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Mapping knowledge and perceptions in nematology: insights and future perspectives from Italian researchers

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ABSTRACT

This study provides the first integrated overview of Italian nematology through bibliometric and perception-based analyses on data retrieved from the Scopus and Web of Science databases. Results highlight a scientifically active and well-connected community, increasingly oriented towards ecological and sustainability issues. Italian research shows a distinctive balance between agricultural, parasitological, and environmental approaches, reflecting the global shift towards One Health and biodiversity conservation. However, nematology remains marginal in academic curricula and public perception. Most practitioners acquired their expertise after graduation, confirming a long-standing educational gap also noted in other European countries. Yet, the strong motivation of younger researchers and the widespread recognition of nematology's usefulness suggest opportunities for renewal. Strengthening academic training and interdisciplinary collaboration could ensure generational continuity and enhance the discipline's visibility. Overall, studying nematodes represents both a scientific challenge and an opportunity. Nematode ubiquity, ecological relevance, and functional diversity make them key to understanding and managing biodiversity across ecosystems. Promoting nematology within education and public communication would not only support scientific progress but also foster a broader appreciation of the often-invisible components sustaining life and ecosystem health.

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1. Introduction

Nematoda *phylum* represents a very ancient lineage of microscopic metazoans (Blaxter & Koutsovoulos 2015). With over 40,000 described species and an estimated diversity ranging from 500,000 to 5 million, they are one of the most abundant metazoans on Earth (Lambshead 1993; Coomans 2002; Zhang 2013; Bennett et al. 2022; Hodda 2022; Hodda et al. 2009). Nematodes have a simple structural body plan, which combined with their overall low number of body cells, great adaptability and molecular complexity, has contributed to the unrivalled success of the *phylum*, which occurs in a wide range of habitats and geographical areas, including the most extreme ones (Sandulli et al. 2014; Schratzberger et al. 2019; Baldrighi et al. 2021; Semprucci et al. 2021).

Nematode species exhibit a remarkable diversity of feeding strategies and life-styles, which can be broadly categorized into free-living species and parasitic forms (Decraemer et al. 2019; Grassi et al. 2022).

Free-living nematodes occupy a wide range of trophic niches in terrestrial and aquatic soil webs, including bacterial feeders, fungal feeders, algal grazers, detritivores, and predators of protozoans and other small metazoans (Semprucci et al. 2022). Through these activities, they contribute significantly to nutrient and mineral cycling, supporting essential ecosystem processes and maintaining biological activity (Ockleford et al. 2017; Schratzberger et al. 2019, 2023). In addition, they regulate microbial communities and enhance the biodegradation of organic matter and toxic compounds (Baldrighi et al. 2021; Semprucci et al. 2025).

Parasitic nematodes, on the other hand, include plant-, animal-, and human-associated species with major ecological, economic, and health implications. Plant-parasitic nematodes (PPN) are of major economic importance, causing global crop yield losses estimated at approximately 12.3%, equivalent to

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157–173 billion USD annually (Hailu & Hailu 2020; Mendoza-de Gives 2022). While some species (e.g. *Ditylenchus*) attack aerial plant parts such as leaves and flowers, most PPN target roots and underground tissues.

Animal and human parasitic nematodes are responsible for a range of diseases affecting livestock, pets, and humans. Genera such as *Ascaris* and *Ancylostoma* cause infections including ascariasis and hookworm disease, while filarial nematodes are associated with severe conditions such as elephantiasis and onchocerciasis (Bird & Kaloshian 2003; Intirach et al. 2024).

In contrast, some parasitic nematodes, such as entomopathogenic nematodes (EPN), provide important ecosystem services by acting as biological control agents of insect pests. EPN use in integrated pest management has proven effective and represents a sustainable alternative to chemical pesticides, helping to reduce environmental and health risks (Dhiman et al. 2019; Li et al. 2023; Tarasco et al. 2023).

Given this functional diversity, nematode communities should be managed within an integrated framework that balances agricultural productivity with ecological sustainability (Semprucci et al. 2025). Moreover, the diversity and composition of free-living nematodes make them valuable bioindicators of soil and water quality, enabling early detection of environmental stressors such as pollution and other anthropogenic disturbances (Manachini & Lozzia 2002; Manachini et al. 2009; Landi et al. 2024; Kakouli-Duarte et al. 2026; Höss et al. 2026).

The nematode *Caenorhabditis elegans* (Maupas, 1900) (Rhabditida: Rhabditidae) represents one of the most widely used model organisms in biological research and has been extensively employed in ecotoxicological studies (Garbo et al. 2019; Glazer & Shapiro-Ilan 2022). In 1998, the publication of its nearly complete genome made *C. elegans* the first animal with a fully sequenced genome (Blaxter 2011). On 22 January 1992, *C. elegans* was launched into space aboard Spacelab as part of a Space Shuttle mission to study its development across two generations in microgravity and to investigate the effects of cosmic radiation (Nelson et al. 1994). However, *C. elegans* is not the only model organism within the *phylum* Nematoda. Indeed, more recently, the emerging potential of another Rhabditidae, such as *Litoditis marina* (Bastian, 1865), and many Monhysteridae species, including *Diplolaimella dievengatensis* (de Man, 1880), *Halomonhystera disjuncta* (Bastian, 1865), and *Diplolaimelloides* spp., has been increasingly recognized (Semprucci et al. 2025).

Despite their ubiquity, ecological relevance, and importance for both human (e.g. *Ascaris*, *Ancylostoma*, filarial nematodes) and veterinary health, as well as for agriculture, nematodes remain relatively underrepresented in research and public awareness compared to other animal groups (Semprucci et al. 2025). This gap reflects not only the technical challenges associated with their microscopic size and taxonomic complexity but also a limited perception of their broader significance across disciplines (Boufahja et al. 2015; Lu et al. 2021; Qing et al. 2022). Understanding how nematodes are perceived and studied within the scientific community is therefore crucial to identifying current knowledge boundaries and guiding future research directions. The present study addresses this objective by examining the Italian nematological community as an emblematic case within the broader international landscape. By analysing national research patterns, collaborations, and thematic priorities, this work provides a contextual yet scalable perspective, offering insights that may contribute to a wider understanding of how nematology evolves and adapts across different scientific and environmental settings.

To explore the state of knowledge, research dynamics, and scientific perceptions, a combined systematic review and bibliometric approach was adopted (Sabella et al. 2022).

Italy has a strong tradition of nematology (e.g. Semprucci et al. 2008; Ambrogioni et al. 2014; Zullini 2021; Sellitto & Dallavalle 2023) especially in agricultural applications, which led to the founding of the Italian Society of Nematology in 1978 (for more information, see https://nematologia.it/). Among the key institutions contributing to the development of nematology in Italy, the Institute of Nematology in Bari and the Consiglio per la Ricerca in Agricoltura (CREA) of Firenze and the University of Milan played an important role, being internationally recognized for its contributions to plant-parasitic nematode research, taxonomy, and management strategies. Although this institute no longer exists as a single entity, its scientific legacy persists through the activities of several research groups within national research institutions (e.g. CNR) and universities that continue to contribute to the field at both national and international levels. Works, especially from the past, are often not available in English and are not

always accessible to everyone, making a broader and more holistic review of the state of research and knowledge of nematodes in Italy necessary (*e.g.*, d'Errico and Bianco 2000; d'Errico et al. 2022; Lamberti et al. 2002).

By integrating the systematic review and bibliometric mapping, this study provides a recent comprehensive overview of nematological research in Italy at international level, highlighting both quantitative trends and qualitative insights into how Italian researchers conceptualize, investigate, and prioritize nematode-related topics. In addition, a questionnaire was conducted among Italian nematologists to explore their views on research priorities, methodological trends, and perceived challenges. We focused on professionals who work with nematodes rather than the general public or students, whose limited exposure could lead to an inaccurate picture of nematology's status. By surveying this group, we aimed to understand when they first learned about nematodes, how relevant they consider nematology to their work, where they obtained any training, and how the discipline is perceived and valued across related fields.

This combination of approaches allows for a deeper understanding of the dynamics shaping nematological research and may be a useful example for understanding common difficulties within the discipline and may support international colleagues facing comparable circumstances, fostering collaboration and contributing to efforts to strengthen the global visibility and relevance of nematology.

2. Materials and methods

To evaluate the state of knowledge and scientific progress related to nematological research in Italy, a three-step methodological framework was designed. The study combined: a systematic literature review, a bibliometric analysis using VOSviewer, and a questionnaire-based survey.

This integrative approach was aimed at providing a comprehensive understanding of both the scientific output and the perceptions of Italian researchers involved in nematology.

2.1 Systematic review

A systematic review was conducted following the methodological guidelines of the European Food Safety Authority (EFSA) and the Cochrane Collaboration (https://www.cochranelibrary.com).

These international standards define a transparent and reproducible workflow composed of certified and traceable steps of which the first was the definition of specific research questions, ensuring methodological rigour and minimizing bias (Sabella et al. 2022).

In detail, the following three research questions were established: 1) What is the current status of indexed nematological research conducted by Italian authors? 2) In which scientific areas and for what purposes are nematodes investigated in Italy? 3) What are the most recurrent, emerging, and underexplored topics within this field?

The literature search was performed using combinations of selected keywords in major databases such as Scopus, Web of Science, and Google Scholar. Boolean operators (AND, OR) were applied to ensure the inclusion of all relevant records. In detail, an initial exploratory search in Google Scholar using the keywords "nematode Italy" yielded approximately 123,000 results, confirming the need for a more controlled and index-based selection process. To ensure quality and traceability, the search was therefore limited to indexed databases and peer-reviewed publications, explicitly excluding grey literature, following approaches commonly adopted in bibliometric analyses of nematode research (e.g. Mesa-Valle et al. 2020).

Scopus (https://www.scopus.com) database and Web of Science (WoS: https://www.webofscience.com/wos) were chosen as the databases for this study due to their broad interdisciplinary coverage, high citation reliability, and extensive metadata availability. In Scopus database, the research was conducted under "All fields", combining the terms "nematode" or "Nematoda" with the filter "affiliation country = Italy". Both searches ("nematode" and "Nematoda") were performed on 5 August 2024.

In Web of Science, the search was carried out in both the WoS Core Collection and WoS All Databases. In the former, queries were performed under "All fields" using the terms "nematode" AND "address = Italy" and "Nematoda" AND "address = Italy". In the latter, analogous searches were conducted under "Topic", maintaining the same filters and substituting "nematode" with "Nematoda".

