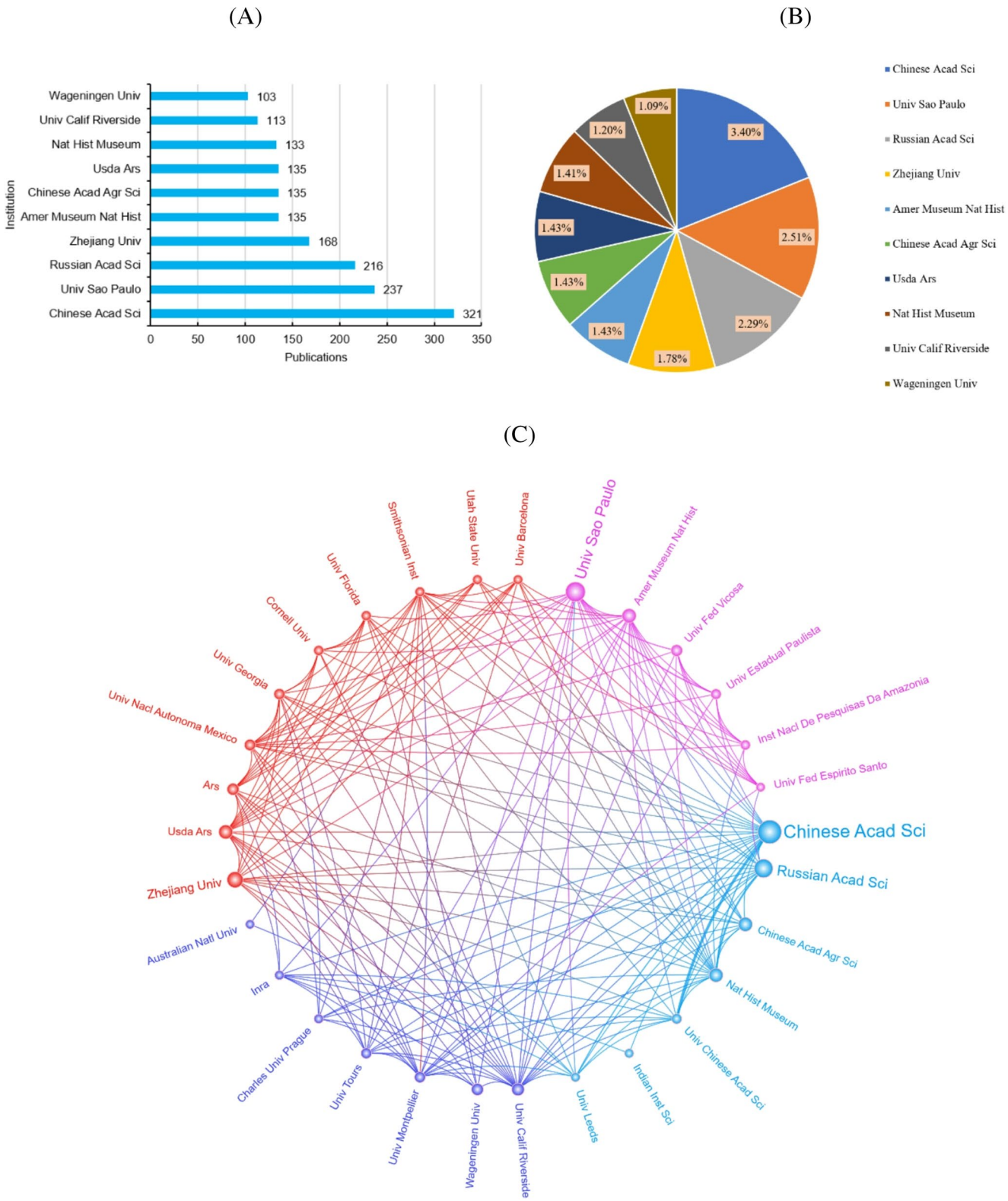

Fig. 4 Contribution of each institution to wasps. (**A**) Top 10 institutions in the number of publications; (**B**) Chart of the proportion of publications of the top 10 institutions; (**C**) Diagram of the inter-agency collaboration network

