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Research Article

Bibliometric analysis of *Meloidogyne incognita* to explore the trends in scientific research

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Background: *Meloidogyne incognita* is a major pest in various vegetable production with very less management options. The scientometric analysis aims to give a comprehensive picture of *M. incognita*, a root-knot nematode (RKN) responsible for crop damage worldwide.

Methods: A thorough search of the SCOPUS database was performed using relevant keywords to identify relevant publications of the last 20 years. The bibliometrix package of R statistical programming language was used to generate compelling descriptive statistics, elaborate network visualizations, and other insightful scientometric metrics.

Results: The Journal of Nematology published a higher number of publications with 3212 citations. Aligarh Muslim University and Indian Agricultural Research Institute, India are the most productive institutions whereas, the National Natural Science Foundation of China funded the highest number of research projects. The quantitative analysis and statistics of SCOPUS data offer valuable insight into the research landscape, highlighting the most active nations, institutions, and authors, along with the most-cited articles and burgeoning research directions.

Conclusion: The study provided deep insight into the different research areas which may help to improve the understanding of research patterns and knowledge about *M. incognita*. Furthermore, the data generated here can be of potential value to researchers and policymakers interested in addressing the challenges associated with *M. incognita* infestations.

Keywords: *Meloidogyne incognita, bibliometric analysis, SCOPUS, scientific research*

Introduction

Root-knot nematodes (*Meloidogyne* spp.) are obligatory sedentary endoparasites, widely acknowledged as highly damaging pests to crops among all plant-parasitic nematodes globally. Their invasion via parasitic proteins disrupts the physiology and functioning of host cells, promoting parasitism and leading to decreased crop yields (Khan et al., 2023). The annual global crop loss attributed to Root Knot Nematodes (RKNs) was estimated to be between $80 billion and $157 billion (Taning et al., 2023). *Meloidogyne* species exhibit an exceptionally broad spectrum of hosts among various plant parasitic nematodes (Tauseef et al., 2021). *Meloidogyne* species including *M. incognita, M. javanica, M. hapla*, and *M. arenaria*, are commonly found in various climates, ranging from hot regions to areas with short winters (Ralmi et al., 2016). The chemical signals in the rhizosphere act as regulators between different plant species, potentially leading to direct or indirect impacts on nematode behaviours (Massalha et al., 2017). Root-knot nematodes infect plants initially at the elongation zone and migrate towards the root tips to penetrate the vascular cylinder, where they establish

a feeding site. Simultaneously, adjacent cells undergo division, resulting in the characteristic gall or root-knot formation, which disrupts root system development and leads to substantial reductions in crop yield (Kyndt et al., 2014). The management of RKNs has remained challenging due to factors such as their wide host range, the potential for rapid population growth within a single growing season, and the limited availability of effective control measures. Management strategies for *Meloidogyne* species involve utilizing cultural and agronomic practices, biological control using fungal and bacterial bioagents, host plant resistance, modern chemical nematicides, and their collective use (Walia & Khan, 2023). Bibliometric analysis provides quantitative insights into the impact of scholarly work, helping researchers and institutions gauge the significance and influence of their publications. It aids to identify emerging trends and key contributors within specific fields, facilitating informed decision-making and resource allocation. The precise description of bibliometric analysis is that it is a method of examining and interpreting citations in scholarly publications that integrates various frameworks, tools, and methodologies. This interdisciplinary approach has spawned diverse metrics, enabling a comprehensive understanding of the intellectual landscape within an academic field (Farooq, 2024). The application of bibliometric methods can uncover and map the accumulated scientific knowledge and the progression of established fields over time. The bibliometric analysis serves as a valuable instrument in pinpointing emerging trends, assessing journal efficacy, and delving into the intellectual framework of a particular field by examining existing literature (Kushartadi et al., 2023). Bibliometric analysis plays a crucial role in guiding research priorities, assessing research impact, and fostering collaboration within various scientific fields. The primary aim of this study was to evaluate the global research output pertaining to *M. incognita* through a bibliometric analysis of scholarly publications indexed in the SCOPUS database from 2004 to 2023.

Materials and methods

This research employed bibliometric analysis; a methodology that has become progressively utilized as a valuable tool for assessing research productivity across various scientific fields. This study used a scientometric approach to analyze the global research output on *Meloidogyne incognita* using the SCOPUS database. The majority of the international journals are covered in the databases. Since this study was based on data that was gathered from public databases and did not involve any direct interaction with human or animal subjects, ethical approval was not required in order to conduct this project. The literature search was conducted with the following keywords: "*Meloidogyne incognita*" choosing "TITLE-ABS-KEY ("*Meloidogyne incognita*")". For every published document to be included, the basic requirement is must. The time span for the literature search was set from 2004 to 2023, the year the study was conducted. Based on the information retrieved from the publications, the following data were extracted: title, year of publication, author details, country, institution, journal, and number of citations to the publication. Using the citation density metric, *i.e*., an average number of citations received per article and per year the annual trend of publications, most productive authors, institutions, journals and country contributions was evaluated.The search was conducted on the SCOPUS database, which is a comprehensive bibliographic database covering various scientific fields. The database includes peer-reviewed articles, conference papers, book chapters, and other sources of scientific information.

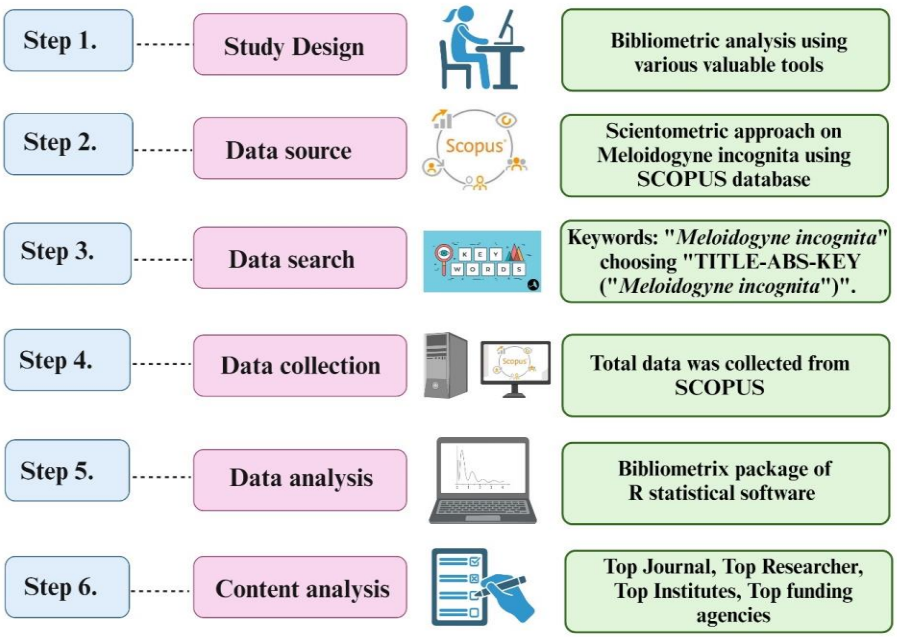

Figure 1. Schematic representation illustrating bibliometric analysis methodology.

