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Articles

Diversity and habitat distribution of tomato (Solanum lycopersicum) nematoda fauna (Zarafshan valley, Uzbekistan)

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Nematodes are the most widespread multicellular organisms found in soil ecosystems. They engage in complex and diverse relationships with plants and other living organisms. Additionally, the composition of nematode communities varies across different climatic conditions. This study was conducted in the Zarafshan Valley of Uzbekistan, where the species and ecological diversity of nematodes have not been thoroughly explored. Our research identified 87 nematode species belonging to seven orders across various biotopes associated with tomato plants in three regions of the Zarafshan Valley. Notably, the majority of these species were found in the rhizosphere soil. For the first time in this region, we classified nematodes into ecological groups based on their trophic characteristics, revealing that the bacterivores group is the most dominant. We calculated ecological indicators for nematodes in different biotopes using the Simpson index (D´), Shannon index (H´), Menhinck index, Margalef index, and Berger-Parker index. The diversity of nematode fauna across these biotopes was analyzed in relation to soil organic matter content, humidity, and pH levels. Our findings further demonstrate that variations in the species and ecological composition of nematodes among biotopes are influenced by multiple factors, particularly their trophic characteristics.

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Keywords

Biotopes, distribution, diversity, nematodes, *Solanum lycopersicum*, humus, ecological diversity

Introduction

Nematodes play a crucial role in soil ecosystems as important links in the food chain (Becerra et al. 2014; Sun et al. 2019; de Castro et al. 2021). Among them, parasitic phytonematodes significantly impact plants and are recognized as a major biotic factor in global food security challenges (Coyne et al. 2018). In fact, annual losses caused by nematodes to agricultural crops amount to approximately $358.24 billion (Abd-Elgawad 2014). Despite being the dominant microfauna in terrestrial soil ecosystems, our understanding of the ecological and edaphic factors that regulate nematode population distribution remains limited, even in well-studied agricultural fields.

Recent research has focused on the effects of nematodes on agricultural plants, particularly tomatoes, examining the damage they cause and the development of control measures (Karuri 2023). This research primarily targets the most destructive tomato pests, namely root-knot nematodes (Abd-Elgawad 2020; Kepenekci et al. 2017; Saidova et al. 2020). However, it is well established that the species composition and ecological diversity of tomato nematodes vary across regions with different climatic conditions (Karuri 2023).

Uzbekistan, located in the heart of Eurasia and characterized by unique climatic conditions, has received insufficient attention regarding its tomato nematode fauna. Although significant efforts have been made to study the biodiversity of invertebrates in Uzbek biocenoses (Narzullayev 2022; Rakhimov 2023; Romantsov and Rakhimov 2024), the species and ecological composition of nematodes in agrocenoses and the characteristics of their fauna formation remain inadequately explored.

Historically, studies on tomato nematodes in Uzbekistan date back several years. For example, Khakimov (2014) identified 53 nematode species associated with tomatoes, including 20 species found in the above-ground parts and root systems, of which 13 were parasitic. Notably, a high prevalence of northern nematodes (*M. hapla*) was recorded in plant tissues; however, anatomical and morphological characteristics of the nematode were not provided. Similarly, Mirzaliyeva et al. (2021) examined the seasonal dynamics of tomato nematode fauna and parasitic species in greenhouse settings. In southern Uzbekistan, severe damage to tomatoes by root-knot nematodes was observed, particularly from four species: *M. incognita*, *M. javanica*, *M. acrita*, and *M. arenaria*. It is important to note that *M. acrita* is now commonly recognized as a synonym for *M. incognita*.

Despite this existing knowledge, certain aspects of the tomato nematode fauna in the middle part of the Zarafshan Valley remain underexplored. Specifically, there is a need to investigate the distribution of tomato nematode fauna by biotope, their ecological diversity, and the various factors that influence their populations. While numerous studies have been conducted, there are still gaps in understanding the primary factors affecting nematode community structure. Some researchers emphasize the organic composition of soil as a key determinant in the formation of nematode fauna in agrocenoses (Pan et al. 2020; Narzullayev 2022). Others highlight the role of weeds, considered a natural habitat for nematodes, in shaping nematode populations (AbdelRazek and Balah 2023). Additionally, concentrations of heavy metals have been found to significantly impact nematode communities in both short- and long-term contexts (Lü et al. 2023).