Results were retrieved and cross-checked to remove duplicates. This procedure provided a comprehensive and transparent overview of the Italian scientific outputs related to nematology, forming the foundation for subsequent bibliometric and perception analyses.

2.2. VOSviewer analysis

To further explore research areas and thematic relationships (corresponding to research questions 2 and 3), a bibliometric mapping was carried out using the software VOSviewer (https://www.vosviewer.com) following the methodology proposed by Van Eck and Waltman (2018).

VOSviewer software (version 1.6.20) employs a distance-based clustering technique where nodes (items) are positioned based on their co-occurrence strength and relatedness (Van Eck & Waltman 2018). The software applies a force-directed layout algorithm, which positions highly connected nodes closer together while pushing unrelated items apart, thereby enhancing network interpretability. The clustering algorithm uses modularity optimization to assign nodes to thematic clusters, with each cluster representing a distinct research focus. Nodes are sized according to the number of publications, and colours indicate the average publication year and average number of citations. Instead, line thickness in the maps indicates the frequency and strength of collaborations between countries. For other information, consider the VOSviewer manual (Van Eck & Waltman 2018).

Data were exported from the Web of Science Core Collection, using the search terms "nematode" in "All fields", "address = Italy", and restricting "Web of Science categories" to Environmental Science and Agriculture. Query words in related literature to "nematodes" were: "Nematoda", "Roundworms", "round-worms", "round worms". Similarly, words closely related were identified: "eelworms", "thread-worms", "nemas". Finally, the Boolean operator "OR" and "AND" were adopted to connect these search words to expand the search and to get the most relevant results, at the same time, excluding the irrelevant data. Subsequently, the document types were filtered by selecting the "articles" and "reviews", and the language was restricted to English.

This search, performed on 22 July 2024, retrieved 235 documents, which were then imported into VOSviewer for analysis. VOSviewer was employed also to conduct co-occurrence analysis (Countries, Organizations, Authors) and co-citation analysis (Journals, Reference) of the scientific sector research domain. We combined the results to visualize the results of the country co-occurrence analysis. VOSviewer parameter settings were: (1) Type of analysis for co-occurrence analysis selected Co-authorship, Unit of analysis = Authors, Organizations, Countries; (2) Type of analysis for co-citation analysis selected Co-citation, Unit of analysis = Cited references and Cited sources; (3) Counting method = Full counting, using a thesaurus file (optional) for synonym merging, word deletion, etc. The remaining parameters were set to default.

These visualizations allowed the identification of the main research domains, collaborative patterns, and international linkages within the Italian community of nematologists

This approach allows researchers to systematically identify dominant research topics, emerging trends, and collaborative networks. By applying overlay visualization, the temporal evolution of research themes can be observed, as newer studies are highlighted with a different colour gradient.

2.3. Questionnaire-based survey

To identify fundamental questions addressable to explore the research priorities, methodological trends, and perceived challenges in the nematode field, a panel of 22 multiple-choice questions was defined (Table S1).

Before launching the full survey, a pre-collection robustness assessment was performed to ensure clarity, interpretability, and appropriateness of the questionnaire. To achieve this, cognitive interviews were conducted with a small but diverse subset of individuals working in nematology or related fields. These participants were selected to reflect different ages, career stages, and disciplinary backgrounds within the nematological community.

During these cognitive interviews, respondents were asked to complete the draft version of the questionnaire while commenting on their understanding of each item ("think-aloud" method). Follow-up probing questions were used to determine whether: 1) the meaning of each question was clear, 2) the answer options were interpreted as intended, 3) any ambiguity or redundancy were present, and 4) any concepts were

missing or required rephrasing. This procedure helped identify and correct issues related to wording, ordering of questions, and potential misinterpretations before data collection began.

In addition, participants were interviewed about their career trajectory and experiences in nematology, allowing the authors to reflect on whether the questionnaire adequately captured the diversity of professional pathways within the field. Their testimonials were not analysed as formal data but contributed qualitatively to refining the instrument.

The online survey was created using Google Forms, which allowed the generation of an HTTP link that was distributed via email and other digital channels to an audience of nematode specialists from academia, research institutions, and public or private companies, and other stakeholders. The survey was promoted also through direct emails and the social media channels of the Italian Society of Nematology (SIN). While our goal was to reach the broadest possible sample of individuals working or engaged in nematological and/or related topics, and to also include those within our personal networks who work outside the nematological society and have a more limited interest, we likely failed to representatively capture the full spectrum of people involved in the field. We designed our study in accordance with the current privacy laws and ethical principles throughout the data collection process. We ensured that this study did not collect personally identifiable information, nor did it include any content that could be potentially distressing or harmful to participants. Before collecting data, each participant reviewed and accepted a formal consent form outlining the study's purpose, their rights, and how their data would be used. Participation in the survey was voluntary and responses were submitted anonymously.

To measure the reliability of the scale, Cronbach's alpha coefficient was calculated (Cronbach 1951). The scale showed acceptable internal consistency, with a Cronbach's alpha value of 0.71 (Taber, 2018).

Each questionnaire item (i.e. each question included in the survey) was rated on a 5-point Likert scale (Maurer & Pierce 1998). Subjects were also asked to indicate their place of residence (countryside or city), age, type of activity, and other consideration that can not be ranked.

To explore possible relationships among participants' responses, a correlation analysis was performed using PAST v4.13 (Hammer et al. 2001). A selection of survey questions was included in the analysis, focusing on those expected to capture related aspects of respondents' perceptions and attitudes. The correlation matrix was computed based on Pearson's correlation coefficients, and the results were visualized as correlation plots. In these plots, the size and colour of the ellipses indicate the strength and direction of the correlation: blue ellipses represent positive correlations, while red ellipses indicate negative ones. The intensity of the colour and the elongation of the ellipse are proportional to the correlation coefficient. Two separate matrices were generated (Panels A and B) to highlight different subsets of questions with potentially stronger internal associations.

3. Results and discussion

3.1 Bibliometric analysis of Italian nematology

In the Table 1, the results of the searches conducted across different databases are summarized. The search performed in Scopus using the keyword "nematode", a term identical in both English and Italian, combined with "Italy" (accessed on 22 July 2024) returned 9,874 documents published between 1964 and 2024. When using the term "Nematoda" (referring to the *phylum*) combined with "Italy" as affiliation, the number of documents retrieved was 2,658 (1959–2024).

In the Web of Science Core Collection, the combination "nematode" and "Italy" produced 2,781 documents (1985–2024), while "Nematoda" and "Italy" resulted in 741 documents for the same time span. In the

Table 1. Number of documents retrieved from different databases for the selected keyword combinations.

Keywords	Scopus: all fields	WoS: core collection	WoS: all databases
Data Range	1964–2024	1985–2024	1959–2024
Nematode & Italy	9,874	2,781	4,822
Data Range	1959–2024	1985–2024	1954–2024
Nematoda & Italy	2,658	741	5,444

Web of Science "All Databases", the combination "nematode" and "Italy" yielded 4,822 documents (1960–-2024), whereas "Nematoda" and "Italy" yielded 5,444 documents (1954–2024).

This comparison highlights that Scopus currently indexes a larger number of documents on nematology than Web of Science, confirming its broader journal coverage and inclusion of more recent conference proceedings and open-access sources (Grassi et al. 2025). However, WoS "All Databases" provides a complementary perspective, encompassing multidisciplinary records that help capture the historical roots of nematological research in Italy.

The oldest paper retrieved in WoS "All Databases" using "Nematode" & "Italy" as terms dates back to 1960 and titled "*Ancylostomiasis* in Calabria" (Tursi 1960), representing one of the earliest national contributions to parasitological nematology. Instead, for "Nematoda" & "Italy", the earliest record corresponds to "The classification of the actinomyces species (= Streptomyces)" (Baldacci et al. 1954), a paper reflecting the early taxonomic framework of microbial and metazoan classification in post-war Italian biology.

In Scopus, the earliest Italian study using "Nematode" & "Italy" was published in 1964, titled "Distribuzione dei nematodi in spiagge pugliesi" (De Zio 1964). This pioneering work investigated nematode distribution in relation to shoreline distance, seasonal variation, and interstitial water content along Apulian beaches, representing one of the first ecological applications of nematode community analysis in Italy. In the following decades, these more ecological and environmental lines of research progressively gained prominence both in Italy and worldwide, where nematodes became recognized bioindicators for assessing ecosystem quality and functioning. These records match the period between 1950 and the early 1960s that is often recognized as the foundation of modern nematology. Indeed, nematology is a relatively recent science compared to plant pathology and entomology, possibly because nematode effects were less visible than those of other agricultural problems (Webster 1998). The period between the 1950s and mid-1970s was a turning point for the discipline, marked by major advances in the study of nematode biology (Webster 1998).

Among the retrieved records, the most-cited paper in Scopus (2,092 citations) is "Effects of fire on properties of forest soils: A review" (Certini 2005), which, although not exclusively nematological, highlights their importance in soil ecology. Indeed, it underscores how soil functioning and resilience, parameters closely linked to nematode community structure, are central to understanding ecosystem recovery after environmental stress (Ferris & Matute 2003; Catani et al. 2025). In this sense, this study reflects the growing convergence between paedological, ecological, and faunistic studies, where nematodes progressively emerged as sensitive bioindicators of soil health and ecosystem change (see Du Preez et al. 2022 for review).

When using "Nematoda" & "Italy", the oldest Scopus paper is "Esponenti endofitici, epifitici e fitosaprobi del lago Trasimeno: facies autunnale" (Di Giovanni 1959), an ecological investigation emphasizing community composition and the role of zoological components in freshwater ecosystems. Although nematodes were not yet the central focus of this early study, it represents a significant step towards a more holistic ecological perspective, where microscopic fauna were considered part of complex trophic and environmental interactions. This approach anticipated the integrative ecological framework that would later characterize aquatic nematology, linking species assemblages to habitat conditions and ecological gradients (*e.g.*, Schratzberger et al. 2023; Martínez et al. 2025).

The most cited study in this category (667 citations) is "Soil nematode abundance and functional group composition at a global scale" (Van Den Hoogen et al. 2019), which established one of the first global quantitative models describing nematode distribution and functional diversity in soils. This study marked, for the first time, a turning point in nematology by moving from local or habitat-specific observations to a truly macroecological perspective. The authors, by integrating high-resolution global datasets, demonstrated how nematode functional groups reflect large-scale environmental gradients and soil processes, providing a foundation for predictive modelling of soil biodiversity. Its influence extended far beyond nematology, reinforcing the concept of nematodes as a unifying biological component linking biodiversity patterns, ecosystem functioning, and biogeochemical cycles across terrestrial and aquatic ecosystems (Schratzberger et al. 2019; Zullini & Semprucci 2020).