The search results were downloaded in a CSV format, which was then imported into Bibliometrix package of R statistical software for further analysis. The data was cleaned, and duplicates were removed using R. Descriptive statistics such as the number of articles, authors, institutions, and countries were generated using R. Network visualizations were also created to visualize the co-authorship and co-citation networks in the literature.
The analysis also included the identification of the most cited articles, top authors, and active institutions in the field of *M. incognita* research. To accomplish this, R was used to generate a list of the top-cited articles, authors, and institutions. A timeline analysis was also conducted to identify the emerging research trends in the field. Overall, this methodology enabled a comprehensive analysis of the global research output on *M. incognita* using advanced data retrieval and analysis techniques (Figure 1).

Results

Based on SCOPUS documentation from 2004 to 2023, 3814 documents were extracted for bibliometric analysis. The aim of the study was to discuss pattern in *M. incognita* research around the globe (Table 1). Using the keyword *Meloidogyne incognita*, a literature search was conducted in order to locate relevant literature. There were 3814 types of documents analyzed with an average of 15.19 citations per document. A total of 3538 articles have been published, with 9481 authors contributing to these articles. From 2004-2023 there were 3814 documents, 3538 of them were articles, 67 of them were reviews, and 30 of the documents were book chapters. Figure 2 represents articles (93%), reviews (2%), book chapters (1%), conference papers (3%), erratum (<1%), notes (<1%), short surveys (<1%), and editorials (<1%), have been published.

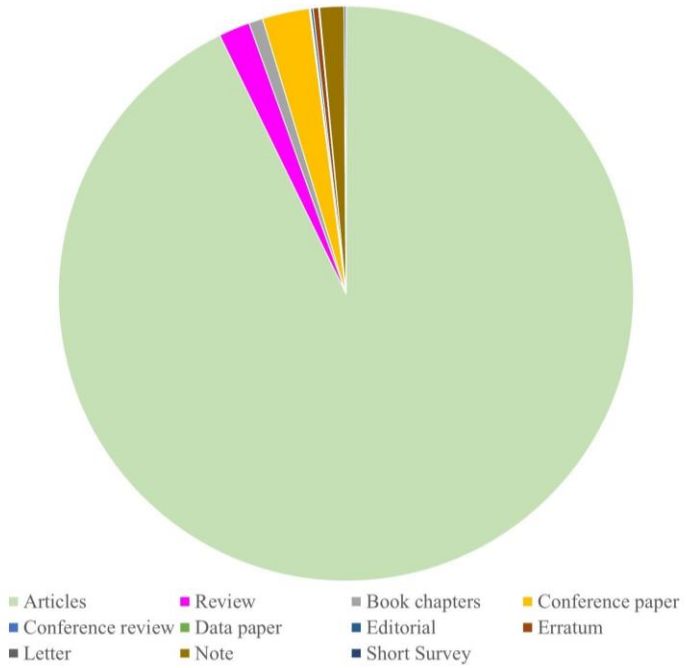

Figure 2. This figure shows a comprehensive overview of articles, reviews, book chapters, conference papers, conference reviews, data papers, editorials, erratum, letters, notes, and short surveys published on *Meloidogyne incognita*

Table 1. The information regarding data was retrieved from SCOPUS from 2004 to 2023

S. No.	Description results	Results
1	Data Source	SCOPUS
2	Keywords	*Meloidogyne incognita*
3	Period	2004-2023
4	Publication sources	738
5	Total documents	3814
6	Average citation per document	15.19
7	References	123321
8	Author's Keywords	6907
9	Authors	9481
10	Published articles	3538

Trends in scientific publication and citations

It has been found that 3814 documents have been retrieved from the total number of publications found in the SCOPUS database. The publications on *M. incognita* increased rapidly in 2011 and 2022 compared to the other years. An annual fluctuation in the number of articles published by the journal can be observed, on a yearly basis. Throughout the year 2019, 2020, 2021, 2022 and 2023, there were a total of 241, 271, 272, 305, 319 and 290 articles published by the journals. In 2017, there were 2.27 citations per year, which is the highest number ever received by a single year (Figure 3 (b)). As a result, the average number of citations per article ranged from 0.78 to 32.66 according to the study. Figure 3 (a) represents the publication trend of *M. incognita* has increased every year, which shows that this pest is actually of great economic importance.