Currently, there are no universally accepted conclusions regarding the factors influencing nematode fauna formation. Consequently, analyzing the species diversity and ecological composition of tomato nematodes in this region will enable nematologists to compare faunal structures across distinct climatic zones. Ultimately, these findings will offer deeper insights into the factors shaping nematode communities.

Materials and methods

Study area

This article is based on materials collected by the authors from 2019 to 2022. The study involved the collection of tomato phytonematodes from soil surrounding the plants and their roots, conducted from May to August using a systematic sampling method. Tomato fields were selected from three farms located in the Payaryk, Jomboy, and Akdarya districts of the Samarkand region (see Fig. 1 and Table 1). The average annual precipitation in the study area ranges from 300 to 350 mm. In these tomato agrocenoses, alternating planting with winter wheat, beans, and cotton has been established (Nomozov and Turdimetov 2016).

Samples were collected from ten plants and their surrounding soil in each field along a diagonal route. Each selected plant was carefully uprooted in the field, and a soil sample of 0.5 kg was taken from two depth layers: 0–15 cm and 15–30 cm. The collected samples were transported to the laboratory in cellophane bags. In the lab, the above-ground parts of the plants and their root systems were examined separately. A total of 40 samples were taken from each vegetable crop field within each farm, yielding 120 samples from each farm and 360 samples from the three districts, culminating in a total of 1,080 samples from the region.

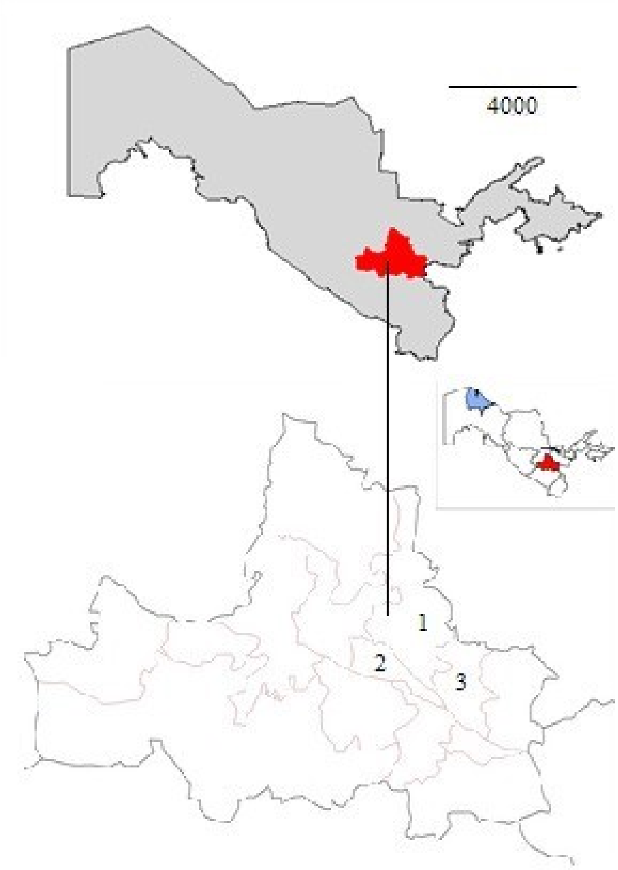

Figure 1. *Locations of sample collection: 1 – Payaryk region, 2 – Akdarya region, 3 – Jambay region.*

Latitude (N)	Longitude (E)	Altitude (m)
39º58'06''	66º43'03''	546
39º43'41''	67º04'47''	671
39º53'48''	66º41'10''	553
39º42'43''	67º03'52''	663
39º42'43''	67º03'52''	663
39º59'18''	66º51'14''	609
39º59'18''	66º51'14''	609

Table 1. *Coordinates where research samples were collected*

In the laboratory, the above-ground parts and root systems were cut into lengths of 0.5–0.7 cm using sharp knives or scissors, and a 10 g subsample was taken for phytohelminthological analysis. Nematodes were isolated from the plant tissues using Berman's funnel method. The collected soil samples were thoroughly mixed, and a 20 g portion was analyzed for nematodes using the funnel and flotation method. Isolated nematodes were fixed in 5–6% formalin solution in test tubes (Van Bezoijen 2006).