A progressive and rapid increase in indexed publications was observed from 1994 to 2020. After this period, a general decline became evident, likely reflecting the temporary slowdown in research productivity and publication output associated with the COVID-19 pandemic (Figure 1).

As shown in Figure 2, most of the documents retrieved from Scopus correspond to research articles (75.7%), followed by review papers (14.7%) and book chapters (4.6%). Conference papers (3.0%) represent a smaller but relevant proportion of the literature, indicating the presence of an active scientific community that regularly presents new findings at conferences. Minor categories such as editorials, letters, short surveys,

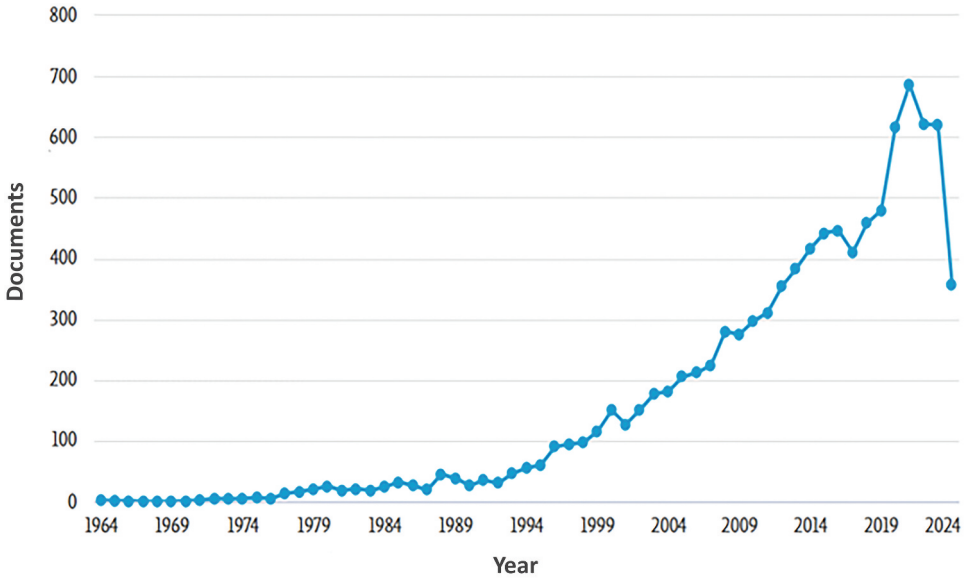

Figure 1. Search results for the keyword "nematode" and affiliation country italy from the Scopus database, showing 9,874 documents published between 1964 and 2024. Data for 2024 refer to publications indexed up to July 2024.

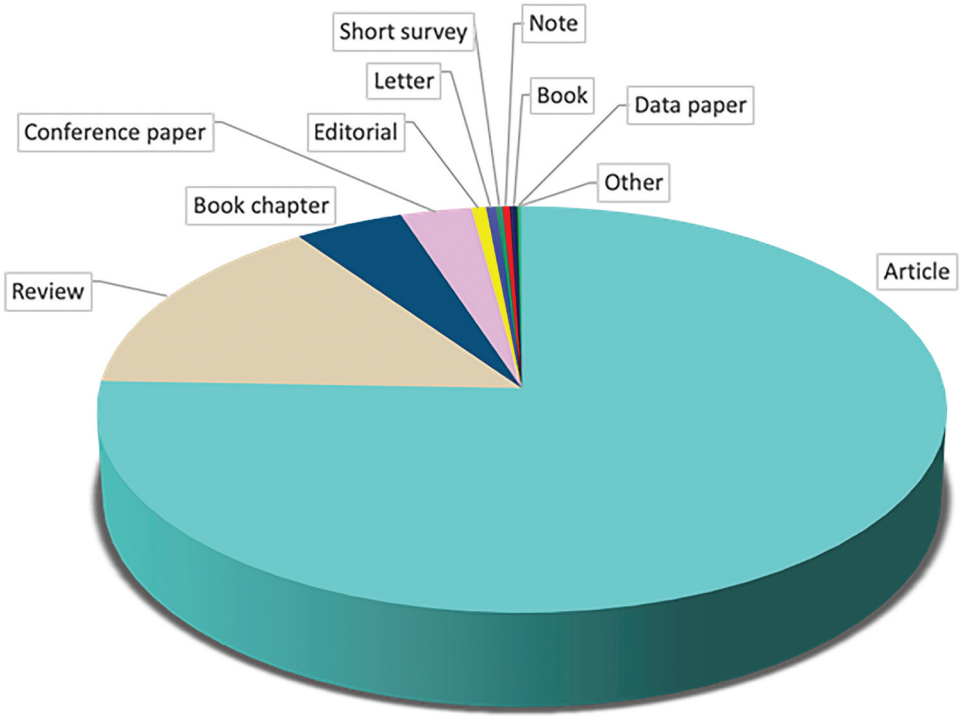

Figure 2. Document type distribution obtained by Scopus database (accessed July 22, 2024) using the keywords "nematode" and italy (1964–2024).

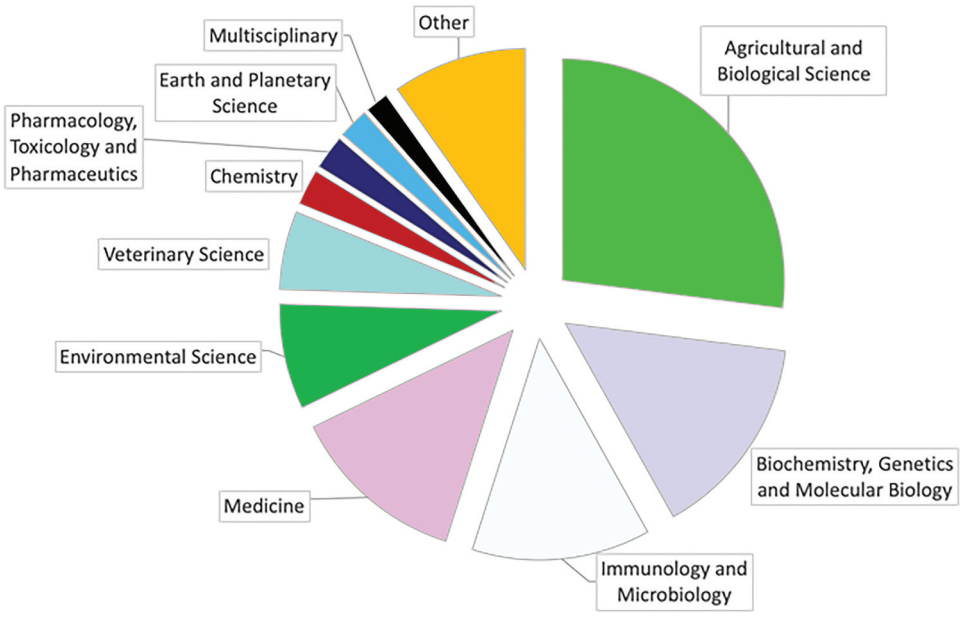

Figure 3. Subject area distribution obtained searching in Scopus database (accessed July 22, 2024) with the keywords "nematode" and italy (1964–2024).

notes, books, and data papers collectively account for less than 2% of the total output. Figure 2 subdivision confirms that nematology-related research in Italy is primarily disseminated through peer-reviewed journal articles, which reflects a mature and consolidated research area. The relatively high percentage of review papers also suggests a growing effort towards synthesizing knowledge and integrating multidisciplinary perspectives, especially in applied and ecological branches of nematology.

The subject area analysis reveals that the main part of publications is concentrated in Agricultural and Biological Sciences (27.0%), confirming the strong applied, agronomic and ecological orientation of Italian research in this field. Biochemistry, Genetics and Molecular Biology (14.9%) and Immunology and Microbiology (13.0%) represent the second and third largest categories, highlighting the integration of nematode studies into molecular and biomedical contexts (Figure 3).

The Medicine category (12.9%) reflects the prominent contribution of parasitological research in Italy, while Environmental Science (7.7%) highlights the role of nematodes as bioindicators in soil and aquatic ecosystems. Smaller but noteworthy contributions come from Veterinary Science (5.7%), Chemistry (2.6%), Pharmacology, Toxicology and Pharmaceutics (2.5%), and Earth and Planetary Sciences (2.2%), showing the interdisciplinary nature and the huge potential of nematological research.

Overall, this pattern demonstrates a balanced coexistence of fundamental biological, health-related disciplines (including Medicine and Veterinary sciences, here grouped as medical-parasitological), and ecological-environmental approaches, mirroring the international change in the nematology from a specialized subdiscipline towards a cross-cutting field central to One Health and ecosystem sustainability research (see Semprucci et al. 2025, b for further details).

3.2. Network analysis using VOSviewer

After performing the search in the Web of Science Core Collection, 235 documents (as of 25 July 2024) were exported and analysed using VOSviewer to generate a keyword co-occurrence map (Figure 4).

Out of 1,934 keywords, 75 met the minimum co-occurrence threshold of five. The VOSviewer keyword co-occurrence map identifies four main thematic clusters. The green cluster encompasses terms related to veterinary and parasitic nematodes, particularly those affecting livestock such as sheep, *Haemonchus contortus* (Rudolphi, 1803) and *Trichostrongylus colubriformis* (Giles, 1892), confirming the long-standing contribution of Italian parasitologists to studies on infection dynamics, diagnosis, and anthelmintic resistance (Knoll et al. 2021; Soliman et al. 2024). The blue cluster reflects the agricultural component, focused on

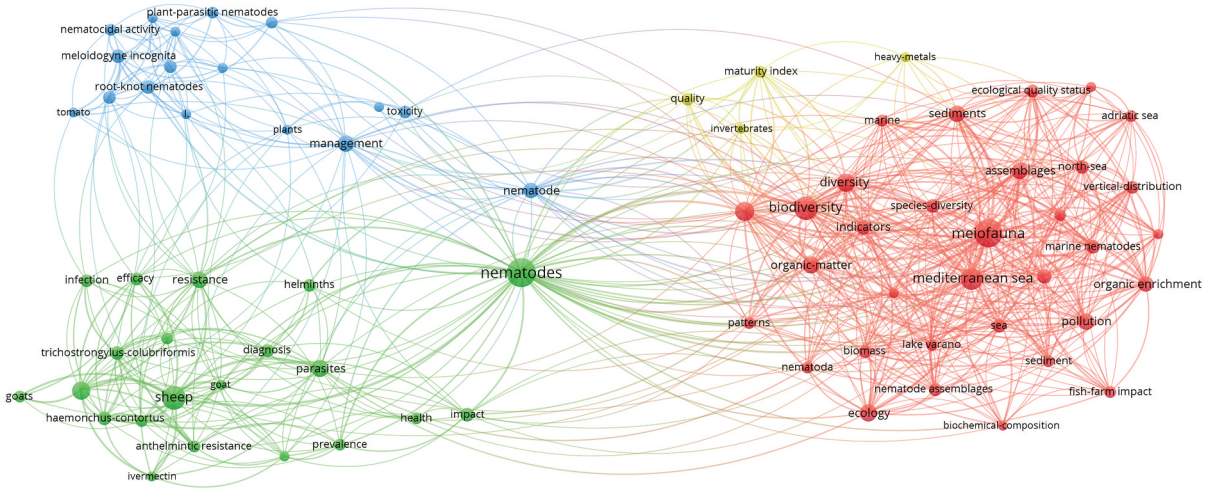

Figure 4. Co-occurrence map (all keywords) generated using VOSviewer.

economically important plant-parasitic nematodes particularly root-knot nematodes such as *Meloidogyne incognita* and emphasizes management, soil health, and crop protection strategies (d'Errico et al. 2022; Catani et al. 2023; Fanelli et al. 2025). It also reflects an extensive body of research on the effects of different plant protection products, agricultural practices, and genetically modified plants on nematode communities and their biodiversity (Catani et al. 2022).