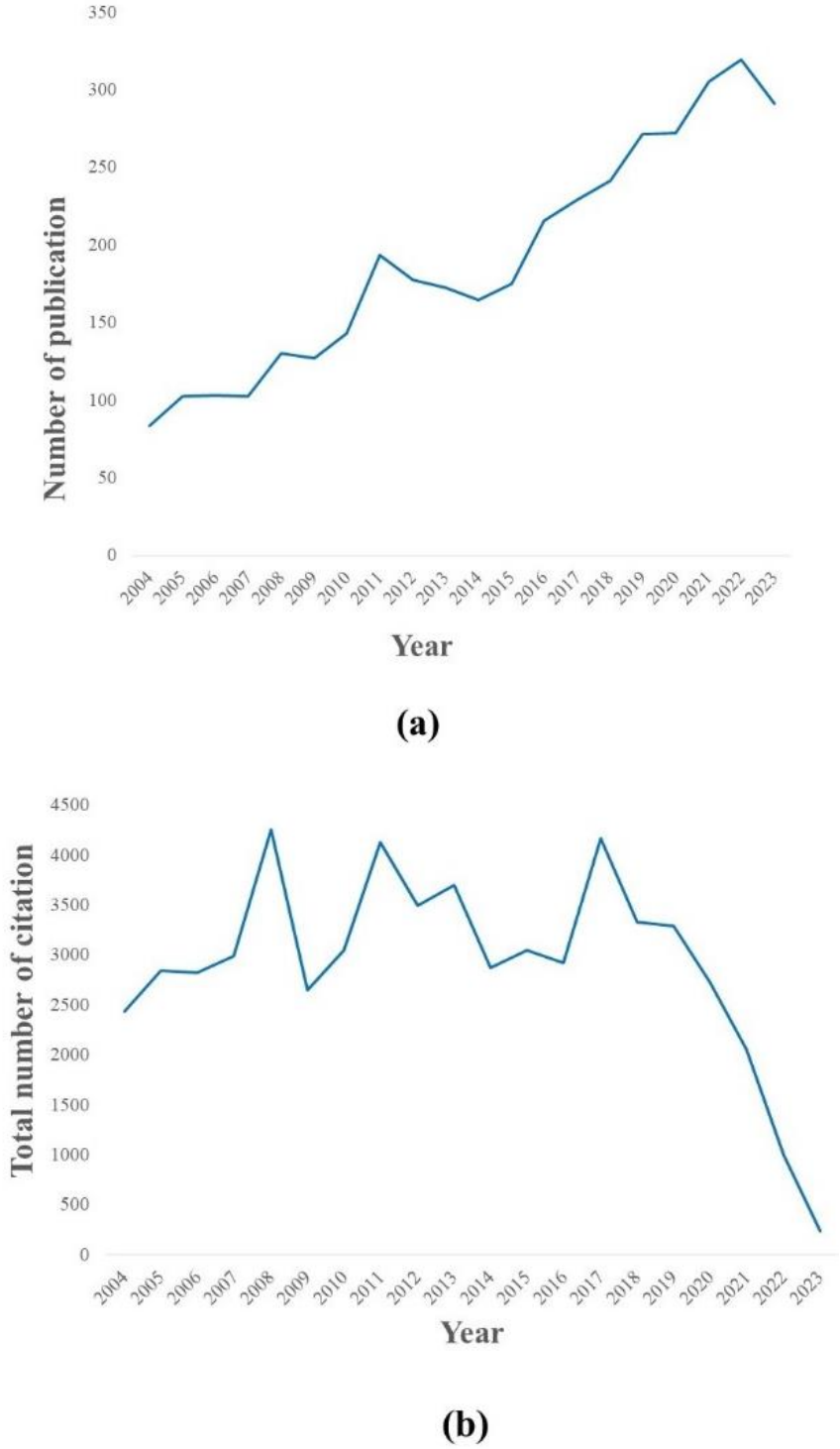

Figure 3. The trend of publication (a) and citation (b) from year 2004 to 2023

Leading Countries and international collaboration

The details of the citations have been generated for various countries, which allows us to see how the research productivity and impact of different countries varies. The United States have the highest number of citations (8390), closely followed by China (7073) and India (5544) with publications related to research on *M. incognita* (Figure 4 a). According to the results of this survey, the USA leads with the most citations, indicating that intensive work was carried by United States on this species of *Meloidogyne*. On the other hand, China is quite close behind with 7073 total citations, indicating that it has made significant contributions to research as well. A number of countries, including India (5534), France (3534) and Brazil (3055), have also displayed considerable total citations, reflecting their active participation in *M. incognita* research. There are countries which demonstrate a higher impact per article, indicating that their research publications are influential and of high quality.

Multinational institutions/organizations or individuals working together to achieve one or more common goals or objectives by collaborating at national and international levels. Figure 4 b represents the most frequent collaborations between China and the USA (61 collaborations), followed by Brazil and France (41 collaborations). The map illustrating international collaborations in *M. incognita* research highlights a wide range of countries contributing their expertise and resources to control RKNs. It was observed from the data that Egypt and Saudi Arabia have collaborated 41 times, India and Saudi Arabia have collaborated 35 times, and China and Pakistan have collaborated 23 times. In addition, Figure 4 b also signifies collaboration between European countries, such as Belgium, France, the United Kingdom, Greece, Italy, and the Netherlands. Additionally, there was frequent collaboration between India and Korea, as well as the USA and Korea.