Temporary and permanent preparations were made for identifying nematode species isolated from both plant tissues and soil samples. The fixed nematodes in formalin were poured into Petri dishes, where they were collected using an entomological needle under a binocular microscope and transferred to clean water in watch glasses. A mixture of 1–2 drops of glycerin and 96% alcohol in a 1:1 ratio was then added to the water containing the nematodes. This mixture was allowed to sit for 14–16 hours, allowing the water to evaporate and the glycerin to permeate the nematode's internal organs, making them visible under the microscope. After this treatment, the nematodes were transferred to a glass slide with a drop of pure glycerin, and subsequently to drops of glyceringelatin mixture for permanent preparations (Van Bezoijen 2006).

For species identification, the external and internal structures of the nematodes were examined under the microscope, and morphometric descriptions were made using de Man indices (L, α, b, c, V) (de Man 1921). Here, L represents the total length of the nematode body (in microns), α is the ratio of body width to length, b is the ratio of esophagus length to total body length, c is the ratio of tail length to total body length, and V indicates the distance from the head to the genital opening as a proportion of the total body length.

Species identification utilized a Micromed MC–2–ZOOM digital stereoscopic microscope for detailed morphological and anatomical examinations. Key identifiable features included the structure of the head, stoma stylet, and anterior part of the digestive system of the phytonematodes.

In addition to these measurements, several additional systematic characteristics were examined, including the head capsule and cuticle structure, the morphology and size of the stylet located in the oral cavity, the size of the esophageal nerve ring junction, the structure of the muscular bulb, the reproductive system of both female and male nematodes, the shape and size of male spicula, and the structure and quantity of chitin teeth present in the oral cavity of some nematode groups, such as Mononchus (Van Bezoijen 2006). Molecular-genetic analysis methods were also employed for identifying Meloidogyne species, which posed specific challenges in morphometric identification (Mirzaev et al. 2024).

Taxonomic positions of nematode species were defined based on classical phylogenetic systematics (Chitwood 1937), utilizing Hodda systematics for phylum classification (Hodda 2022).

Trophic groups and ecological indices

The isolated and identified nematodes were categorized into trophic groups: bacterivores, fungivores, predatory nematodes, omnivores, and plant parasites, following Yeates et al. (1993). Ecological indicators of nematodes by biotope were calculated using the Simpson index (D´), Shannon index (H´), Menhinck index, Margalef index, and Berger–Parker index, with the calculations performed using PAST 4.0 soft-ware (Hammer et al. 2001).

Soil analysis

Soil pH and moisture content were measured as factors influencing nematode community diversity. These parameters were determined using a ZD-07 4-in-1 Soil Survey Instrument (China). The humus content in the soil was assessed based on existing literature (Nomozov and Turdimetov 2016). The soils of the study area are classified as gray soils, with humus content ranging from 0.8% to 1.5%.

Results

Upon analyzing samples collected from tomato plants and their rhizosphere in laboratory conditions, a total of 87 nematode species were identified and taxonomically analyzed. These species belong to seven orders: Dorylaimida, Monhysterida, Mononchida, Araeolaimida, Tylenchida, Rhabditida, and Diplogastrida, which are part of the classes Adenophorea and Secernentea. Among these, the Tylenchida order exhibited the highest diversity, comprising 37 species, followed by Rhabditida with 21 species, and Dorylaimida with 18 species. The remaining orders – Diplogastrida, Monhysterida, Mononchida, and Araeolaimida –contained between 1 to 4 species each. In the above-ground part of the tomato plants, Rhabditidae and Cephalobidae families (from the Rhabditida order) were predominant, while the root systems were primarily dominated by families from the Tylenchida order, namely Rhabditidae, Cephalobidae, Aphelenchoididae, Tylenchidae, Pratylenchidae, Hoplolaimidae, and Meloidogynidae. It is noteworthy that species from the order Dorylaimida were occasionally found in small quantities within the plant roots (Table 2).