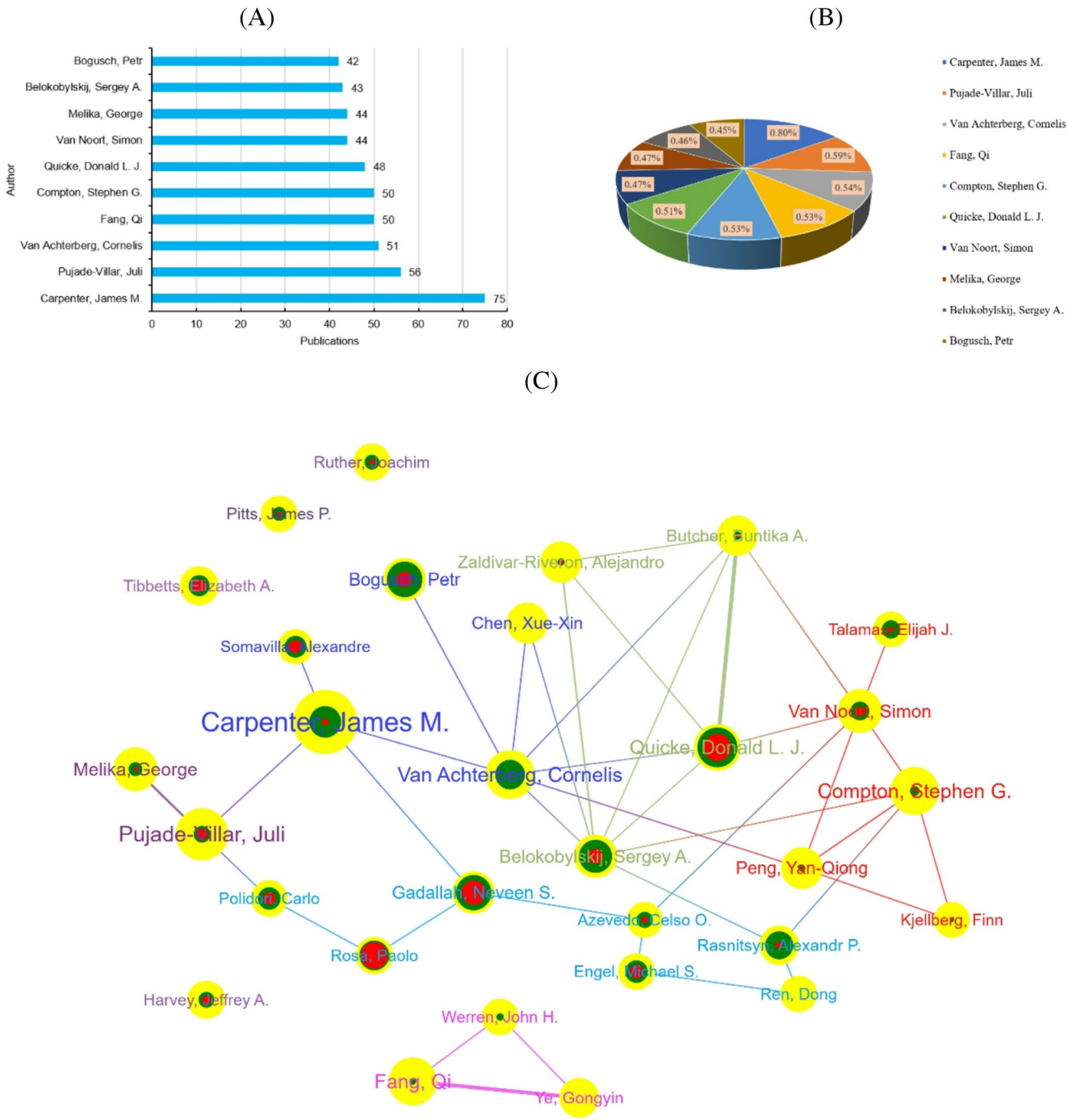

Fig. 5 Each author's contribution to wasps. (**A**) The top 10 authors in the number of publications; (**B**) The proportion of publications by the top 10 authors; (**C**) Collaborative network diagram of the authors

clearly analyzed using this matrix. Consequently, insights into the prominence of publishing journals and producing institutions related to wasps were gained, and future potential distribution institutions along with submission journal selection directions were revealed.

As shown in Fig. 6, cross-disciplinary research strength was demonstrated by Chinese Acad Sci through its publication distribution across multiple journal types. The orientation of applied entomology was highlighted by Univ São Paulo's focus on *Zootaxa* and *Sociobiology*. *Insects* were selected by Zhejiang Univ, while a combination of basic and applied research was reflected through *Zootaxa* and the *Journal of Hymenoptera Research (JHR)* preferred by Amer Museum Nat Hist. From published journals, *Zootaxa* was

Fig. 6 Matrix analysis of wasp institutional journals

identified as highly sought after by numerous institutions with the largest publication volume. Secondary publication volumes were recorded for *Insects*, *JHR*, and *Plos One*. The third gradient was composed primarily of journals including *Zookeys*, *Scientific Reports*, *Biological Control*, *Sociobiology*, and *Ecological Entomology*. The rise of emerging forces was highlighted by frequent participation of Chinese and Brazilian institutions, while the trend of interdisciplinary integration was reflected in active cross-journal interactions among multiple institutions. Collectively, connections between research breadth, journal positioning, and dynamic adjustments in global scientific forces were sketched, providing visual support for subsequent analysis of institutional cooperation models and journal selection strategies.

Keyword frequency analysis of wasp

Emergent words were utilized as quantitative indicators of academic hotspots, where its intensity (breakout rate) and duration were combined to form the spatio-temporal coordinates of the research paradigm. Through this approach, the popularity and cutting-edge viewpoints of specific research directions within the field were reflected. The breakthrough rates of these keywords were represented by parenthetical values. This breakout rate was defined as the rate of change in word frequency—a criterion employed to examine frequency change levels within given time periods. It was used to calculate breakthrough indicators and quantitative changes for primary keywords. Breakout rate indicator values were displayed after each keyword, while the historical occurrence of keywords was represented by red lines.

Through keyword emergence analysis, 11 high-frequency terms (Hymenoptera, Transcriptome, Poland, Chemical Signature, Cretaceous, Cloning, etc.) were identified. Their time spans were delineated by red lines and year markers (Fig. 7). "Hymenoptera" was maintained in the spotlight with a leading breakout index of 0.0151 and was distinguished terminologically. Transcriptome was observed to gain prominence after 2015 and remained a persistent hotspot. "Poland" was repeatedly emphasized during 2016, 2018, 2021, and 2023. Furthermore, "Eumenine Wasps", "Pollinating Wasp" and "Lectotypification" were recognized as keywords emerging exclusively in recent years.