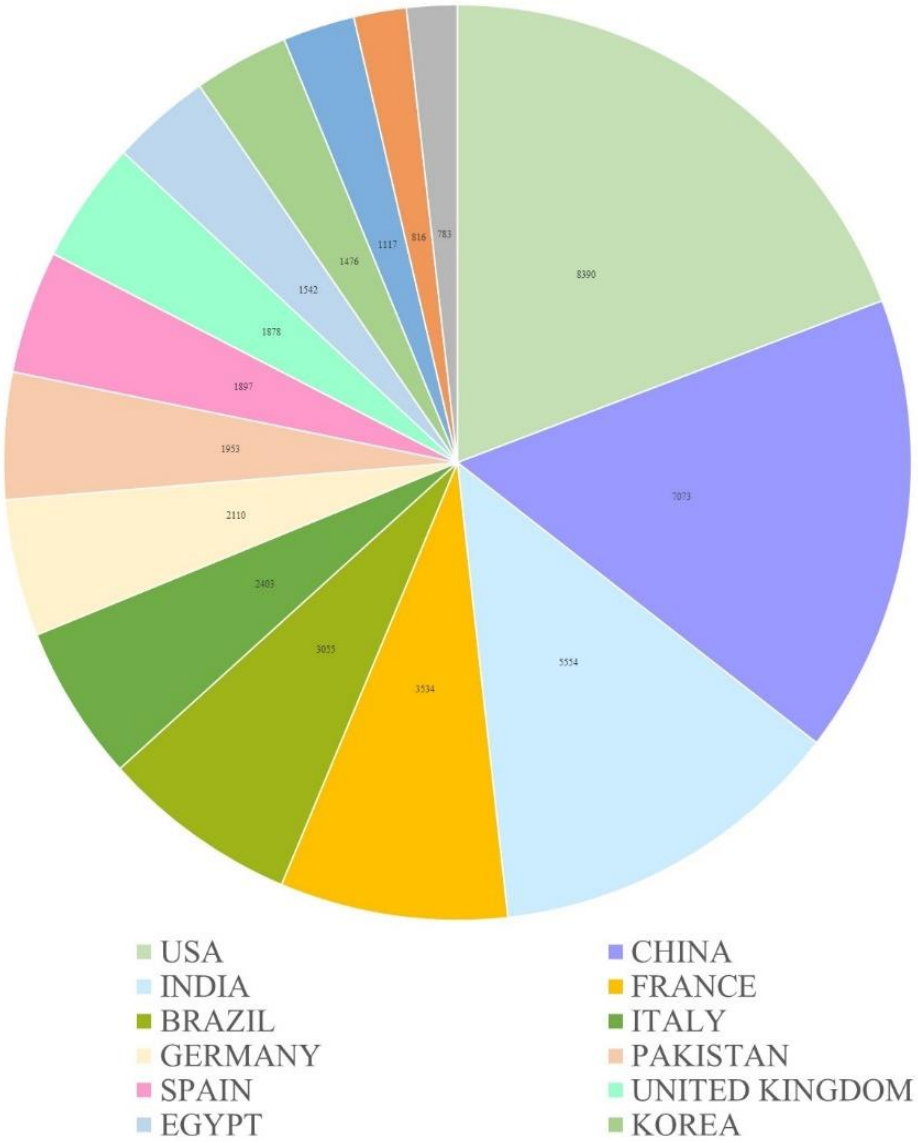

Figure 4(a). An analysis of countries with the highest citation counts

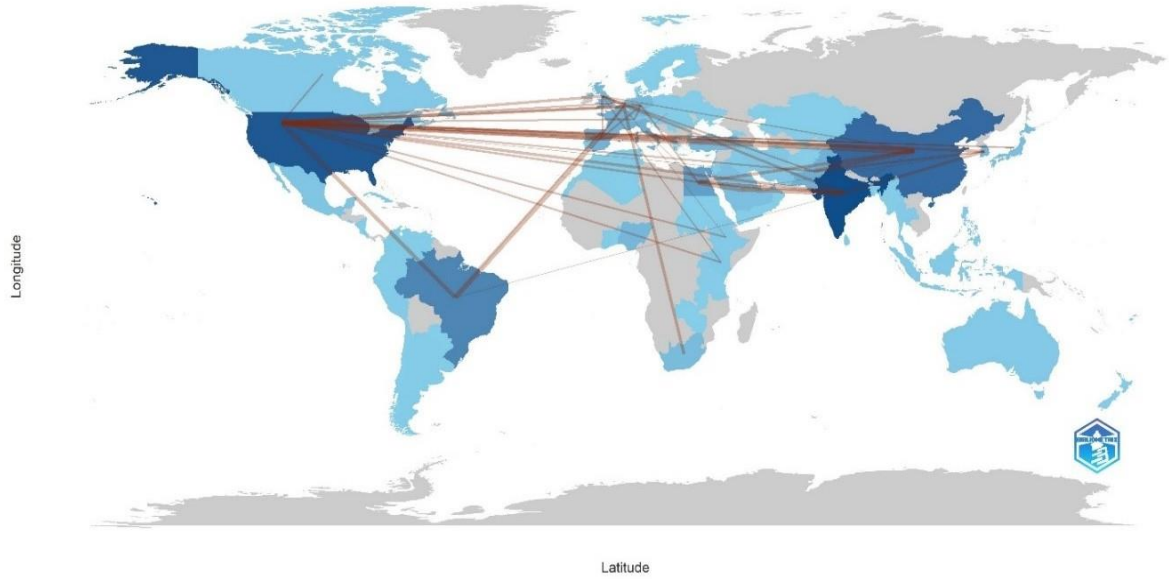

Figure 4 (b). Global research collaboration among countries

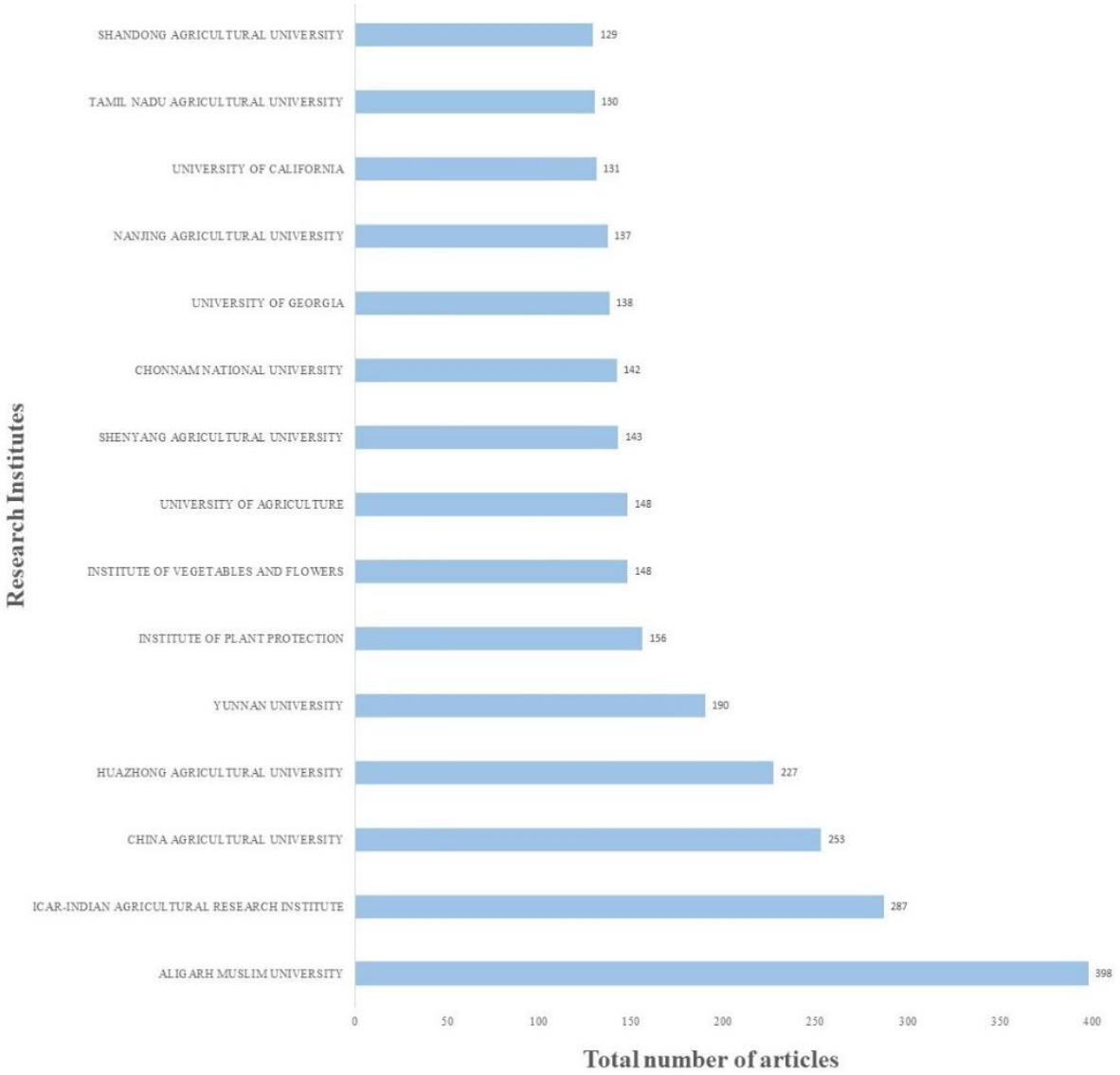

Figure 5 (a). Top 15 productive institutions publishing on *M. incognita.*

Top research institutes with interconnected collaboration networks

Aligarh Muslim University was the most influential institution, publishing 398 articles. As far as *M. incognita* is concerned, China and India are the two countries that are producing the most results. Aligarh Muslim University (AMU) stands first followed by ICAR-Indian Agricultural Research Institute (287) and China Agricultural University (253) (Figure 5a). The study from AMU found that plant extracts may be better alternatives to chemical nematicides, and ligand-targeted protein interactions could help in the key findings of biomolecules and important proteins for control of RKNs (Abdullah et al., 2023). The ICAR funded research confirms that atmospheric CO_2 significantly affects *M. incognita* growth, interfering with sugar-protein ratio in root systems (Berliner et al., 2023).

A visual representation of the collaboration among different institutions can be seen in Figure 5b. The nodes in this network represent institutions that work on *M. incognita* and collaboration relationships between are represented by the linkers between them. Aligarh Muslim University published 287 articles in collaboration with different institutions. AMU collaborating members include National Research Center, Guru Nanak Dev University, Cairo University, and King Saud University. Additionally, there are institutions that collaborate with many international institutions, as shown in Figure 5b.