The red cluster is associated with marine and environmental nematology, dominated by terms such as "Mediterranean Sea", "meiofauna", "biodiversity", "ecological quality status", and "organic matter". This cluster highlights the growing Italian leadership based on number of publications in marine benthic ecology, where nematodes are increasingly used as bioindicators of sediment quality and ecological status under the EU Water and Marine Strategy Framework Directives (*e.g.*, Franzo et al. 2022; Grassi et al. 2023). This body of evidence has contributed to the inclusion of nematode-based analyses in several European Food Safety Authority (EFSA) Opinions and guidelines, as well as in the EU Soil Monitoring Law, formally adopted in late 2025. The yellow cluster, in turn, connects to broader concepts of soil quality, heavy metal contamination, and maturity index, illustrating the expansion of nematode-based assessment from marine to terrestrial systems (*e.g.*, Corsini et al. 2020; Catani et al. 2025; Frontalini et al. 2025).

When compared to the global bibliometric landscape, Italy's profile shows both convergences and distinctive features. Internationally, nematological output is largely driven by agricultural and molecular agendas—led by countries such as the United States, China, India, Brazil, and the United Kingdom—as documented by worldwide assessments of plant-parasitic nematodes and by the exponential expansion of the *C. elegans* literature (*e.g.*, Mesa-Valle et al. 2020; Berk et al. 2024; Grassi et al. 2025).

In contrast, Italian research shows a distinctive ecological orientation, complemented by the above cited contributions from agricultural and veterinary nematology. This convergence between applied and ecological disciplines reflects, as noticed above, and also detectable in the grey literature (data not reported here), a shift from species-specific or economically driven studies towards broader evaluations of ecosystem functioning and health (Semprucci et al. 2025). The pattern mirrors the influence of European environmental policies (Ockleford et al. 2017) and the Mediterranean's role as a natural laboratory for studying animal biodiversity, natural and anthropogenic impact, and the potential effects of environmental changes on human health (*e.g.*, Van Den Hoogen et al. 2019; Cocozza di Montanara et al. 2022; Semprucci et al. 2025). Overall, these results support the idea that Italian nematology is evolving towards an integrative and sustainability-oriented science, bridging ecology, parasitology, and agricultural research, and contributing significantly to the global dialogue on biodiversity conservation and ecosystem resilience.

The collaboration network reveals Italy as a central hub in international nematological research, with strong and diversified connections to both European and non-European countries. The colour gradient, ranging from blue (earlier collaborations) to yellow (more recent ones), illustrates the temporal evolution of these partnerships (Figure 5).

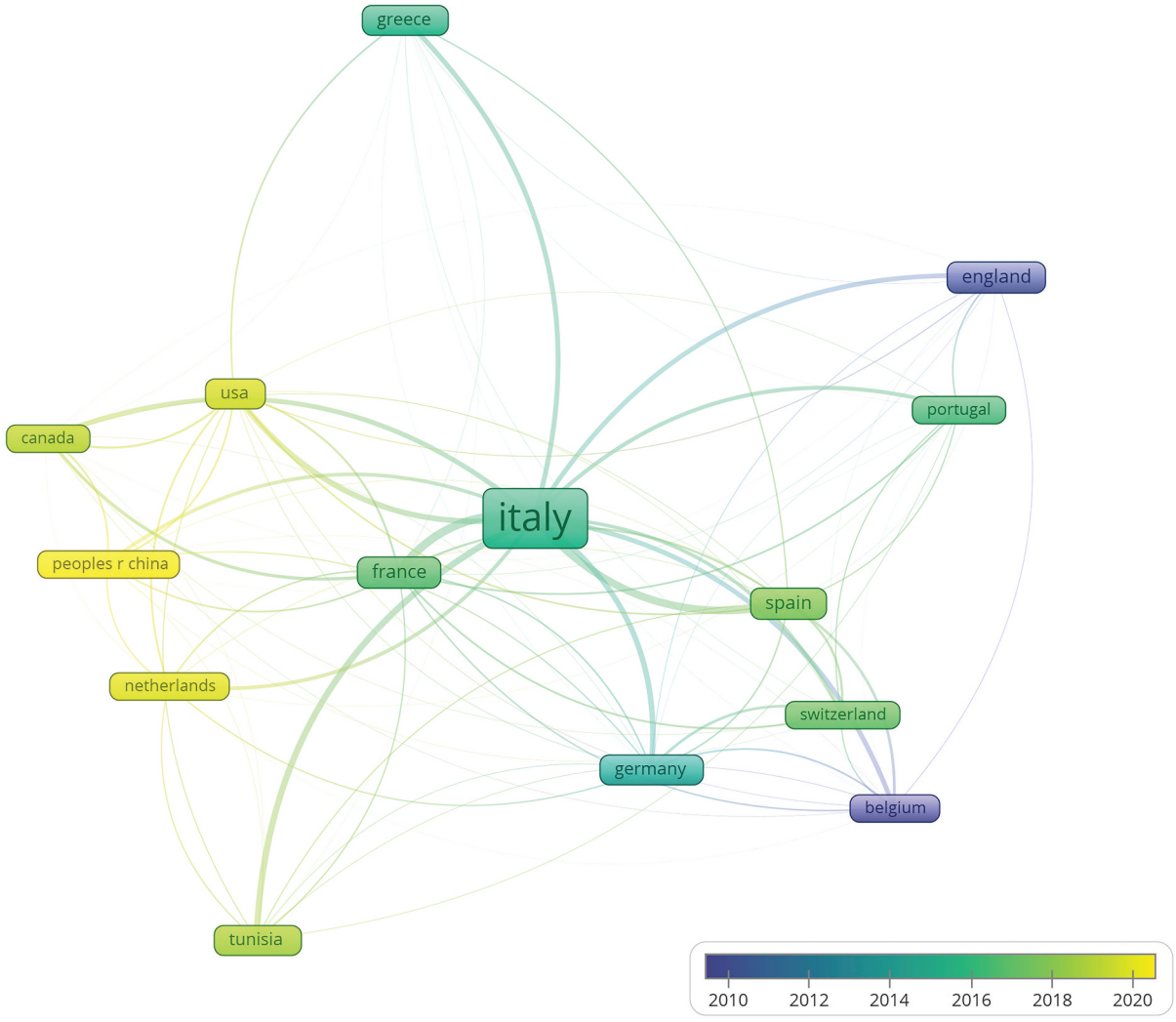

Figure 5. Bibliographic coupling map (countries) generated using VOSviewer.

During the early 2010s, collaborations were predominantly established with the United Kingdom, Belgium, Germany, and Greece, reflecting long-standing academic exchanges within Europe, often linked to veterinary and agricultural nematology. Between 2015 and 2018, the network expanded to include Portugal, France, Spain, Switzerland, and Tunisia, suggesting a consolidation of Mediterranean and francophone scientific cooperation, particularly in ecological and marine studies.

In the most recent period (2018–2020), Italy's collaborative landscape further broadened towards global partners such as the United States, the People's Republic of China, Canada, and the Netherlands, suggesting a trend towards increasingly collaborative research frameworks.

Overall, the structure of the network highlights Italy's bridging role between traditional European research nodes and emerging global centres of nematological excellence. This connectivity mirrors the country's interdisciplinary profile and reinforces Italy's contribution to the international agenda on biodiversity conservation, sustainable agriculture, and One Health frameworks.

The co-authorship network shows a highly interconnected national research structure, centred around the National Research Council (CNR), which acts as a major hub linking multiple Italian universities (Figure 6). The CNR exhibits strong collaborative links with institutions such as the University of Cagliari, the Polytechnic University of Marche, and the Stazione Zoologica Anton Dohrn, reflecting its central role in coordinating marine, ecological, and environmental research.