As shown in Fig. 8A, research focus was visually presented through the word cloud. The popularity of parasitoid wasp applications in biological control was reflected by the

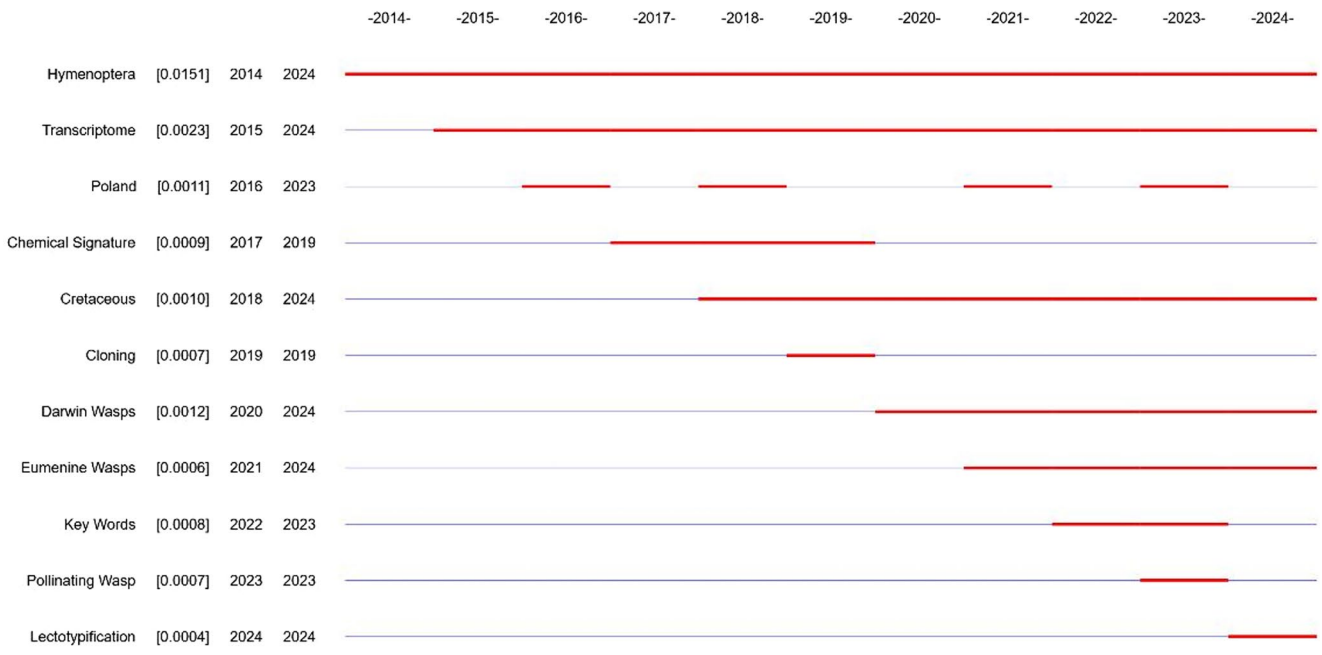

Fig. 7 Analysis of the top 10 keyword breakthroughs on wasp

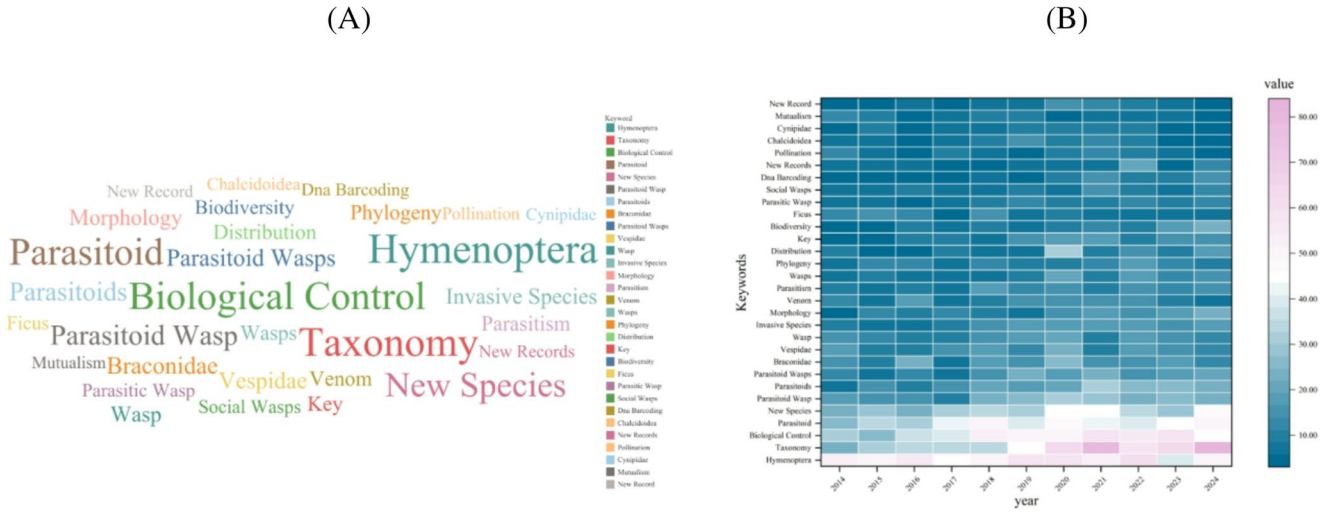

Fig. 8 Analysis of the top 30 keywords of wasp ranking. (**A**) The word cloud image of the key words; (**B**) Heat map of key words

prominent display of "Biological Control" and "Parasitoid Wasps". "Taxonomy" and "Hymenoptera" were positioned at the visual core, highlighting taxonomy's fundamental role in wasp research. The presence of "New Species", "Morphology", and "Phylogeny" suggested that taxonomic research was frequently accompanied by morphological identification, phylogenetic analysis, and new species discovery.