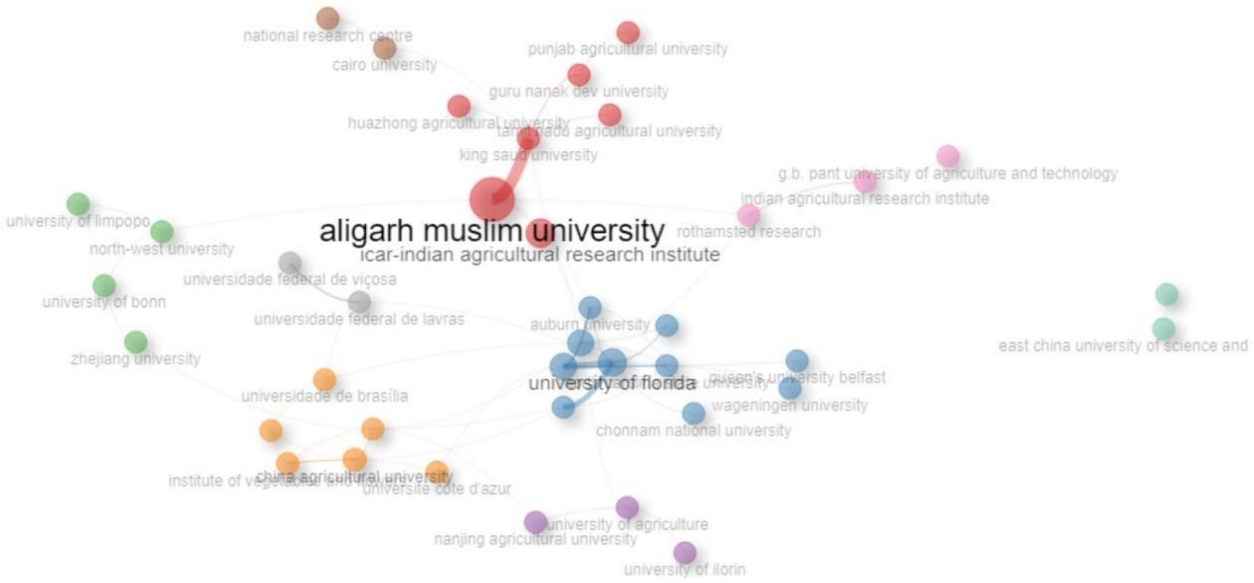

Figure 5 (b). Networks analysis reveals interconnected collaboration among institutions

Author's contributions

The scientific production output of each author was determined by considering the number of articles with h-index, g-index, citations, and the number of publications contributed to *M. incognita* research. *M. incognita* research was most productively carried out by Pierre Abad from France who had the highest h-index (25), g-index (29) and total citations (3054) in the field. Pierre Abad worked on epigenetic inheritance, biochemical characterisation, parasite-host response, adaptive evolution, plant trihelix transcription factor in case of *M. incognita* since 2004 to 2023 (Zhao et al., 2024). In case of highest number of publications, Zaki Siddiqui (Aligarh Muslim University, India), is on the top (Figure 6 (c)). A recent study by Zaki Siddiqui showed the use of manganese oxide nanoparticles in the management of *M. incognita* (Siddiqui et al., 2024). In terms of the number of publications, Uma Rao is ranked 2nd working at ICAR- Indian Agriculture Research Institute, India. Table 2 and Figure 6 represents the h-index, g-index, total number of publications, and total number of citations for top 15 authors.

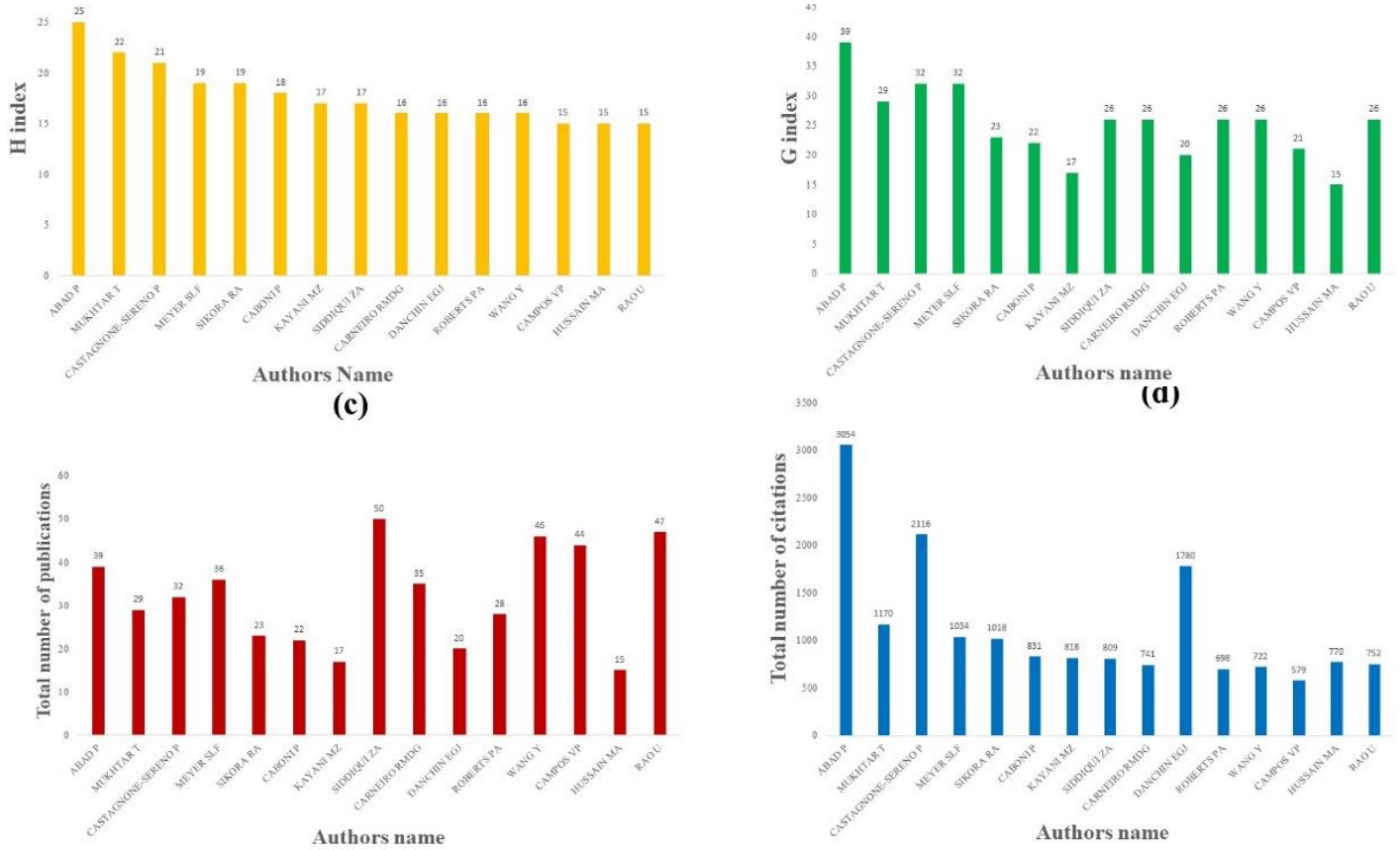

Figure 6. The figure shows the (a) Authors with H-index, (b) Authors with G-index, (c) Authors with the highest number of Publication, (d) Authors with the highest number of Citations.