Distinct regional clusters can also be observed. The red cluster, grouping universities such as Urbino, Genoa, Ancona, Bari, and Palermo, highlights an Adriatic–Tyrrhenian network with a strong focus on marine

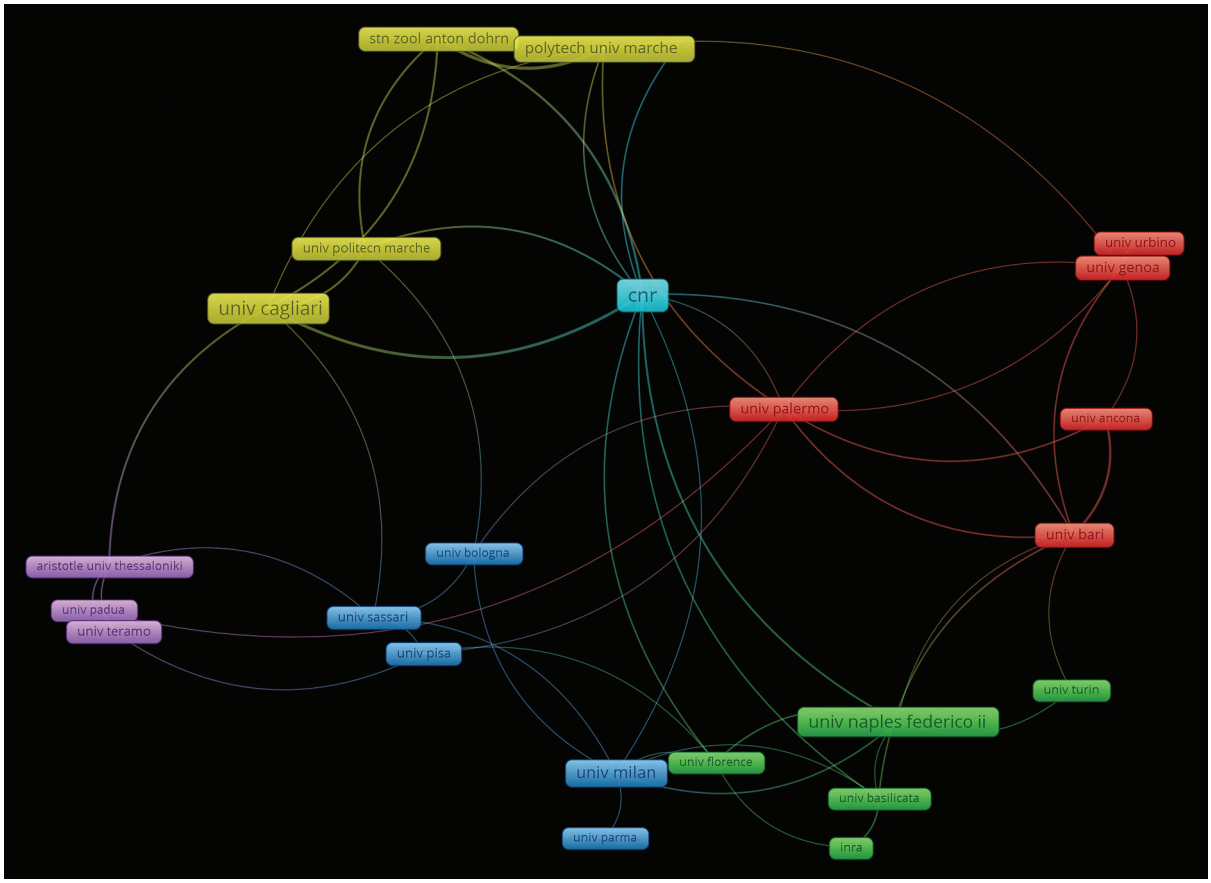

Figure 6. Co-authorship and institutional collaboration network generated using VOSviewer, showing the main Italian research institutions involved in nematology and their international partners.

biodiversity and environmental assessment. The blue cluster, including Milan, Bologna, Pisa, Parma, and Sassari, represents a broader collaboration among universities active in biological, agricultural, and biotechnological studies, often linked to CNR initiatives (Figure 6). The green cluster, centred around the University of Naples Federico II, connects to INRA (France) and the Universities of Turin, Florence, and Basilicata, indicating strong interdisciplinary collaboration that spans from parasitology to soil and crop science.

The yellow cluster includes institutions such as the University of Cagliari, the Polytechnic University of Marche, and the Stazione Zoologica Anton Dohrn, representing an additional group of interconnected research centres within the national network.

Interestingly, international partners such as the Aristotle University of Thessaloniki (Greece) appear integrated into the Italian network within the purple cluster, together with Italian institutions such as the Universities of Padua and Teramo, confirming the country's openness to Mediterranean and European partnerships (Figure 6). The presence of polycentric clusters rather than a single dominant node suggests a distributed research model, where regional excellence centres contribute autonomously while maintaining a dense web of cooperation.

Overall, the map demonstrates that Italian nematology is characterized by a collaborative, cross-institutional, and multidisciplinary network. This structure not only has enhanced national scientific productivity but also strengthened Italy's visibility and leadership in European and global initiatives on biodiversity, ecosystem health, and sustainable agriculture.

3.3. Questionnaire-based survey and its interpretation

A total of 80 questionnaires were completed by researchers and professionals (Supplementary Table S1; Figure S1). The age distribution shows a predominance of mid-career respondents (41–60 years, 55%), while

28% are early-career (20–40 years) and 18% are over 60 (Fig. S1A). Educational levels are generally high, with 50% holding a university degree, 43% a postgraduate qualification, and only 8% a technical or high school diploma (Fig. S1B).

The geographical distribution indicates that 40% of respondents work in southern Italy, followed by northern (34%) and central regions (23%), while 4% operate abroad (Fig. S1C). This pattern likely reflects the greater prevalence of nematode-related problems in high-value crops, such as tomatoes and melons, particularly in southern Italy's horticultural systems, where *Meloidogyne* spp. are widespread (Russo et al. 2007; Di Vito et al. 2009). Consistently, 68% of respondents graduated in Agricultural Sciences, 18% in Biological Sciences, and 11% in Natural Sciences (Fig. S1D), confirming the predominance of agronomic and applied backgrounds among Italian nematologists.

Almost half of the respondents (48%) are public-sector employees, while smaller proportions are PhD students (4%) or retired/unemployed (1%) (Fig. S1E). Most participants work in Research & Development, Diagnostics/Analysis, or Academic Research (38%, 25%, and 24%, respectively) and were first introduced to nematodes through professional activities rather than mass media (Fig. S1F–G). These data underline that nematology in Italy remains research-driven and institutionally concentrated, rather than widely disseminated across different professional contexts. In this respect, the mentorship of experienced nematologists played a crucial role both in shaping our initial approach to nematology and in facilitating the transfer of know-how (Fig. S1F–G).

Over 40% of participants devote much or most of their working time to nematode-related activities (Fig. S1I), and all respondents, regardless of affiliation, spend at least some time on nematological tasks (Fig. S1P–T). Nearly half consider nematological skills to be very important for their work, and 94% find them useful (Fig. S1L). However, approximately 60% reported that nematodes were rarely addressed during their university studies (Fig. S1M). This educational gap echoes a broader European trend: many nematologists began their careers as mycologists, entomologists, or zoologists due to the historical lack of formal university programs in nematology (Sasser & Krishnappa 1980; Vallotton 1987). The same limitation has been noted in other regions, where the discipline often evolved as a specialization within plant pathology or soil ecology rather than as an independent academic field (Decraemer & Hunt 2006).

Perceptions of employability and career development are generally positive. About 66% of respondents believe that nematological expertise improves job opportunities, and more than 90% describe the field as stimulating and intellectually rewarding (Fig. S1P–U). Most participants (88%) foresee strong potential for future growth, particularly in research and innovation, in line with global calls for integrating nematology into broader frameworks such as One Health and soil biodiversity conservation (Semprucci et al. 2025).

Interest in academic training is also high: 49% "very much" and 41% "a lot" support the introduction of elective university courses on nematodes (Fig. S1V). This demand was strongest among Agricultural Science graduates but also present in Natural, Biological, Environmental Sciences, and Human Medicine, reflecting the growing interdisciplinary nature of nematology (Perry & Moens 2011).

More than 86% of participants believe that nematode-related information should be shared more broadly with the public, pointing out that awareness remains limited compared to other, often less ecologically significant taxa (Fig. S1X–AA). Universities and secondary schools were identified as the most effective communication channels, followed by television, highlighting the need for educational outreach and science communication efforts (Fig. S1H–AA).

This limited awareness can be partly explained by the small size and low visibility of nematodes, which place them among the so-called "invisible biodiversity", often overlooked in public perception despite their ecological importance (Martínez et al. 2025). Moreover, when nematodes are recognized, they are predominantly associated with parasitic forms and agricultural damage, reinforcing a biased and incomplete perception of their role.

This repugnance and unfamiliarity of nematodes had already been highlighted many years ago in the scientific journal dedicated to science teachers (Manachini 1998), problems that remained at the level of knowledge and communication of invertebrates in general even in 2021 (Salvador et al. 2021), and which are often linked to the lack of knowledge that can lead to false beliefs and fears (Leto et al. 2024).

This perception contrasts with the fundamental contributions of nematodes to biological and biomedical sciences. Research on model organisms such as *Caenorhabditis elegans* has led to major discoveries in cell biology and genetics, including mechanisms of apoptosis, gene regulation, and development, recognized by

several Nobel Prizes (Glazer & Shapiro-Ilan 2022). In addition, nematodes have contributed to key innovations in applied science, such as biological control through entomopathogenic nematodes and the discovery of novel bioactive compounds, including antimicrobial agents (Semprucci et al. 2025). Emphasizing these positive and innovative roles is essential to rebalance public perception and enhance the visibility and attractiveness of the discipline.

While previous studies have emphasized the importance of public engagement in biodiversity conservation (Jarić et al. 2020), our findings specifically highlight the need to include microscopic and functionally important taxa, such as nematodes, within science communication and citizen science frameworks.

Overall, the survey portrays nematology in Italy as a specialized yet undervalued field, rich in expertise but still marginal within academic curricula and public perception. Respondents recognize that career opportunities are often greater abroad (Fig. S1AB–AC), reflecting the higher investment in nematode research and diagnostics in other countries (Norton 2020). Strengthening education, training, and visibility at the national level would thus be key to sustaining the discipline's long-term development.

A correlation analysis was performed to identify the most significant associations among survey variables (Figure 7). Age (Q1) correlated negatively with both the perceived importance of nematology (Q10) and time dedicated to it (Q9), suggesting that younger respondents are generally more engaged and optimistic about