Temporal dynamics were further revealed through heat maps (Fig. 8B). A significant increase in popularity for "Taxonomy" and "Hymenoptera" was observed since 2019. When combined with word cloud weights, this indicated that wasp taxonomy research had continued to deepen in recent years. The continuity of biological control as a classic application direction was demonstrated by the long-term equilibrium of its thermal signature. The popularity of "New Species" was observed to fluctuate and rise from 2017 to 2021, echoing taxonomic trends. This pattern suggested that regional surveys or technological innovations (e.g., "DNA Barcoding" from the word cloud) contributed to new species reporting. Keywords including "Parasitoid Wasps" and "Braconidae" were maintained at consistently high popularity levels. When evaluated alongside "Biological Control", the ecological functions (pest control) and diversity research of parasitoid wasps were established as long-term focal areas.

Subject word analysis

A thematic evolution model was integrated into ITGInsight, enabling systematic identification of emerging patterns and dynamic shifts through temporal mapping of conceptual transitions. Node dimensions were scaled to annual keyword emergence intensity, and directional connections indicated thematic derivation or convergence patterns. Topic evolution analysis was conducted to elucidate processes governing thematic emergence, extinction, intensification, attenuation, aggregation, and fission, with evolutionary patterns reflecting the historical contextualization of disciplinary knowledge. As demonstrated in the thematic evolution analysis of scientific resources (Fig. 9), dominant themes over the past decade included "new species", "natural enemy", "parasitoid wasp", "first time", and "biological control", which exhibited progressive annual growth in frequency. Initial investigations (2014–2016) prioritized "new species", "parasitoid wasp", "natural enemy" and "biological control", which were the research focuses. A notable shift was detected in 2017, when "first time" emerged as a prominent keyword cluster, followed by intensified focus on "parasitoid wasp" and "host species" during 2018–2019. Subsequent progression (2020–2024) maintained high frequency usage of "new species", "parasitoid wasp" and "biological control", meanwhile, "honey bee" and "invasive species" were also noticed.

Analysis of wasp research fields

As shown in Fig. 10A, the peak position in publication volume from 2014 to 2024 was consistently held by "Entomology" highlighting its core role in wasp taxonomy, morphology, and fundamental biology research. This dominance was complemented by "Zoology" and "Environmental Sciences & Ecology" which maintained a high publication scale throughout the period. Group identification and system positioning were anchored by the former discipline, while ecological niche analysis and interaction relationship exploration were supported by the latter two.

Figure 10B was shown to illustrate the evolution of the wasp research field from 2014 to 2024. Different colored bars were used to represent different research topics, while the lines were employed to indicate the correlations and evolutions among the topics. From 2014 to 2024, research related to wasps was mainly focused on the fields of "Entomology", "Zoology", and "Environmental Sciences & Ecology". First, during the early stage (2014–2016), "Entomology" was dominant, and relatively high proportions were held by "Zoology" and "Environmental Sciences &