Table. 2. The table includes top 15 authors showing their h-index, g-index, total citation, number of publication and publication year

S. No.	Authors Name	Affiliation and Country	h-index	g-index	Total citation	No. of Publications	PY
1	Abad P	Pierre Abad (INRA, France)	25	39	3054	39	2004
2	Mukhtar T	Tariq Mukhtar (Pir Mehr Ali Shah Agricultural University, Pakistan)	22	29	1170	29	2011
3	Castagnone-Sereno P	Philippe Castagnone-Sereno (INRA, France)	21	32	2116	32	2004
4	Meyer SLF	Susan L. F. Meyer (USDA, ARS, USA)	19	32	1034	36	2004
5	Sikora RA	R.A. Sikora, Germany	19	23	1018	23	2004
6	Caboni P	Pierluigi Caboni (University of Cagliari, Italy)	18	22	831	22	2010
7	Kayani MZ	Muhammad Zameer Kayani (Pir Mehr Ali Shah Agricultural University, Pakistan)	17	17	818	17	2011
8	Siddiqui ZA	Zaki Siddiqui (Aligarh Muslim University, India	17	26	809	50	2004
9	Carneiro RMDG	Regina M.D.G. Carneiro (EMBRAPA, Brazil)	16	26	741	35	2004
10	Danchin EGJ	Eitenne G.J. Danchin (James Hutton Institute, UK)	16	20	1780	20	2008
11	Roberts PA	Philip A Roberts (University of California, California)	16	26	698	28	2005
12	Wang Y	Yunsheng Wang (Human Agricultural University, China)	16	26	722	46	2013
13	Campos VP	Vicente P. Campos (Universidade	15	21	579	44	2006

		Federal de Lavras, Brazil)					
14	Hussain MA	Muhammad Arshad Hussain (Regional Agricultural Research Institute, Pakistan)	15	15	770	15	2011
15	Rao U	Uma Rao (ICAR, India)	15	26	752	47	2012

Journal name

The analysis showed top 15 journals with the highest number of publications and citations (Figure 7, Table 3). The "Journal of Nematology" is the topmost productive journal that has been published by the Society of Nematologists since 1969, in *M. inocgnita* research with 175 publications, 31 h-index and 3212 citations (Figure 7). The work published in this journal is based on the plant resistance development a promising approach to deal with the RKN problem. Plants can be engineered to resist pathogens and parasites by RNA interference (RNAi) (Gangwar & Sirohi, 2023). Top 2nd ranked journal "Nematology", with 150 publications, and 2555 total citations, is an international journal dedicated solely to publishing original research in all dimensions of nematology about molecular biology and field studies. Journal deals and appreciate papers that discuss parasites of arthropods and nematodes (Aparajita et al., 2024). The other main stream journals are Indian Journal of Nematology, Archives of Phytopathology, Nematropica, and Crop Protection. Since recent 2022-2023 years more papers have been published on Mi-gene resistance of *M. incognita*, histopathological studies, molecular characterization of *Meloidogyne* species and biological management of this pest. As defined by SCImago Journal Rank (SJR) the journals, i.e., Plant Disease, Crop Protection, Frontiers in Plant Science, Journal of Agricultural and Food Chemistry, European Journal of Plant Pathology, Pest Management Science, Egyptian Journal of Biological Pest Control, Plos One are scoring Quartile 1 (Q1). A scientific journal's prestige and importance in its field is measured by its SJR as mentioned in Table 3 for all top 15 journals.

Table 3. The details regarding the topmost journal published on *M. incognita*. The table contains information regarding top 15 journals, their publishers, number of publications on *M. incognita*, number of citation and SJR

S. No.	Journal Name	Country	Publisher	No. of Publications	No. of citation	SJR
1	Journal of Nematology	United States	Society of Nematologists	175	3212	Q2 0.47
2	Nematology	Netherlands	Brill Academic Publishers	150	2555	Q2 0.44
3	Indian Journal of Nematology	India	Nematological Society of India	118	123	Q4 0.18
4	Archives of Phytopathology	United Kingdom	Taylor and Francis Ltd.	99	565	Q3 0.13
5	Nematropica	United States	Organizationof Nematologists of Tropical America	97	644	Q4 0.18
6	Acta Horticulturae	Belgium	International Society for Horticultural Science	86	322	Q4 0.15
7	Plant Disease	United States	American Pyhtopathological Society	83	1107	Q1 0.68
8	Crop Protection	United Kingdom	Elsevier	80	2595	Q1 0.71
9	Frontiers in Plant Science	Switzerland	Frontiers Media S. A	54	717	Q1 1.23
10	Journal of Agricultural and Food Chemistry	United States	American Chemical Society	53	1900	Q1 1.09
11	European Journal of Plant Pathology	Netherlands	Springer Netherlands	52	1003	Q1 0.52
12	Pest Management Science	United Kingdom	John Wiley and Sons Ltd.,	47	1140	Q1 1.02
13	Egyptian Journal of	Egypt	Egyptian Society	44	395	Q1

	Biological Control	Pest	for Biological Control of Pest			0.58
14	Plos One	United States	Public Library of Science	43	1449	Q1 0.89
15	Pakistan Journal of Zoology	United Kingdom	Zoological Society of Pakistan	38	482	Q4 0.19

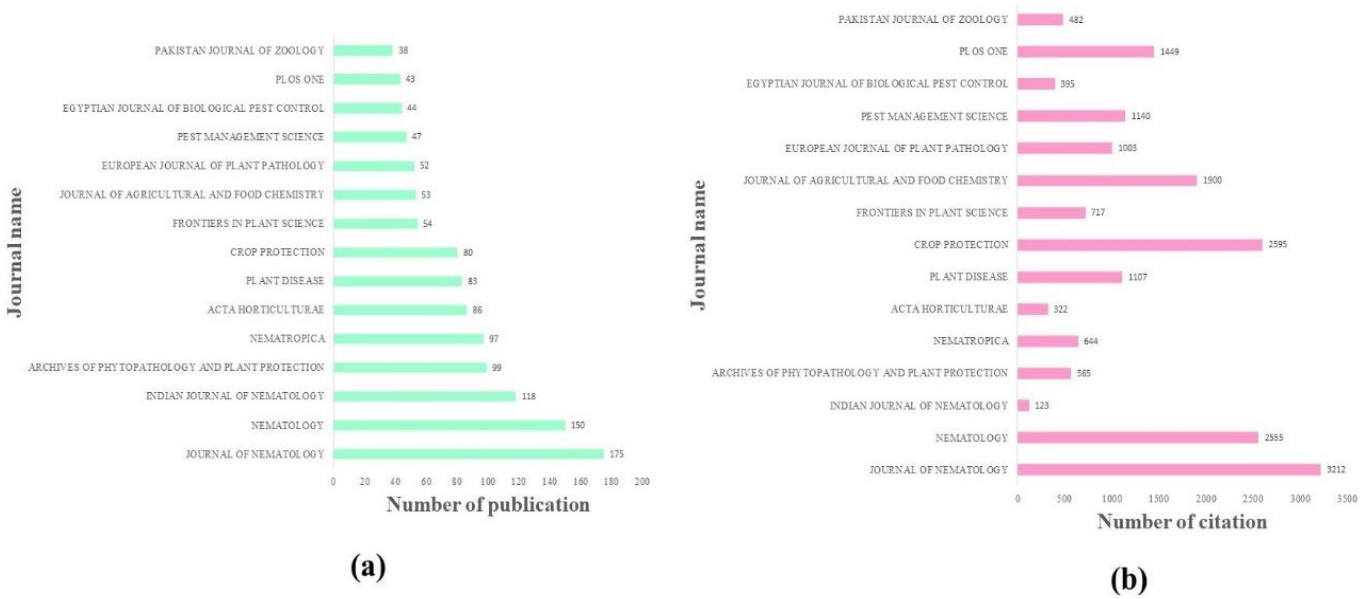

Figure 7. The figure shows the number of topmost journals with (a) the Highest number of publications and (b) the Highest number of citations

Funding agencies

In order to support scientific research, funds are an important financial source. Among the top three countries with the highest number of projects funded, China, Brazil, and South Korea were on the top three positions. China's National Natural Science Foundation was ranked as the number one funding agency among the top 15 funding agencies in the world. Two funding agencies Conselho Nacional de Desenvolvimento Científico e Tecnológico and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior from Brazil ranked 2nd and 3rd in financial assistance. The maximum number of funded projects was 223 from China as shown in Table 4 and Figure 8. Indian Council of Agricultural Research ranked 7th in terms of funding *M. incognita* research. According to findings from ICAR, employing resistant varieties is considered the most economically efficient and rewarding approach for controlling *M. incognita* (Zonunpui et al., 2022).