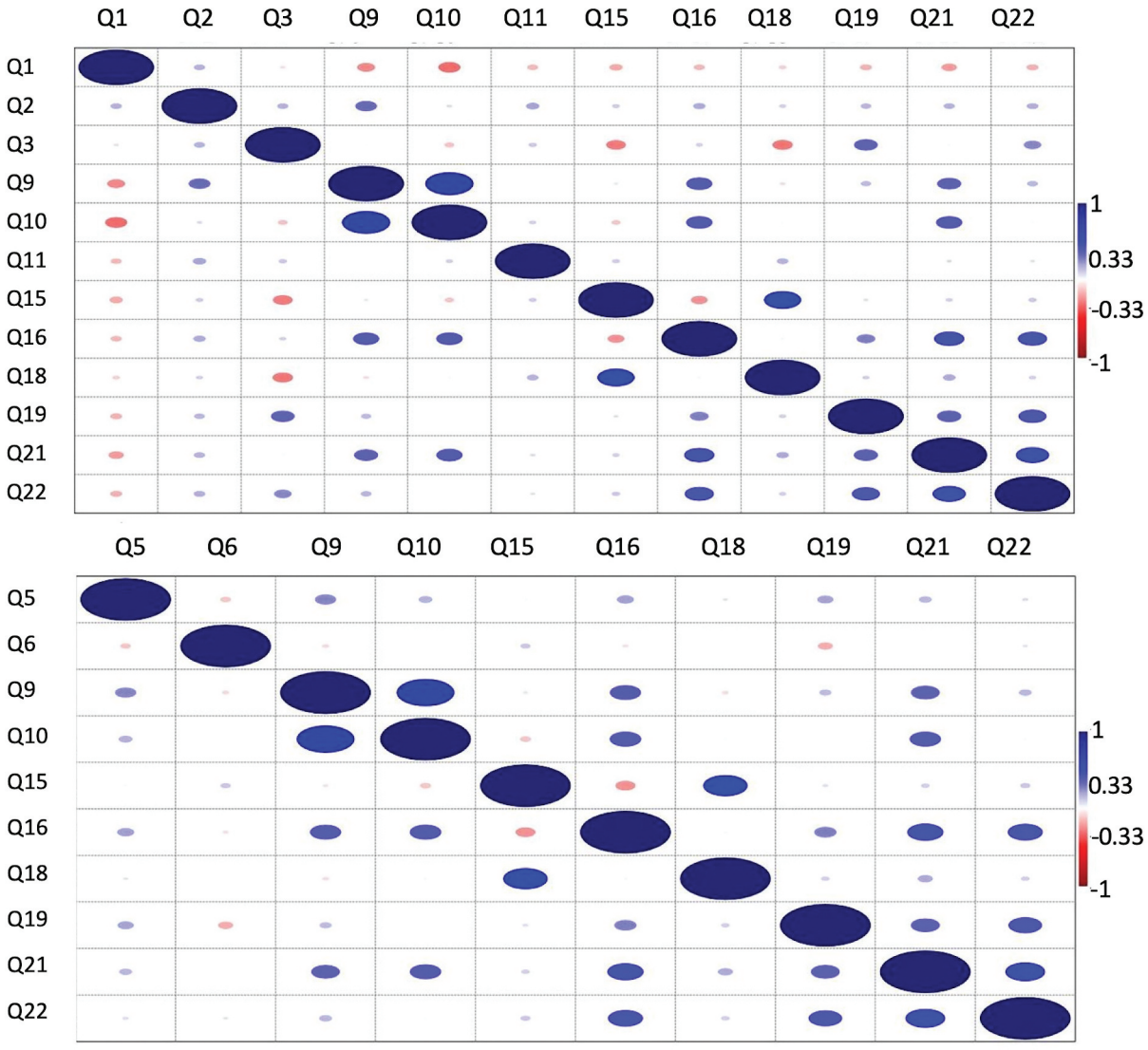

Figure 7. The graph was created using the statistical software past, in which some of the survey questions were entered. The graph shows whether there is a correlation between the selected questions. Blue ellipses indicate a positive correlation, while red ones indicate a negative correlation. The size of the ellipses reflects the correlation value.

the field's relevance. This pattern may reflect generational changes in research orientation and awareness of biodiversity issues.

A positive correlation was observed between geographical area (Q2) and time dedicated to nematology ($r = +0.3$) (Q9), indicating stronger involvement in southern Italy, likely due to the prevalence of plant-parasitic nematodes such as *Meloidogyne incognita* in local agricultural systems (Russo et al. 2007; Greco et al. 2024). Respondents who invest more time in nematology (Q9) also assign greater value to specialized training (Q10; $r = +0.6$) and strongly support the inclusion of university courses on nematodes (Q16), consistent with their belief in the discipline's future potential (Q21).

Higher educational levels (Q3) correlate positively with awareness of the need to promote nematode-related knowledge (Q19; $r = +0.3$) and negatively with the perception that public information is scarce (Q18; $r = -0.3$), suggesting that advanced academic exposure fosters both critical awareness and a commitment to outreach.

Altogether, the correlation patterns support the idea that education, professional engagement, and disciplinary perception are mutually reinforcing. Addressing educational gaps, investing in structured training, and expanding communication strategies could significantly enhance nematology's visibility and societal relevance in Italy and beyond.

3.3.1. Limitations of the questionnaire

Although this study provides an integrated assessment of Italian nematology using bibliometric, network, and perception-based analyses, several limitations should be acknowledged, particularly regarding the questionnaire component. Firstly, the survey relied on voluntary participation and convenience sampling through professional networks, the Italian Society of Nematology (SIN), and personal contacts. As a result, respondents likely overrepresent individuals who are more engaged with nematology or have stronger professional ties to the discipline. This introduces self-selection bias and limits the ability to generalize findings to all individuals working with nematodes in Italy, particularly those in private industry, diagnostics laboratories, or non-academic agricultural sectors.

Secondly, the participants in this study were predominantly involved in nematology-related activities and were largely drawn from the field of agricultural nematology; therefore, the results may not fully represent all research domains. Because dissemination occurred mainly through SIN channels and academic networks, researchers working in agronomy, plant protection, and marine ecology were proportionally over-represented (see Q13 and Figure S1O), whereas professionals from human medicine, veterinary parasitology, and environmental agencies were under-represented. This imbalance may have influenced certain responses, particularly those related to perceived importance, career relevance, and educational needs, resulting in a more favourable overall appraisal of nematology.

However, by receiving the answers of more than 80 professionals working with nematodes, the study provides the first systematic insight into: how Italian specialists enter the field, their educational background, the extent of nematology training received, perceived gaps in academic curricula, the importance of nematodes in daily professional practice. This "human dimension" is a great contribution, revealing structural challenges in education and highlighting opportunities for capacity building and future curriculum development. Nevertheless, the methodological approach developed here, including the combination of bibliometrics, network analysis, cognitive interview-validated surveys, and national community assessment, sets a precedent for similar work in other countries. This positions the Italian case study as a model that can support cross-national comparisons, global monitoring of disciplinary development, and coordinated international initiatives.

Conclusions

This study is the first to combine a systematic literature review, bibliometric mapping, and a perception-based national survey to provide a comprehensive overview of nematology in Italy. By integrating scientific output, research networks, and expert perspectives, the study offers a multidimensional understanding of the field that has not previously been available. This triangulation produces a uniquely comprehensive view of the field, its productivity, thematic orientation, and human capital, something that has not been done before to the best of our knowledge.

The results depict a national community that is scientifically mature, well-connected, and increasingly oriented towards sustainability and ecosystem health. Italian nematology is rooted in a solid tradition of agricultural science and parasitology but has progressively evolved towards integrative, ecology-driven approaches, reflecting global shifts in biodiversity and conservation research. The coexistence of agronomic, veterinary, and environmental studies highlights nematodes as versatile models bridging fundamental and applied science, from soil and marine ecology to plant protection and human health.

Despite this scientific vitality, the discipline remains underrepresented in academic curricula and public discourse. The survey results underscore a persistent educational gap, with many practitioners acquiring nematological expertise only after entering the workforce. This structural limitation, shared with other European countries since the mid-20th century, still constrains the recruitment of new specialists and the visibility of the field. However, the strong interest expressed by younger researchers and the widespread recognition of nematology's usefulness indicate fertile ground for revitalization. Incorporating nematode-focused modules in university programs and strengthening postgraduate training could consolidate expertise and ensure generational continuity. In this context, recent educational online initiatives, also including an adult lifelong learning for professional sector, such as the nematology course organized by the SIN in 2023 (see https://nematologia.it/ for further information and updates), represent an important step forward. This course, accredited by the major national professional orders, was attended not only by professionals but also by PhD candidates, graduates and students aiming to deepen their knowledge of nematology, thereby contributing to capacity building and dissemination of expertise in the field.

The correlation analysis also reveals a positive relationship between professional engagement, perceived importance of the discipline, and support for specialized training. These links suggest that nematology's future lies in reinforcing education, interdisciplinarity, and outreach. The respondents' optimism about the field's prospects, together with the country's international research networks, indicates that Italy can play a leading role in promoting nematodes as both scientific models and indicators of environmental quality and new agricultural approaches. However, achieving such a role requires addressing key challenges, including the need for structured nematology courses within bachelor's and master's degree programmes. In addition, increasing the visibility of nematodes beyond their role as parasites, particularly by emphasizing their ecological functions and importance in ecosystem monitoring, is essential.

A long-term strategy should move beyond individual training initiatives towards the development of a coordinated national framework, capable of integrating existing expertise, fostering interdisciplinary collaboration, and strengthening connections with international research and training networks. In this context, the SIN already plays a key coordinating role at both national and international levels, facilitating connections among researchers, institutions, and early-career scientists, and representing a strategic platform for further developing integrated research, training, and outreach activities.

More broadly, this study emphasizes that nematodes, despite their invisibility and complexity, embody many of the challenges and opportunities of modern biodiversity research. Their ubiquity, functional diversity, and responsiveness to environmental change make them key players in soil and aquatic ecosystem functioning. By integrating nematology within the frameworks of One Health, ecosystem conservation, and environmental education, it is possible to bridge gaps between disciplines and enhance the societal impact of biodiversity science.

In this context, recent outreach initiatives, such as the NemArt competition promoted by the SIN ((https://nematologia.it/attivita/concorso-nemart-il-bello-dei-nematodi/) and culminating in a public award ceremony, represent innovative efforts to disseminate nematological knowledge beyond academia, combining scientific content with creative and artistic engagement. Notably, the competition generated a range of educational products, including videos, comics, poems, and songs for children, further contributing to the communication of nematode diversity and ecological relevance to a broader audience.

The purpose of the competition was to spread knowledge about nematodes using various art forms, ranging from audiovisual media to sculpture, photography, song, fairy tales, and more. The aim, for participants, was to make even what is unknown or "little appreciated" by most people captivating, fascinating, mysterious, or even frightening. The works, however, had to draw inspiration from scientific information related to this animal *phylum*.

The competition was well attended, with contributions from outside Italy. Given its immense success, the SIN has now decided to hold a second edition of the NemArt competition, with the awards ceremony scheduled for the 16th SIN Congress in 2028.

In conclusion, strengthening nematology's visibility in academia and public perception is not merely a disciplinary goal, but a necessary step towards a more complete and inclusive understanding of life's diversity and its conservation. The Italian experience presented here, including recent efforts in education and public engagement, may serve as a model for other countries looking to integrate future perspectives in taxonomy, ecology, and education into a coherent strategy for sustainable research and biodiversity stewardship.

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Author contributions

CRediT: **F. Prestana:** Data curation, Formal analysis, Writing – original draft; **F. Semprucci:** Validation, Writing – original draft, Writing – review & editing; **E. Grassi:** Writing – original draft, Writing – review & editing; **B. Manachini:** Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Ambrogioni L, d'Errico FP, Greco N, Palmisano AM, Roversi PF. 2014. Nematologia agraria generale e applicate. Società Italiana di Nematologia. pp. 482.