The distribution of phytonematode diversity was uneven across the vegetative organs of the tomato plant and its rhizosphere layers. For instance, the aboveground part of the tomato contained 246 individuals representing 13 species, while the roots had 36 species and a total of 815 individuals. The upper 0–15 cm layer of the tomato rhizosphere demonstrated a significant relative diversity of species, hosting 79 species, which accounted for 90.8% of the overall nematode fauna. This layer was markedly different from both the lower rhizosphere layers and the vegetative parts of the plants in terms of nematode population density. In fact, the number of individuals in this upper layer (2,580) exceeded the total number of individuals found in both the vegetative parts and the lower rhizosphere soil. Additionally, the 15–30 cm layer of the rhizosphere contained 1,746 individuals representing 65 species.

In the overall nematode fauna associated with tomatoes, species were categorized into five ecological groups based on their feeding habits, type of food, and their relationship with the plants (Fig. 3). Of these groups, plant-feeding nematodes were notably dominant, with 28 species identified. Although herbivorous nematodes, comprising 26 species, were also significant, this category included several distinct subgroups (Table 2). Furthermore, 14 species of omnivores, 13 species of hyphal-feeding nematodes, and 6 species of predatory nematodes were recorded within the fauna. The representatives from these ecological groups exhibited varying diversity across different biotopes.

Ecological groups*	Species	Plant samples		Rhizosphere	
		Above ground part	Root	0–15 cm	15–30 cm
1	2	3	4	5	6
A.P.	*Mononchus truncatus* Bastian, 1965	–	–	+	+
A.P.	*Clarcus parvus* de Man, 1880	–	–	+	+
A.P.	*Mylonchulus solus* Mulvey, 1961	–	–	+	+
A.P.	*M. sigmaturus* Cobb, 1917	–	–	+	+
O.	*Dorylaimus stagnalis* Dujardin, 1845	–	–	+	+
O.	*Laimydorus filiformis* Bastian, 1865	–	–	+	+
O.	*Mesodorylaimus bastiani* Bütschli, 1873	–	–	+	+
O.	*M. pendzchikenticus* Tulaganov , 1949	–	–	+	–
O.	*Eudorylaimus dogielli* Andrássy, 1959	–	+	+	+
O.	*E. kirjanovae* Tulaganov, 1949	–	–	+	–
O.	*E. labiatus* (de Man, 1880)	–	–	+	+
O.	*E. minutus* (Bütschli, 1873)	–	–	+	+
O.	*E. monhystera* (de Man, 1880)	–	+	+	+