Table 4. The leading agencies which have funded research projects on *Meloidogyne incognita*

S. No.	Funding agency	Country	No. of projects funded
1	National Natural Science Foundation of China	China	223
2	Conselho Nacional de Desenvolvimento Científico e Tecnológico	Brazil	124
3	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior	Brazil	119
4	National Key Research and Development Program of China	China	77
5	Fundação de Amparo à Pesquisa do Estado de Minas Gerais	Brazil	49
6	U.S. Department of Agriculture	US	41
7	Indian Council of Agricultural Research	India	37
8	Aligarh Muslim University	India	33
9	European Regional Development Fund	Europe	33
10	European Commission	Europe	32
11	Empresa Brasileira de Pesquisa Agropecuária	Brazil	30
12	Indian Agricultural Research Institute	India	30
13	Agriculture Research System of China	China	29
14	Cotton Incorporated	US	29
15	Fundamental Research Funds for the Central Universities	Europe	29

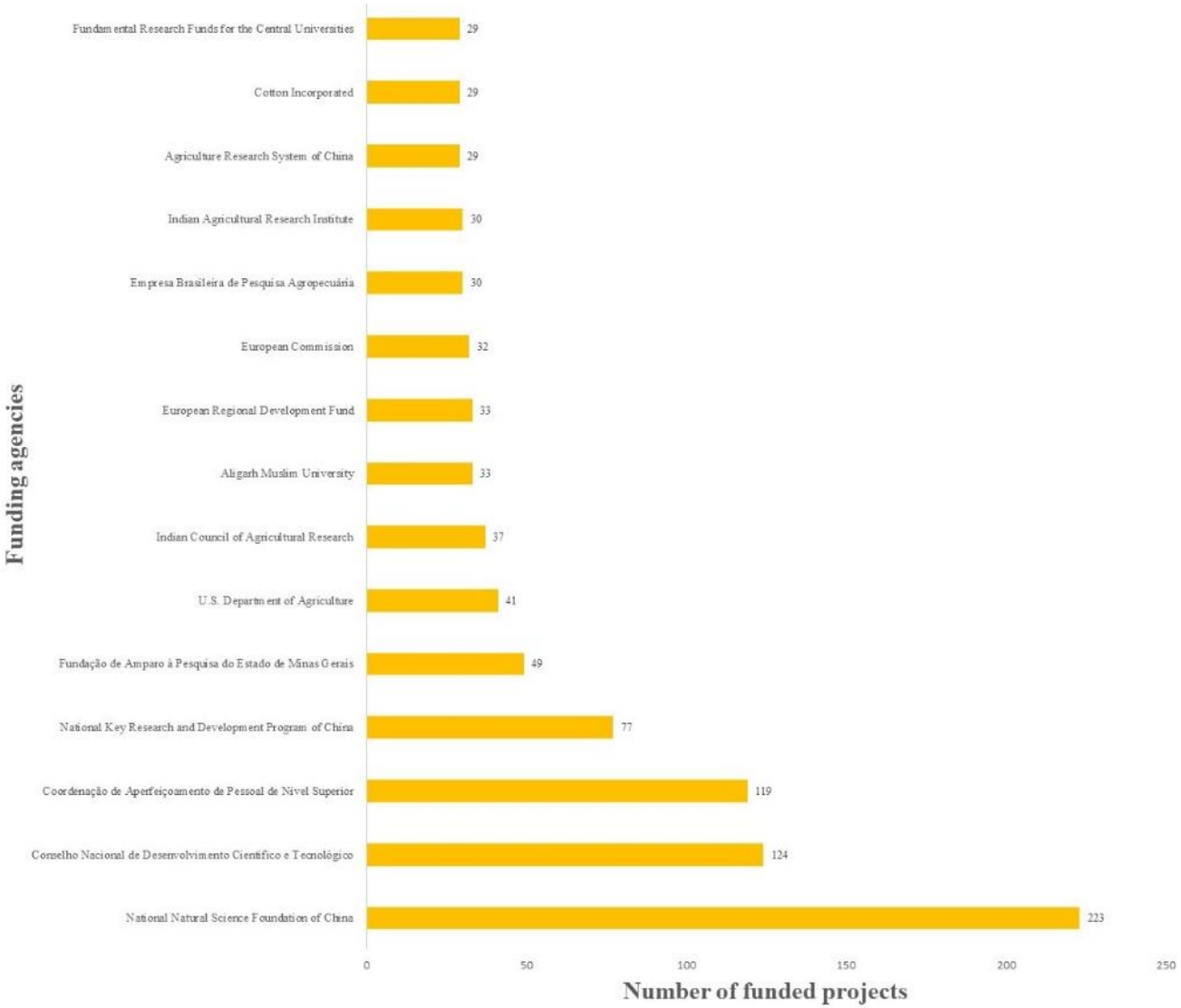

Figure 8. Top 15 funding agencies on *M. incognita* projects worldwide

Trend topics

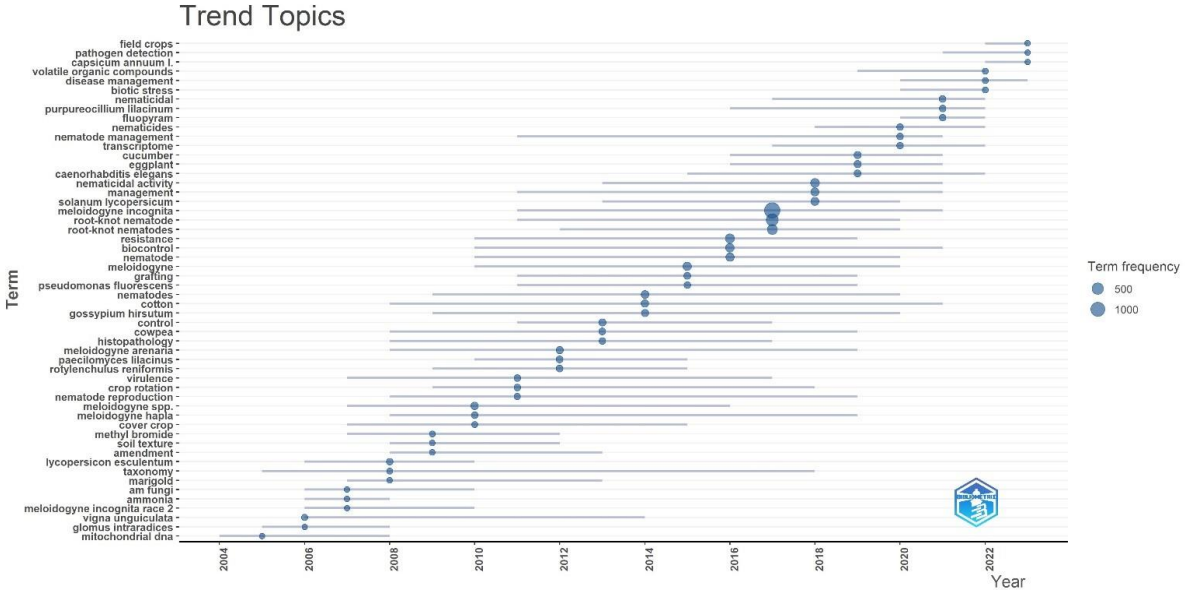

Figure 9. Evolution of bibliometric analysis trends: 2004-2023

The Figure 9 gives a new perspective on the most popular areas of interest from 2004 to 2023. From 2022, field crops will be a new area of interest, as well as pathogen detection in crops (Çatalkaya et al., 2024). Volatile organic compounds (VOCs) emitted by bacteria from a variety of environmental sources are discovered and their potential application helpful in control of *Meloidogyne* species (Diyapoglu et al., 2022). More research has been done on VOCs during 2020-2022 period. The *Meloidogyne* species affected various crops including *Capsicum annum*, *Solanum lycopersicum*, *Lycopersicon esculentum* and many more (Irdani et al., 2023). Research focused on studying a nanopesticide system with targeted delivery to roots to achieve efficient prevention and control of RKNs. Since the nanopesticide system is root-targeted and leaves application of Glycine-nanoparticles effectively prevented and controlled RKNs (Zhong et al., 2024). As a result, root-targeted delivery offers a novel and effective strategy for protecting crops from RKN invasion and facilitating sustainable agriculture.

Discussion

Meloidogyne species are the most widely distributed, having a wide host range, and are endoparasites that feed on vascular structures, which makes them most destructive pest. The bibliometric analysis examined different studies on *M. incognita*, including the number of publications, leading countries and institutions, analysis of term associations, and exploration of key terms in highly cited articles. For the keyword analysis "*Meloidogyne incognita*", all the research articles and reviews that has been published in *Journal of Nematology*, *Nematology*, *Indian Journal of Nematology*, *Archives of Phytopathology* are the top three sub-cateogries from 2004-2023. In addition to the above pattern, there is a related pattern in the number of citing articles and journals as well. During this analysis the top countries, top institutions, top journals, top authors and topmost funding agencies has been studied and analysed. Recent trends in bibliometric analysis have revealed a multifaceted exploration of diverse topics