Baldacci E, Spalla C, Grein A. 1954. The classification of the actinomyces species (= Streptomyces). Archiv für Mikrobiologie 20(4):347–357. DOI: 10.1007/BF00690879

Baldrighi E, Vasapollo C, Grassi E, Alvisi F, Cesaroni L, Balsamo M, Semprucci F. 2021. Meiobenthic assemblages as ecological indicator of natural variability induced by ecosystem engineers. Regional Studies in Marine Science 45:101824. DOI: 10.1016/j.rsma.2021.101824

Bennett J, Poulin R, Presswell B. 2022. Large-scale genetic investigation of nematode diversity and their phylogenetic patterns in New Zealand's marine animals. Parasitology 149(13):1794–1809. DOI: 10.1017/S003118202200138X10.1017/S003118202200138X

Berk Ş, Özdemir S, Pektaş AN. 2024. Visualization of scientific production in *Caenorhabditis elegans*: A bibliometric analysis (1980–2023). Genomics and Informatics 22:3. DOI: 10.1186/s44342-024-00002-7

Bird DM, Kaloshian I. 2003. Are roots special? Nematodes have their say. Physiological and Molecular Plant Pathology 62 (2):115–123. DOI: 10.1016/S0885-5765(03)00045-6

Blaxter M. 2011. Nematodes: The worm and its relatives. PLoS Biology 9(4):e1001050. DOI: 10.1371/annotation/083d39ea-2269-4915-9297-bc6d9a9f7c58

Blaxter M, Koutsovoulos G. 2015. The evolution of parasitism in Nematoda. Parasitology 142(S1):S26–S39. DOI: 10.1017/S0031182014000791

Boufahja F, Semprucci F, Beyrem H, Bhadury P. 2015. Marine nematodes taxonomy in Africa: Promising prospects against scarcity of information. Journal of Nematology 47:198–206.

Catani L, Grassi E, di Montanara AC, Guidi L, Sandulli R, Manachini B, Semprucci F. 2022. Essential oils and their applications in agriculture and agricultural products: A literature analysis through VOSviewer. Biocatalysis and Agricultural Biotechnology 45:102502. DOI: 10.1016/j.bcab.2022.102502

Catani L, Manachini B, Grassi E, Guidi L, Semprucci F. 2023. Essential oils as nematicides in plant protection—A review. Plants 12(6):1418. DOI: 10.3390/plants12061418

Certini G. 2005. Effects of fire on properties of forest soils: A review. Oecologia 143(1):1–10. DOI: 10.1007/s00442-004-1788-8

Cocozza di Montanara A, Baldrighi E, Franzo A, Catani L, Grassi E, Sandulli R, Semprucci F. 2022. Free-living nematodes research: State of the art, prospects, and future directions. A bibliometric analysis approach. Ecological Informatics 72:101891. DOI: 10.1016/j.ecoinf.2022.101891

Coomans A. 2002. Present status and future of nematode systematics. Nematology 4(5):573–582. DOI: 10.1163/15685410260438836
Corsini A, Zaccheo P, Crippa L, Manachini B. 2020. Nematode colonization of pyrite cinder-polluted soil. Redia 103:137–145. DOI: 10.19263/REDIA-103.20.22
Cronbach LJ. 1951. Coefficient alpha and the internal structure of tests. Psychometrika 16(3):297–334. DOI: 10.1007/BF02310555
Decraemer W, Eisendle-Flöckner U, Abebe E. 2019. Phylum Nematoda. In: Rogers DC, Thorp JH, editors. Freshwater invertebrates. Thorp and Covich's Academic Press. pp. 269–299. DOI: 10.1016/B978-0-12-385024-9.00009-5
Decraemer W, Hunt DJ. 2006. Structure and classification. In: Perry RN, Moens M, editors. Plant nematology. Centre for Agriculture and Bioscience International. pp. 3–32.
D'Errico FP, Bianco M. 2000. Problemi nematologici in Campania. Nematologia Mediterranea 28:11–15.
d'Errico G, Greco N, Vinale F, Marra R, Stillittano V, Davino SW, T D. 2022. Synergistic effects of *Trichoderma harzianum*, 1, 3 dichloropropene and organic matter in controlling the root-knot nematode *Meloidogyne incognita* on tomato. Plants 11(21):2890. DOI: 10.3390/plants11212890
De Zio S. 1964. Distribuzione dei nematodi in spiagge pugliesi. Italian Journal of Zoology 31(2):907–920. DOI: 10.1080/11250006409441123
Dhiman U, Rana S, Kesar S, Panwar A, Devi M, Kumar V, Paschapur AU, Singh L, Jeevan B, Singh AK, Parihar RD. 2019. Entomopathogenic Nematodes: Their Occurrence and Pathogenicity. In: Upadhyay SK, editor. Parasitology Taxonomy and Bioecology. New Delhi: Write and Print Publications. pp. 61–83.
Di Giovanni MV. 1959. Esponenti endofitici, epifitici e fitosaprobi del Lago Trasimeno: Facies autunnale. Italian Journal of Zoology 26(2):615–636. DOI: 10.1080/11250005909439313
Di Vito M, Greco N, Lamberti F. 2009. The nematode problem in Mediterranean horticulture. Nematologia Mediterranea 37:1–13.
Du Preez G, Daneel M, De Goede R, Du Toit MJ, Ferris H, Fourie H, Geisen S, Kakouli-Duarte T, Korthals G, Sánchez-Moreno S, Schmidt JH. 2022. Nematode-based indices in soil ecology: Application, utility, and future directions. Soil Biology and Biochemistry 169:108640. DOI: 10.1016/j.soilbio.2022.108640
Fanelli E, Vovlas A, D'Addabbo T, De Luca F. 2025. Molecular mechanism of *cinnamomum zeylanicum* and *Citrus aurantium* essential oils against the root-knot nematode, *Meloidogyne incognita*. Scientific Reports 15:6077.
Ferris H, Matute MM. 2003. Structural and functional succession in the nematode fauna of a soil food web. Applied Soil Ecology 23(2):93–110. DOI: 10.1016/S0929-1393(03)00044-1
Franzo A, Baldrighi E, Grassi E, Grego M, Balsamo M, Basili M, Semprucci F. 2022. Free-living nematodes of Mediterranean ports: A mandatory contribution for their use in ecological quality assessment. Marine Pollution Bulletin 180:113814. DOI: 10.1016/j.marpolbul.2022.113814
Frontalini F, Greco M, Semprucci F, Cermakova K, Merzi T, Pawlowski J. 2025. Developing and testing a new ecological quality status index based on marine nematode metabarcoding: A proof of concept. Chemosphere 370:143992. DOI: 10.1016/j.chemosphere.2024.143992
Garbo F, Pivato A, Manachini B, Moretto CG, Lavagnolo MC. 2019. Assessment of the ecotoxicity of phytotreatment substrate soil as landfill cover material for in-situ leachate management. Journal of Environmental Management 231:289–296. DOI: 10.1016/j.jenvman.2018.10.014
Glazer I, Shapiro-Ilan DI, Sternberg PW, editors. 2022. Nematodes as model organisms. Wallingford, UK: CABI Publishing.
Grassi E, Catani L, Magni P, Gravina MF, Semprucci F. 2023. Taxonomic and functional diversity of nematode fauna: Two sides of the same coin in the ecological quality assessment of transitional environments. Estuarine Coastal and Shelf Science 295:108550. DOI: 10.1016/j.ecss.2023.108550
Grassi E, Cocozza di Montanara A, Battistelli M, Micucci M, Guidi L, Gianfanti F, Baldrighi E, Catani L, Sandulli R, Semprucci F. 2025. *Caenorhabditis elegans* in the research of plants-derived nutraceuticals: A VOSviewer-based trend analysis. Heliyon 11(13):e43595. DOI: 10.1016/j.heliyon.2025.e43595
Grassi E, Montefalcone M, Cesaroni L, Guidi L, Balsamo M, Semprucci F. 2022. Taxonomic and functional nematode diversity in Maldivian coral degradation zones: Patterns across reef typologies and depths. PeerJ 10:e13644. DOI: 10.7717/peerj.13644
Greco N, Minuto A, d'Errico FP, d'Errico G. 2024. Synthetic nematicides in Italy: Past and present role in the management of plant parasitic nematodes and future perspectives of control. Redia 107:107–117. DOI: 10.19263/REDIA-107.24.16
Hailu FA, Hailu YA. 2020. Agro-ecological importance of nematodes (round worms). Acta Scientific Agriculture 4 (1):156–162. DOI: 10.31080/ASAG.2020.04
Hammer Ø, Harper DAT, Ryan PD. 2001. Past: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4:9.
Hodda M. 2022. Phylum Nematoda: Trends in species descriptions, the documentation of diversity, systematics, and the species concept. Zootaxa 5114(1):290–317. DOI: 10.11646/zootaxa.5114.1.2
Hodda M, Peters L, Traunspurger W. 2009. Nematode diversity in terrestrial, freshwater aquatic and marine systems. Nematodes as Environmental Indicators 45–93. DOI: 10.1079/9781845933852.0045
Höss S, Traunspurger W, Semprucci F, Schratzberger M. 2026. Nematode-based Pollution indices for aquatic ecosystems. In: Kalkouli-Duarte T, Korthals G, Sanchez-Moreno S, Du Preez G, de Goede R, editors. Nematodes as environmental bioindicators: From theory to practice. CABI Book. pp. 105–118. DOI: 10.1079/9781800624221.0006

Intirach J, Shu C, Lv X, Gao S, Sutthanont N, Chen T, Lv Z. 2024. Human parasitic infections of the class Adenophorea: Global epidemiology, pathogenesis, prevention, and control. Infectious Diseases of Poverty 13(1):48. DOI: 10.1186/s40249-024-01216-1

Jarić I, Courchamp F, Correia RA, Crowley SL, Essl F, Fischer A, Jeschke JM. 2020. The role of species charisma in biological conservation. Frontiers in Ecology and the Environment 18:345–353. DOI: 10.1002/fee.2195

Kakouli-Duarte T, Atira L, Da Costa Monteiro L, Godjo A, Van Rensburg CJ, Karpinska A, Pulavarty A, Semprucci F, Vieyra-Ramírez A, Viketoft M. 2026. Environmental policy and nematodes. In: Kalkouli-Duarte T, Korthals G, Sanchez-Moreno S, Du PREEZG, de Goede R, editors. "Nematodes as environmental bioindicators: From theory to practice". CABI Book. pp. 273–291. DOI: 10.1079/9781800624221.0016

Knoll S, Dessì G, Tamponi C, Meloni, L., Cavallo, L., Mehmood, N., Jacquiet, P., Scala, A., Cappai, M.G. and Varcasia A. 2021. Practical guide for microscopic identification of infectious gastrointestinal nematode larvae in sheep from Sardinia, Italy, backed by molecular analysis. Parasites and Vectors 14(1):505. DOI: 10.1186/s13071-021-05013-9

Lamberti F, FP D, Talamè M, Carella A. 2002. Prospettive per il controllo dei nematodi fitoparassiti. Nematologia Mediterranea 30:55–56.