O.	*E. muchabbatae* Tulaganov, 1949	–	–	+	+
O.	*E. sulphasae* Tulaganov, 1949	–	–	+	+
O.	*E. skrjabini* Tulaganov, 1949	–	–	+	+
O.	*E. parvus* (de Man, 1880)	–	–	+	+
O.	*E. uzbekistanicus* Tulaganov, 1949	–	–	+	+
H.F.	*Tylencholaimus minimus* de Man, 1876	–	–	+	–
A.P.	*Nygolaimus brachyuris* (de Man, 1880)	–	+	+	+
B.F.	*Alaimus primitivus* de Man, 1880	–	–	+	+
H.F.	*Diphtherophora communis* de Man, 1880	–	–	+	+
B.F.	*Anaplectus granulosus* (Bastian, 1865)	–	–	+	+
B.F.	*Plectus cirratus* Bastian, 1865	–	+	+	+
B.F.	*Proteroplectus parvus* (Bastian, 1865)	–	+	+	–
B.F.	*Rhabdolaimus aquaticus* de Man, 1880	–	–	–	+
B.F.	*Monhystera similis* Bütschli, 1873	–	–	+	+
B.F.	*M. paludicola* de Man, 1881	–	–	+	+
B.F.	*Rhabditis brevispina* Claus, 1863	+	+	+	+
B.F.	*Rh. filiformis* (Bütschli, 1873)	–	+	+	+
B.F.	*Rh. intermedius* Cobb , 1893	–	+	+	+
B.F.	*Pelodera cylindrica* (Cobb, 1898)	–	+	+	+
B.F.	*Mesorhabditis monhystera* (Bütschli, 1873)	+	+	+	+
B.F.	*Diploscapter rhizophilus* Rahm, 1928	–	+	+	+
B.F.	*Panagrolaimus rigidus* (Schneider 1866)	–	+	+	–
B.F.	*P. subelongatus* (Cobb, 1914)	–	–	+	+

B.F.	*Cephalobus oryzae* Karimova, 1957	–	–	+	+
B.F.	*Cephalobus persegnis* Bastian, 1865	–	–	+	+
B.F.	*Eucephalobus oxyuroides* (de Man, 1876)	–	–	+	+
B.F.	*E. filiformis* (de Man, 1880)	–	–	+	+
B.F.	*Eucephalobus striatus* (Bastian, 1865) Thorne, 1937	–	–	+	+
B.F.	*Heterocephalobus elongatus* (de Man, 1880)	+	+	+	+
B.F.	*Acrobeles ciliatus* von Linstow, 1877	–	–	+	+
B.F.	*Acrobeloides bütschli* (de Man, 1885)	–	–	+	+
B.F.	*A. emarginatus* (de Man, 1880)	–	–	+	+
B.F.	*A. nanus* (de Man, 1880)	–	–	+	+
B.F.	*Chiloplacus lentus* (Maupas, 1900)	–	–	+	+
B.F.	*Cervidellus insubricus* (Steiner, 1914)	–	–	+	+
B.F.	*Diplogaster rivalis* (Leydig, 1854)	–	+	+	+
H.F.	*Aphelenchus avenae* Bastian, 1865	+	+	+	+
H.F.	*Paraphelenchus pseudoparietinus* (Micoletzky, 1922)	+	+	+	–
H.F.	*Aphelenchoides bicaudatus* (Imamura, 1931)	+	+	+	–
H.F.	*A. cyrtus* Paesler, 1959	–	–	+	–
H.F.	*A. helophilus* (de Man, 1880)	–	–	+	–
H.F.	*A. kühnii* Fischer, 1894	–	–	+	–
H.F.	*A. limberi* Steiner, 1936	–	+	+	–
H.F.	*A. parietinus* (Bastian, 1865)	+	+	+	+
H.F.	*A. subparietinus* Sanwal, 1961	–	+	+	–

H.F.	*A. subtenius* (Cobb, 1926)	–	–	+	–
H.F.	*A. zeravschanicus* Tulaganov, 1949	–	–	+	–
A.P.	*Seinura demani* (Goodey, 1928)	–	–	+	+
P.F. (e)	*Aglenchus agricola* (de Man, 1884)	–	+	+	+
P.F. (e)	*A. bryophilus* Steiner, 1914	–	+	+	+
P.F. (f)	*Tylenchus davainei* Bastian, 1865	+	+	+	+
P.F. (f)	*T. leptosoma* de Man, 1880	+	–	–	+
P.F. (f)	*Filenchus polyhypnus* (Steiner & Albin, 1946)	–	–	+	+
P.F. (e)	*Lelenchus discrepans* Andrássy, 1954	–	–	+	+
P.F. (b)	*Ditylenchus destructor* Thorne, 1945	+	+	+	+
P.F. (b)	*D. dipsaci* Kühn, 1857	+	+	+	–
P.F. (b)	*D. pumilus* Karimova, 1957	+	+	–	–
P.F. (d)	*Neotylenchus abulbosus* Steiner, 1931	–	–	+	–
P.F. (d)	*Nothotylenchus acris* Thorne, 1941	–	+	+	+
P.F. (b)	*Pratylenchus pratensis* (de Man, 1880)	–	+	+	+
P.F. (b)	*P. thornei* Sher & Allen, 1953	–	+	–	–
P.F. (b)	*P. tumidiceps* Merzheevskaya, 1951	–	+	–	–
P.F. (d)	*Hoplolaimus tylenchiformis* Daday, 1905	–	–	+	+
P.F. (d)	*Helicotylenchus erythrinae* (Zimmermann, 1904)	–	+	+	+
P.F. (d)	*H. multicinctus* (Cobb 1893)	–	+	+	+
P.F. (d)	*Tylenchorhynchus tener* Erzhanova, 1964	–	–	+	+
P.F. (d)	*Merlinius dubius* (Steiner, 1914)	–	–	+	+