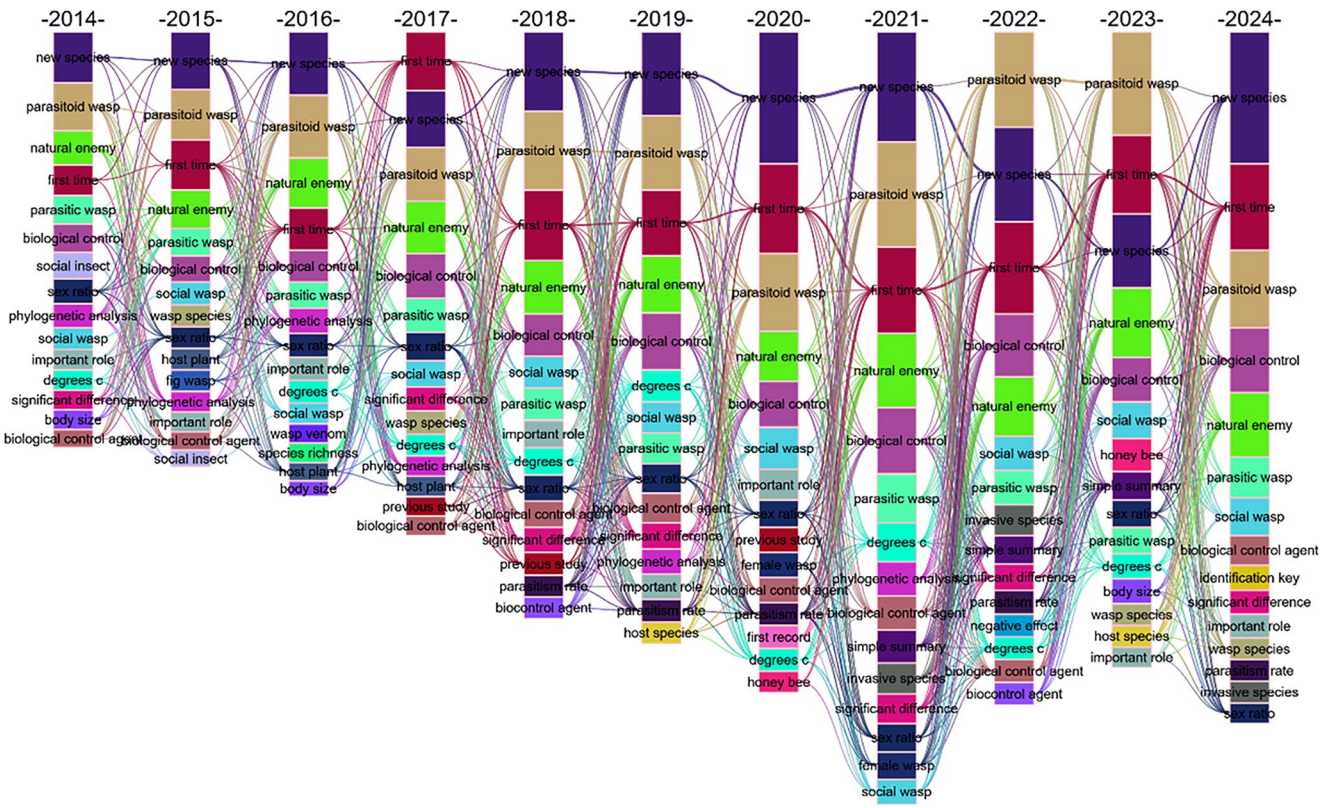

Fig. 9 Diagram of wasp subject word evolution

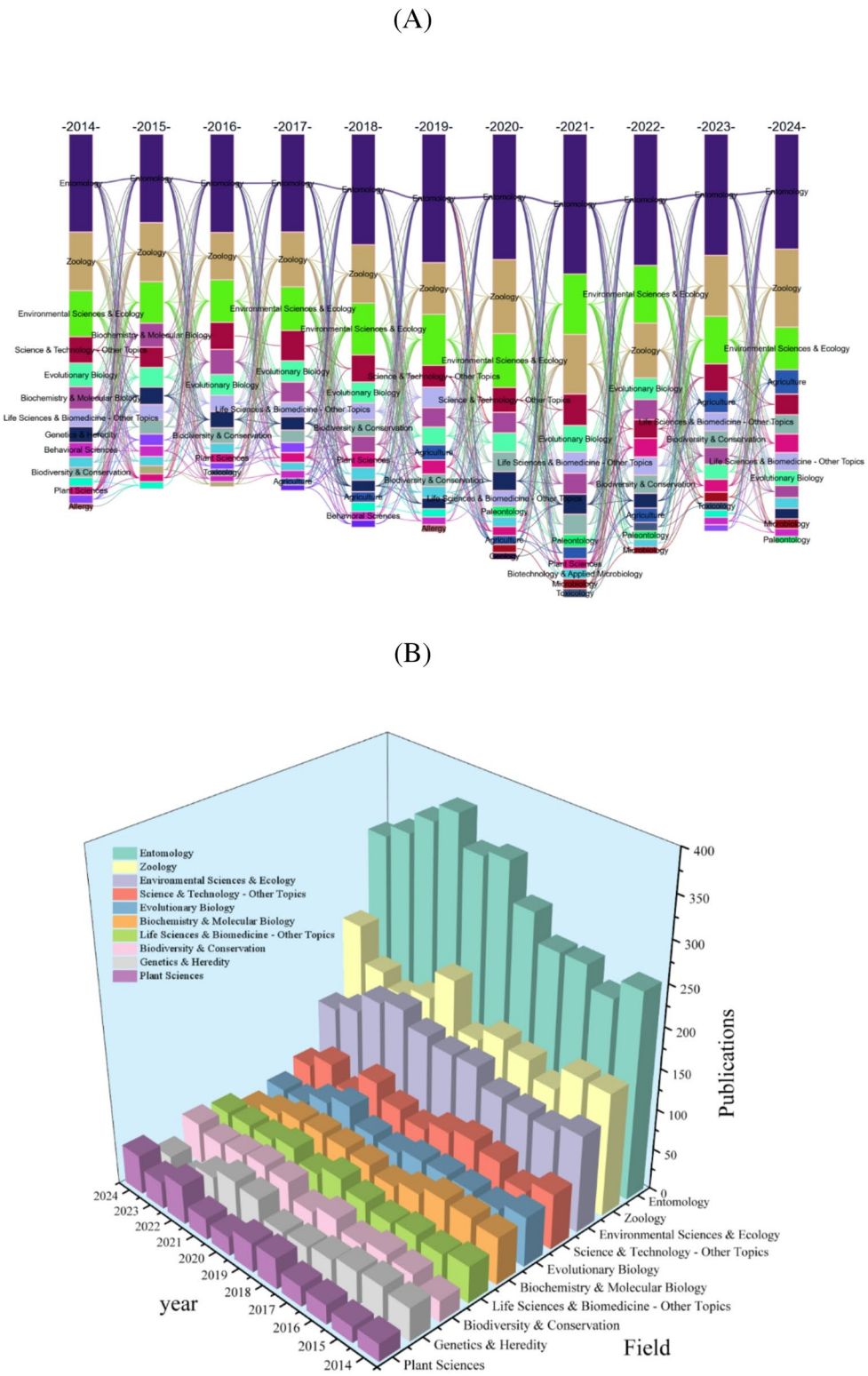

Fig. 10 (**A**) Cross-domain chart of the top 10 years in terms of the number of articles published by wasps; (**B**) Evolution diagram of wasp research field

Ecology". Subsequently, from 2017 to 2019, an increase was observed in the proportion of research in fields such as "Evolutionary Biology" and "Biochemistry & Molecular Biology". Finally, from 2020 to 2024, research in fields such as "Biotechnology & Applied Microbiology" and "Agriculture" was gradually observed. Furthermore, these three fields were consistently maintained as the primary research fields throughout the past ten years.