across various disciplines. Breeding and genetic modification are among the major approaches to developing nematode-resistant crop varieties (Ploeg et al., 2023). The development of sustainable management strategies, which includes the use of biocontrol agents, organic amendments, as well as novel chemical approaches as part of the research process (Figure 10). Infections caused by *Meloidogyne* can be controlled by biocontrol agents such as fungi, bacteria, nematodes, and viruses (Yao et al., 2023).

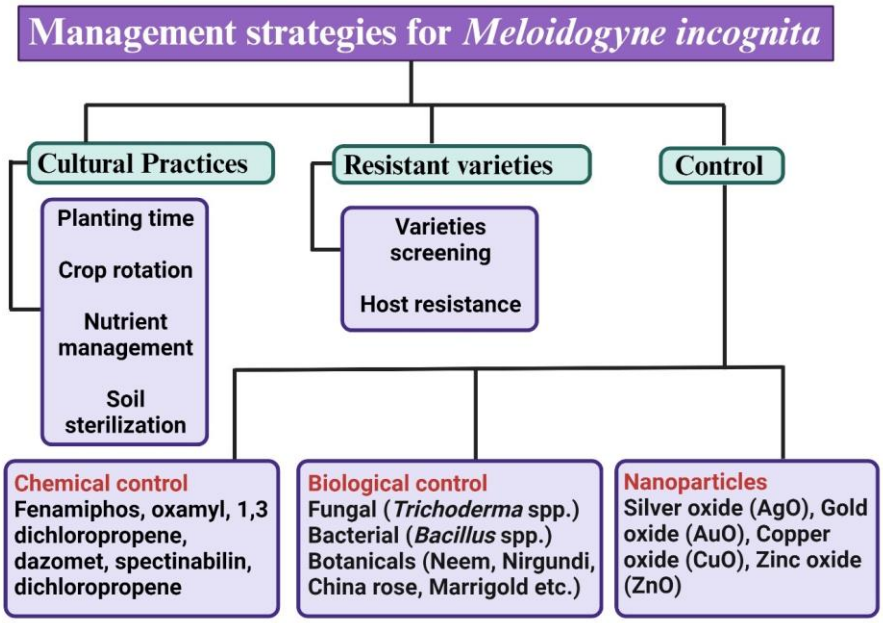

Figure 10. Different management strategies of *Meloidogyne incognita*

Furthermore, molecular interactions between nematodes and their hosts are increasingly being studied, in order to develop targeted control methods. Metabolite analysis has provided new insights into nematode defence responses and the identification of novel compounds that may be involved (Gupta et al., 2023). Moreover, advances in genomics and transcriptomics have allowed researchers to unravel *M. incognita*'s genetic and gene expression profiles, providing valuable insights into its biology and pathogenicity (Rocha & Schwan, 2023). To understand plant–nematode interactions, omics approaches and techniques can be used to address DNA, RNA, proteins, metabolites, and microbial communities. Plant resistance to RKN may be improved by determining the specific metabolic pathways involved in the nematode defence response.

Conclusion

A concerted effort has been made in recent years to develop innovative and sustainable solutions to mitigate the damage caused by *M. incognita*, which is an economically significant plant parasite. There is much work to be done in this field in order to better understand nematode effector molecules in plant-nematode interactions. As we develop innovative and sustainable strategies to mitigate *M. incognita*'s impact on agriculture, omics approaches hold great promise for advancing our understanding of its biology (Sena et al., 2024). A potential nanoparticle that has been shown to be effective against a variety of pests still needs to be explored against nematodes. Natural materials can be added to nanoparticles (NPs) to enhance their stability and environmental friendliness. There have been numerous studies demonstrating that green synthesis promotes seedling growth and reduces phytotoxicity in crops (Sundararajan et al., 2024). Therefore, agro-nanotechnology will be able to solve the ever-adaptive plant parasite problem with environmental sustainability. More study is needed to be done in the exploring bioactive compounds that is present in the plants for green synthesis of nanoparticles. In this bibliometric analysis, information will be provided on the current state in the scientific field as well as all possible developments to be made in the future to combat this pest.

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Author contributions

SK, DS: Conceptualization and methodology; KC, DS, SCS: Data mining and curation; KC, DS: Visualization and validation; KC: Writing original draft; SK: Supervision.

Conflict of interests

The authors declared no conflict of interest.

Ethics approval

NA.

AI tool usage declaration

No AI tool was used in manuscript preparation.

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