P.F. (c)	*Rotylenchus goodeyi* Loof & Oostenbrink, 1958	–	–	+	+
P.F. (c)	*R. robustus* de Man, 1876	+	–	+	+
P.F. (d)	*Paratylenchus amblycephalus* Reuver, 1959	–	–	+	+
P.F. (d)	*P. macrophallus* de Man, 1880	–	+	+	+
P.F. (a)	*Meloidogyne hapla* Chitwood, 1949	–	+	**	**
P.F. (a)	*M. incognita* (Kofoid & White, 1919)	–	+	**	**
P.F. (a)	*M. javanica* (Treub, 1885)	–	+	**	**

Table 2. *Taxonomic and ecological composition of nematode fauna associated with tomatoes and their rhizosphere*

Note:

*A.P. – animal predation; O. – omnivores; B.F. – bacterial feeding; H.F. – hypal feeding; P.F. (a) – sedentary parasites; P.F. (b) – migratory endoparasites; P.F. (c) – semi-endoparasites; P.F. (d) – ectoparasites; P.F. (e) – epidermal cell and root hair feeders; P.F. (f) – algal, lichen (algal or fungal component), or moss feeders that feed by piercing;

** The larvae were not identified at the species level.

In the above-ground portion of the plant, bacterial-feeding, hyphal-feeding, and plant-feeding nematodes were present, with migratory endoparasites being more numerous in both species and individual counts compared to other groups. The root system contained representatives from all ecological groups except semiendoparasites. In this biotope, bacterial-feeding nematodes emerged as a subdominant group, constituting 30.5% of the root nematode fauna. Although herbivorous nematodes were dominant in the root system, they too comprised several subgroups based on their feeding characteristics.

Despite the differences in the number of species between the 0–15 cm and 15–30 cm soil layers, their ecological compositions were quite similar. A notable decrease in the number of species and individuals of hyphal-feeding nematodes was observed exclusively in the 15–30 cm soil layer.