Discussion

Publishing trends

Over the past decade (2014–2024), a significant growth trend was maintained in the field of wasp research. This was reflected in the statistically positive trajectory observed in the cumulative publication index, and the high fitting degree of the exponential growth function (R^2=0.9309) was considered not only to reflect increased academic attention to wasps, but also to reveal the synergistic effect of multiple driving factors. However, between 2021 and 2024, fluctuations in the number of publications were observed, and their causes were identified as multi-faceted. Possible reasons include: First, the ongoing impact of the global COVID-19 pandemic (2020–2023) was highlighted(Obrenovic et al. 2024; Riccaboni and Verginer 2022). As wasp research often involved cross-border cooperation and field investigations, data collection was severely delayed and research progress was hindered, which was directly linked to publication declines(Raynaud et al. 2021). Second, discernible changes have been noted in the broader publishing environment, with one striking manifestation emerging in 2024: academic journals across various disciplines universally encountered significantly extended review processes. This lengthening of the review cycle, which affected both established journals and emerging publications alike, was marked by prolonged intervals between manuscript submission and the first round of reviewer feedback, as well as delayed final decisions due to factors such as increased editorial workloads, stricter evaluation criteria, and challenges in securing timely responses from peer reviewers. Concurrently, layout constraints led high-quality journals to prefer highly innovative research articles, which was recognized to increase publication difficulty for conventional studies. Furthermore, continuous elevation of experimental ethics requirements increases compliance costs and time investments, indirectly affecting research efficiency and publication speed(Guillot et al. 2023). Finally, shifts detected in research funding and journal preferences are reflected in the fact that in recent years, interdisciplinary research (e.g., ecology-artificial intelligence integration) has been increasingly favored by journals, while national funding has been redirected toward such fields(Ryo 2024). Consequently, traditional taxonomy was evaluated as less innovative, resulting in reduced resources for basic biological research and threatening its sustainability. Therefore, enhancement of capabilities to address external shocks and improvement of research innovativeness were deemed crucial for maintaining healthy development. Notably, increased research funding and strengthened institutional support were provided across multiple countries, establishing foundations for effective collaboration among researchers, institutions, and nations, which were expected to promote continued advancement in this field(Pohl 2020).

National publishing trends and cooperation

Among the 9,436 scientific publications analyzed, research papers from the United States accounted for 25.06%, highlighting its significant dominance. This status was mainly attributed to the world's largest research funding system and top-tier university network maintained by the United States, which provided strong support for wasp research(Ridwan et al. 2024). China was ranked second with 1,469 papers (15.57% of global output). China's southwestern regions (e.g., Yunnan) were identified as a global biodiversity hotspot where an extremely rich variety of wasp species was documented, establishing a unique natural sample bank for taxonomic research(Chen et al. 2024; Zhang et al. 2022). Third place was occupied by Brazil (1,068 articles), whose advantage was rooted in the world's largest tropical rainforest ecosystem(Gomes et al. 2020). Within this system, high wasp diversity was recorded, and long-term focus was given by local scholars to species surveys and ecological service functions. Notably, China, the US, and Brazil were recognized as the most active countries in international cooperation. This regional distribution pattern was formed through two key factors: on the one hand, technological transformation advantages were demonstrated by the USA and China(Zhu et al. 2021). on the other hand, the world's richest wasp species resources were concentrated in Brazil. Consequently, advanced technology sharing combined with natural environmental resources was observed to significantly enhance overall research quality(Fu et al. 2021).

Institutional publications and collaborations

Institutional output was shown to exhibit a highly centralized trend, primarily concentrated in four core institutions: Chinese Acad Sci, Univ São Paulo, Russian Acad Sci, and Zhejiang Univ. Among these, the output of the Chinese Academy of Sciences was particularly distinguished. This prominence was enabled by its abundant scientific research

resources and sustained investment in wasp research(Mi et al. 2021). These institutions have showcased their strengths through sustained high-quality outputs in specialized domains, as exemplified by the Chinese Academy of Sciences' cross-journal distribution and the University of São Paulo's concentration on *Zootaxa* and *Sociobiology*.

The reinforcement of this core status was enabled by international cooperation networks. Close collaborative ties were maintained by Chinese Acad Sci and Univ São Paulo with other institutions, strongly confirming that in contemporary scientific environments, which established extensive strategic partnerships was considered essential for sustaining institutional research competitiveness.

A complex cooperation network was formed through close connections among numerous global institutions and universities. This demonstrated that international collaboration had become the dominant paradigm for advancing scientific progress in the field. Regardless of size or location, all institutions were observed actively collaborating across borders to integrate complementary resources, technologies, and knowledge, thereby jointly driving research implementation and disciplinary advancement(Rossoni et al. 2024).

Author publications and collaborations

At the author level, James M. Carpenter from the United States (75 articles) was distinguished the highest publication count. His significant quantitative advantage was recognized as establishing his status as the discipline's most prolific contributor. Immediately following, indispensable roles were played by Juli Pujade-Villar from Spain (56 articles), along with Cornelis van Achterberg (51 articles) and Qi Fang (50 articles) from China. On the other hand, through in-depth analysis of author collaboration networks, Cornelis van Achterberg was identified as the central hub. Crucially, such networks were leveraged to integrate cross-disciplinary expertise, driving wasp research toward comprehensive interdisciplinary development. Consequently, expansion and deepening of these collaborative frameworks were deemed necessary for subsequent research. Establishment of new cooperative relationships was encouraged among authors to jointly explore novel research directions and breakthroughs(Maltseva and Batagelj 2022).