Lambshead PJD. 1993. Recent developments in marine benthic biodiversity research. Oceanis 19:5–24.

Landi S, d'Errico G, Manachini B. 2024. Nematode communities in soils of the same volcanic origin across a gradient of naturalization: From intensive agriculture to forest. Sustainability 16(15):6307. DOI: 10.3390/su16156307

Leto E, Pace F, Sciotto G, Manachini B. 2024. Less known is more feared-A survey of Children's knowledge of and attitudes towards honeybees. Insects 15(5):368–381. DOI: 10.3390/insects15050368

Li J, Li Y, Wei X, Cui Y, Gu X, Li X, Yoshiga T, Abd-Elgawad MM, Shapiro-Ilan D, Ruan W, Rasmann S. 2023. Direct antagonistic effect of entomopathogenic nematodes and their symbiotic bacteria on root-knot nematodes migration toward tomato roots. Plant and Soil 484(1–2):441–455. DOI: 10.21203/rs.3.rs-1810422/v1

Linda C, Eleonora G, Loretta G, Priscilla F, Camilla T, Barbara C, Anna A, Federico G, Roberta A, Guido F, Luana DC. 2025. Ecotoxicological assessment of Basil essential oil on soil nematode communities. Environmental Pollution 370:125898. DOI: 10.1016/j.envpol.2025.125898

Lu X, Wang Y, Fung S, Qing X. 2021. I-Nema: A biological image dataset for nematode recognition. arXiv preprint arXiv:2103.08335. 10.48550/arXiv.2103.08335

Manachini B. 1998. Nematode sarai tu! Naturalmente Scienza 11(3):211–223.

Manachini B, Corsini A, Bocchi S. 2009. Soil quality indicators as affected by a long term barley-maize and maize cropping systems. Italian Journal of Agronomy 4(1):15–22. DOI: 10.1017/S0021859620000994

Manachini B, Lozzia GC. 2002. First investigations into the effects of bt corn crop on Nematofauna. Bollettino di Zoologia Agraria e di Bachicoltura Serie II 34:85–96.

Martínez A, Bonaglia S, Di Domenico M, Fonseca G, Ingels J, Jörger KM, Laumer C, Leasi F, Zeppilli D, Baldrighi E, Bik H. 2025. Fundamental questions in meiofauna research highlight how small but ubiquitous animals can improve our understanding of nature. Communications Biology 8(1):449. DOI: 10.1038/s42003-025-07888-1

Maurer TJ, Pierce HR. 1998. A comparison of likert scale and traditional measures of self-efficacy. Journal of Applied Psychology 83:324–329.

Mendoza-de Gives P. 2022. Soil-borne nematodes: Impact in agriculture and livestock and sustainable strategies of prevention and control with special reference to the use of nematode natural enemies. Pathogens 11(6):640. DOI: 10.3390/pathogens11060640

Mesa-Valle CM, Garrido-Cardenas JA, Cebrian-Carmona J, Talavera M, Manzano-Agugliaro F. 2020. Global research on plant nematodes. Agronomy 10:1148. DOI: 10.3390/agronomy10081148

Nelson GA, Schubert WW, Kazarians GA, Richards GF, Benton EV, Benton ER, Henke R. 1994. Radiation effects in nematodes: Results from IML-1 experiments. Advances in Space Research 14(10):87–91. DOI: 10.1016/0273-1177(94)90455-3

Norton DC. 2020. The changing face of nematology: Education, awareness, and application. Journal of Nematology 52: e2020–24.

Ockleford C, Adriaanse P, Berny P, Brock T, Duquesne S, Grilli S, Hernandez-Jerez AF, Bennekou SH, Klein M, Kuhl T, Laskowski R, Machera K, Pelkonen O, Pieper S, Stemmer M, Sundh I, Teodorovic I, Tiktak A, Topping CJ, Wolterink G, Craig P, de Jong F, Manachini B, Sousa P, Swarowsky K, Auteri D, Arena M, Rob S. 2017. Scientific opinion addressing the state of the science on risk assessment of plant protection products for in-soil organisms. The EFSA Journal 15(2):2. DOI: 10.2903/j.efsa.2017.4690

Perry RN, Moens M. 2011. Introduction to plant-parasitic nematodes; modes of parasitism (Plant Nematology Perry RN, Moens M, Starr JL eds). CABI. pp. 3–20.

Qing X, Wang Y, Lu X, Li H, Wang X, Li H, Xie X. 2022. NemaRec: A deep learning-based web application for nematode image identification and ecological indices calculation. European Journal of Soil Biology 110:103408. DOI: 10.1016/j.ejsobi.2022.103408

Russo G, Greco N, FP D, Brandonisio A. 2007. Impact of the root-knot nematode, *Meloidogyne incognita*, on potato during two different growing seasons. Nematologia Mediterranea 35:227–235.

Sabella G, Mulè R, Robba L, Agrò A, Manachini B. 2022. Could Europe apply a suitable control method for the small hive beetle (coleoptera: Nitidulidae)? Journal of Economic Entomology 115(2):401–411. DOI: 10.1093/jee/toac001

Salvador RB, Tomotani BM, KL O, Cavallari DC, Tomotani JV, Salmon RA, Kasper J. 2021. Invertebrates in Science communication: Confronting scientists' practices and the public's expectations. Frontiers in Environmental Science 9:606416. DOI: 10.3389/fenvs.2021.606416

Sandulli R, Semprucci F, Balsamo M. 2014. Taxonomic and functional biodiversity variations of meiobenthic and nematode assemblages across an extreme environment: A study case in a blue Hole cave. Italian Journal of Zoology 81(4):508–516. DOI: 10.7717/peerj.13644

Sasser JN, Krishnappa K. 1980. The development of nematology on a world basis. Journal of Nematology 12:153.

Schratzberger M, Danovaro R, Ingels J, Montagna P, Rohal Lupher M, Semprucci F, Somerfield P. 2023. Hidden players—meiofauna mediate ecosystem effects of anthropogenic disturbances in the ocean. In: Giere O, Schratzberger M, editors. New horizons in Meiobenthos research. Cham: Springer. pp. 175–255.

Schratzberger M, Holteman M, van Oevelen D, Helder J. 2019. A worms's world: Ecological flexibility pays off for free-living nematodes in sediments and soils. Bio-Science 69(11):867–876. DOI: 10.1093/biosci/biz120

Sellitto VM, Dallavalle E. 2023. I nematodi nel suolo Biocontrollo dei nematodi fitoparassiti. Edagricole. p. 186 pp.

Semprucci F, Appolloni L, Grassi E, Donnarumma L, Cesaroni L, Tirimberio G, Chianese E, Di Donato P, Russo GF, Balsamo M, Sandulli R. 2021. Antarctic special protected area 161 as a Reference to assess the effects of anthropogenic and natural impacts on meiobenthic assemblages. Diversity 13(12):626. DOI: 10.3390/d13120626

Semprucci F, Boufahja F, Grassi E, Al-Zharani M. 2025. Review article: The multifaceted role of nematodes in advancing the one health approach. Annals of Applied Biology 1–14. DOI: 10.1111/aab.70038

Semprucci F, Grassi E, Balsamo M. 2022. Simple is the best: An alternative method for the analysis of free-living nematode assemblage structure. Water 14(7):1114. DOI: 10.3390/w14071114

Semprucci F, Grassi E, Cocozza di Montanara A, Sandulli R, Baldrighi E. 2025. Emerging marine nematodes as model organisms: Which species for which question? Diversity 17:59. DOI: 10.3390/d17010059

Semprucci F, Sandulli R, De Zio-Grimaldi S. 2008. Adenophorea, nematodi marini. In: Relini G. (ed) Checklist della flora e della fauna dei mari italiani. Biologia Marina Mediterranea 15(suppl):184–209.

Soliman S, Salem H, El-Saadony M, Ahmed A, Saad A, M E-S. 2024. *Haemonchus contortus* infection of goats and the use of anthelmintic natural alternative: An updated review. Journal of the Hellenic Veterinary Medical Society 75 (2):7201–7210. DOI: 10.12681/jhvms.29905

Taber KS. 2018. The use of Cronbach's alpha when developing and reporting research instruments in Science education. Research in Science Education 48(6):1273–1296. DOI: 10.1007/s11165-016-9602-2

Tarasco E, Fanelli E, Salvemini C, El-Khoury Y, Troccoli A, Vovlas A, De Luca F. 2023. Entomopathogenic nematodes and their symbiotic bacteria: From genes to field uses. Frontiers in Insect Science 3:1195254. DOI: 10.3389/finsc.2023.1195254

Tursi L. 1960. Ancylostomiasis in Calabria. Annali della Sanità Pubblica 21:721–779.

Vallotton R. 1987. Reflections on the present and the future of nematology. Revue Nérnatol. IO 3:251–255.

Van Den Hoogen J, Geisen S, Routh D, Ferris H, Traunspurger W, Wardle DA, de Goede RGM, Adams BJ, Ahmad W, Andriuzzi WS, Bardgett RD, Bonkowski M, Campos-Herrera R. 2019. Soil nematode abundance and functional group composition at a global scale. Nature 572(7768):194–198. DOI: 10.1038/s41586-019-1418-6

Van Eck NJ, Waltman L. 2018. Vosviewer manual 1.6.11, manual version 1.6.9.

Webster JM. 1998. Nematology: From curiosity to space science in fifty years! The Annals of Applied Biology 132(1):3–11. DOI: 10.1111/j.1744-7348.1998.tb05180.x

Zhang ZQ. 2013. Animal biodiversity: An update of classification and diversity in 2013. Zootaxa 3703(1):5–11. DOI: 10.11646/zootaxa.3703.1.3

Zullini A. 2021. Nematodi di acqua dolce: manuale di identificazione al genere e metodi di raccolta. Biologia Ambientale 35:250.

Zullini A, Semprucci F. 2020. Morphological differences between free-living soil and freshwater nematodes in relation to their environments. Nematology 22:125–132. DOI: 10.1163/15685411-00003330