Explore research hotspots through keyword breakthroughs and heat map analysis

The early research landscape was dominated by topics such as "Taxonomy", "Biological Control", and "Parasitoid research", mainly because they were considered indispensable for understanding the ecological functions and application value of wasps(Brock et al. 2021). The rise of technology-driven hotspots (since 2015) was marked by "Transcriptome", which rapidly became a persistent hot topic starting in 2015(Yan et al. 2016). This was driven by the significant reduction in the cost of next-generation sequencing technology in the 2010. Consequently, transcriptome analysis was established as a routine and powerful tool for studying the gene expression, venom composition, and social behavior mechanisms of wasps(Tan et al. 2020). An emerging focus "Invasive Species" was observed as research deepened and global species mobility intensified. Concerns about the risk of wasp invasion were significantly increased, prompting extensive attention to research related to "Invasive Species" around 2018(Oi et al. 2024). In traditional fields (in recent years), wasp deepening was noted in topics such as "Taxonomy", "Biological Control" and "Parasitoid", which showed an increasing trend(Shimbori et al. 2023). Wasp was benefited by the advancement of research techniques (e.g., more advanced gene sequencing technologies) and was driven by the expansion of research perspectives(Van Klink et al. 2022). These factors jointly promoted in-depth studies of wasps toward microscopic mechanisms and macroscopic evolution levels. For future directions, continued focus was suggested on the discovery of new species, deep analysis of relationships between morphological characteristics and biological functions, and the construction of a more complete phylogenetic tree(Fernandez-Triana et al. 2023). Meanwhile, biological control research could be continuously optimized to provide more efficient and precise strategies for integrated management of agricultural and forestry pests(Cacho and Hester 2022).

Analyze the research hotspots through the evolution analysis of subject terms

The research topic of wasps was shown to have a clear evolution trajectory that expanded from the basic to the in-depth and from the macro to the micro. Early studies were primarily focused on directions such as "new species", "parasitoid wasp", and "biological control", which were mainly driven by the urgent need to improve the construction of wasp species banks and explore its ecological service value(Brock et al. 2021). Subsequently, the research perspective was gradually broadened: First, it was extended to an in-depth exploration of the relationship between host and parasitic wasp species; subsequently it was extended to the study of interactions between wasps in ecosystems(Fardiansah et al. 2025; Gobatto et al. 2023). Finally, in recent years, in-depth molecular-level analysis of wasps was conducted. The deepening and expansion of this research topic were driven by the close correlation between wasps in their ecological niches, along with new research perspectives and powerful tools provided by the rapid development of

molecular biology techniques for analyzing wasps' biological characteristics(Luo et al. 2022). These factors were jointly credited with promoting continuous research development toward microscopic mechanisms (molecular level) and complex interspecific interaction relationships. Finally, "Vespidae Venom" and "Dna Barcoding" also demonstrate the role of wasp in the medical field.

Analyze the research direction through the evolution analysis of the research field

The distribution of disciplinary fields in wasp research was shown to exhibit a clear evolutionary trajectory. Initially, research was highly concentrated in the fields of "Entomology", "Zoology", and "Environmental Sciences & Ecology", primarily because these disciplines were recognized as the basis for understanding the basic biological characteristics of wasps and its functions in ecosystems(Kishinevsky and Keasar 2022). Subsequently, with the deepening of research and advancements in technical methods, increased attention was gradually given to the fields of "Evolutionary Biology" and "Biochemistry & Molecular Biology". This shift was driven by researchers' exploration of wasps' genetic characteristics and evolutionary patterns at deeper levels, such as molecular mechanisms and evolutionary processes(Orr et al. 2024; Santos et al. 2022). In recent years, significant emphasis was placed on applied fields such as "Biotechnology & Applied Microbiology" and "Agriculture". This trend was propelled by the increasingly prominent application value of wasps in medicine and agricultural ecosystem services, which strongly promoted the vigorous development of applied research(Bitume et al. 2024). It should be emphasized that these fields were not isolated but interrelated and mutually reinforcing, jointly promoting the comprehensive development of wasp research. Furthermore, the emergence of the "Other Topics" category suggests a reflection of nascent interdisciplinary directions or marginal cross-disciplinary fields(De León et al. 2025). As research deepened, these directions could be expanded and refined, injecting novel methods and perspectives into wasp research to generate innovative achievements.

Theoretical and practical implications of bibliometric analysis

A bibliometric analysis of wasp research was conducted using the ITGInsight tool, providing important insights for ecology, biological control, and medicine. The knowledge graph was deconstructed through visual analysis, revealing the evolution of core themes and interdisciplinary characteristics of wasp research, with significant application potential being demonstrated particularly in biological control.

Firstly, core research clusters (wasp venom, ecological regulation, biological control technology) were identified through keyword co-occurrence and hotspot analysis, and theoretical connection gaps were discovered across fields. For instance, a gap in mechanism analysis was observed between research on antitumor activity of wasp venom peptides and targeted drug carrier development. This gap had given rise to key theoretical propositions including toxin structure modification specificity and synergy of nano-delivery systems, laying a theoretical foundation for medicinal development. In practical applications, bottlenecks in biological control technology transformation were accurately identified by the ITGInsight visualization tool. High-value innovation directions such as "development of interspecific pheromones between wasps and pests" and "optimization of large-scale breeding technologies" were clearly defined, thus guiding scientific research resources to converge in ecological and biological control fields. For agricultural pest management, the regulatory potential of wasps as natural enemies was revealed, providing empirical evidence for promoting the standardized demonstration project of "Colony Behavior Regulation - Field Release Technology" and helping to reduce reliance on chemical pesticides. In ecological protection, strategic references for biodiversity management in agroforestry ecosystems were provided by the trend of "evolution of wasp pollination function". Additionally, the constructed quantitative analysis framework could be replicated and applied to similar insect resource studies. Through dynamic data tracking, a full-chain knowledge graph from basic research to bioconversion technology could be constructed, significantly enhancing technology transfer efficiency. This interdisciplinary integration paradigm not only deepened theoretical understanding but also directly empowered innovation and practical implementation of biological control technologies.

Implications of the improved bibliometric analysis for policy and decision-making

The fine bibliometric analysis proposed in this study was provided as an in-depth understanding of the evolution of wasp research and was laid as the foundation for policies and decision-making in ecology, agronomy, and medicine. By mapping out prominent trends, this analysis serves as a valuable tool for policymakers and industry stakeholders, with specific applications including guiding healthcare and biomedical policies, informing agricultural and ecological strategies, supporting industrial innovation, and optimizing strategic research funding and cooperation.

Firstly, key technology clusters such as "bee colony behavior regulation" and "large-scale breeding" should be analyzed and identified. Priority could be given to

formulating subsidy policies for "integrated application of ecological pest control technologies for wasps", and establishing standardized bases and release procedures in fruit and vegetable production areas to reduce pesticide dependence. Subsequently, in the field of ecology and public security, guiding documents for habitat protection and security prevention and control be formulated in conjunction to standardize development risk assessment. By leveraging the achievements of "Standardization of First Aid Techniques for Bee Venom Allergy", efforts should be made to encourage health and wellness departments to be improved in relevant emergency response norms, and to be built in community emergency networks and antivenom serum reserves. Finally, in terms of international cooperation, based on the technological complementarity among China, the United States, and Europe, efforts should be made to promote the international joint research project on ecological regulation and resource utilization of wasps, and to facilitate technology sharing and the joint construction of venom databases. Despite challenges such as climate adaptability and safety standards, the metrological framework constructed in this study was provided as a core tool for the above-mentioned precise policy implementation. Through the pilot feedback mechanism and popular science education, the huge ecological and economic value of wasp research in the field of biological control could be systematically released.

Limitations of the current study

Bibliometric analysis was considered a useful tool for systematic review and assessment of research and development in a specific field. The analysis of spatio-temporal growth trends, research and innovation hotspots and development limitations of wasp-published articles were outlined. However, it was noted that by searching terms associated with wasps within documents' keywords, titles, abstracts, authors, and assignees to retrieve data from the WoS Core Collection, some articles contributing to the field might have been missed. This limitation is underscored by searches in other databases; for instance, using alternative terms such as "hornets" or "yellowjackets" in conjunction with "bibliometrics" can yield additional relevant results that were not captured by our WoS query. Consequently, publications using such alternative terminology were potentially excluded from our analysis. Moreover, screening, filtering, and synonym merging during data processing were recognized as processes subjected to minimal subjectivity. For future studies, the use of multiple databases beyond WoS was recommended to enable comparison and coverage of additional relevant information.

Conclusion

This study conducted a bibliometric analysis of 9,436 publications, depicting the evolution of global wasp research (2014–2024) and revealing a field increasingly defined by its involvement in pressing societal challenges. The collaborative infrastructure has been integrated into a strategic, application-oriented network centered on major contributors such as the United States, China, and Brazil, reflecting the attention various countries pay to global challenges in wasp research. While these powerful alliances reflect a concern for large-scale issues, the relative isolation of some experts was identified as a factor hindering the timely sharing of their foundational biological knowledge with the broader community. This impedes the application of such knowledge to practical problem-solving, resulting in an underutilization of expertise. Furthermore, the sustained prominence of "Biological Control" and "Taxonomy" is directly linked to the urgent needs of sustainable agriculture and biodiversity conservation. The rise of "Transcriptome" research marks a key shift toward solving mechanistic puzzles in venom biochemistry and species discovery. Through this bibliometric approach, changes in the global research direction of wasps are clearly presented, providing an overview of recent progress for researchers worldwide and offering a reference for future research goals. The pathways for the dissemination and translation of wasp research outcomes are also clarified. Journals such as *Zootaxa* are highlighted as important channels for disseminating findings, providing researchers with more platform options to showcase their work and helping to ensure the prompt visibility of new results. These findings provide a strategic and evidence-based foundation for guiding future research. To address the identified challenges through actionable goals, several priorities are suggested, such as optimizing the deployment of parasitic wasps for targeted pest management. In addition, the development of genomic tools for rapid species identification in conservation contexts is recommended, and the establishment of systematic bioprospecting projects is proposed to formally link taxonomic expertise with pharmacological screening. Most importantly, the promotion of collaboration is emphasized as indispensable, particularly cooperation that builds bridges between isolated taxonomic experts and applied research teams globally.

This study clarifies that wasp research is evolving into a more coherent and problem-solving undertaking. By translating the identified problems into specific solution goals, such as integrating the knowledge of taxonomic experts and establishing interdisciplinary translation mechanisms, a problem-centered development roadmap has been

formulated. This roadmap aims to provide clear guidance for wasp research and to maximize the scientific and social impact of the field. It is intended not merely to stimulate further research, but to help address practical challenges in ecological restoration, sustainable agricultural development, and human health security. The ultimate goal is to ensure that more research achievements are produced in this field, that these achievements exert practical value, and that the societal significance of academic research is thereby enhanced.

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Data availability This bibliometric study used metadata from Web of Science Core collection. Derived datasets generated via ITGInsight platform are not publicly shareable due to licensing restrictions.

Declarations

Clinical trial number Not applicable.

Competing interests The authors declare no competing interests.

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