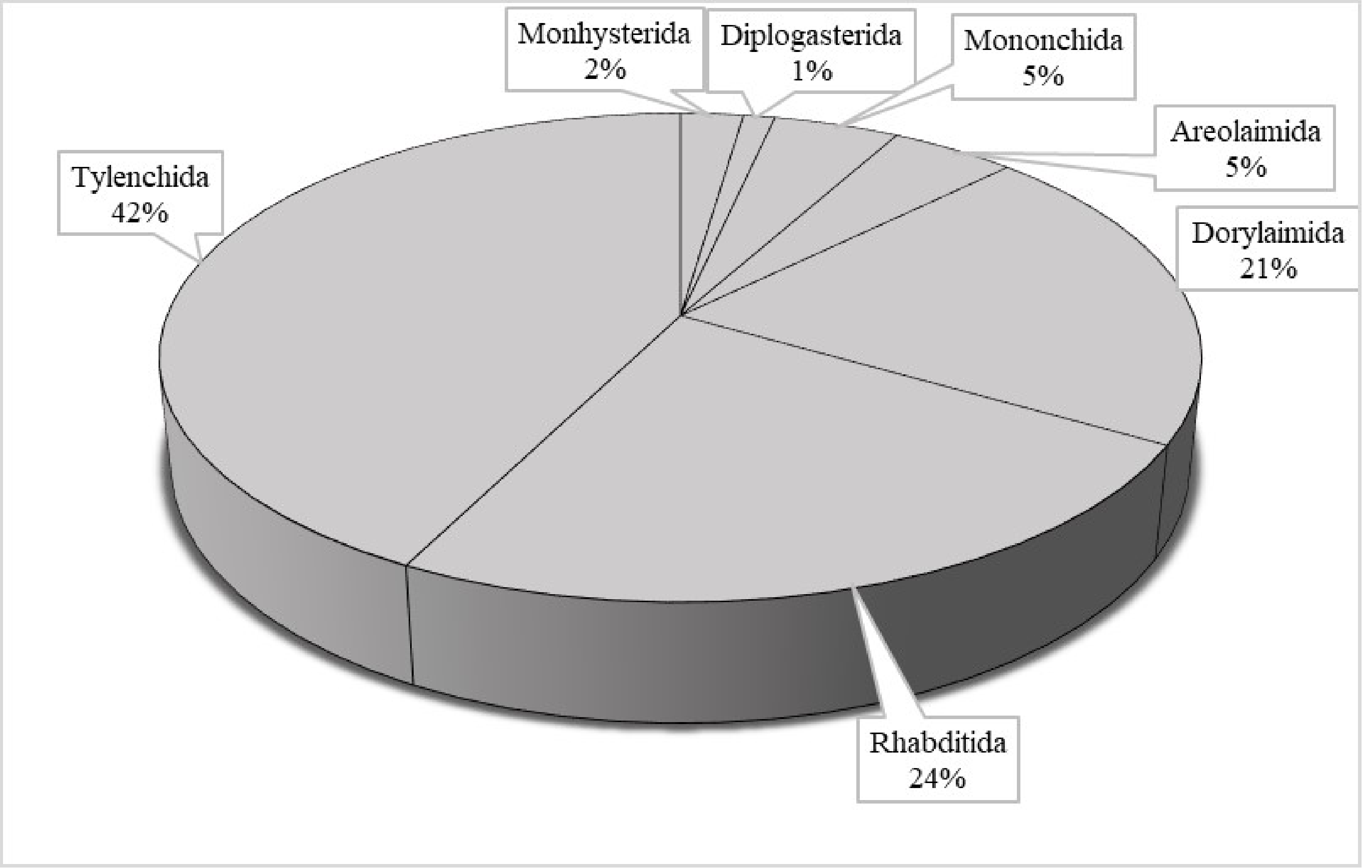

Figure 2. *Taxonomic fistrubution of fauna.*

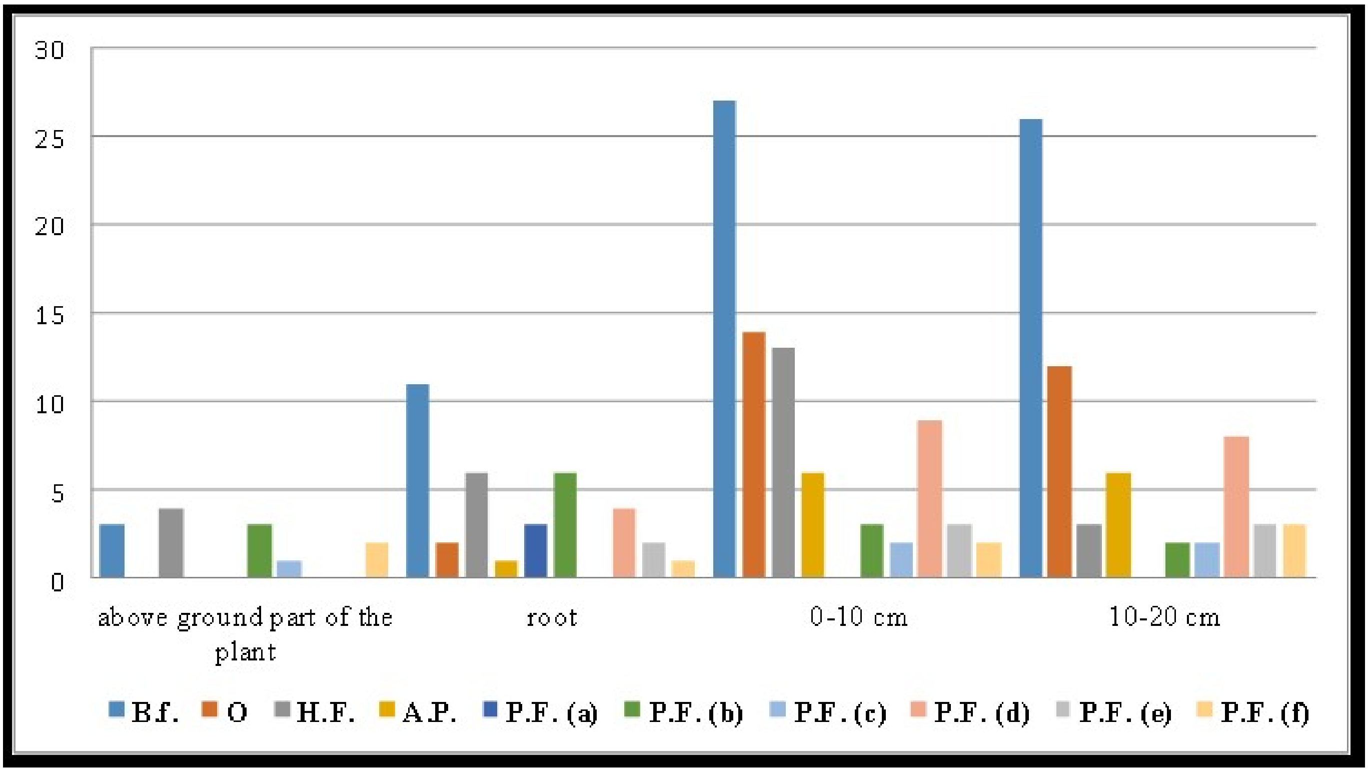

Figure 3. *Habitat distribution of ecological groups (see Table 2 for abbreviations).*

Discussion

When systematically analyzing the nematode fauna identified in this research, it became evident that the composition of taxonomic units at the class, genus, and family levels aligns with findings from previous studies (Matveeva et al. 2017; Keshava and Shwetha 2023). However, the composition of the fauna differs notably from that found in natural biocenoses (Thomas 1978; Sohlenius and Wesilewska 1984; Kumar and Ahmad 2017; Narzullayev et al. 2023). Despite the relatively high species richness observed (87 species), it remains lower compared to natural biocenoses (Narzullayev 2022), which can be attributed to the unique conditions present in natural environments (Obed et al. 2017). Nonetheless, the diversity of the nematode fauna in the studied area can be considered high, likely influenced by the regular application of organic fertilizers in agrocenoses (Mulder et al. 2003; Pan et al. 2020). The co-application of mineral fertilizers alongside organic fertilizers in these agrocenoses may have a negative impact on nematode diversity (Puissant et al. 2021). The pH of the study area (ranging between 5.5 and 6.5) may also play a role in these findings, as lower pH values are generally more favorable for nematodes (Kitagami et al. 2017).

Diversity assessments using various ecological indices across different biotopes revealed significant differences between the vegetative parts of the plants and the soil layers (A and B in Table 3). However, no significant differences were observed at varying soil depths (C and D in Table 3), which corresponds with previous studies (Liu et al. 2022). Overall, the ecological indices suggest that nematode diversity is relatively rich, which may be linked to the practice of crop rotation in these fields. An increase in the duration of tomato planting tends to decrease nematode diversity, particularly through an increase in root-knot nematodes (RKN) (Zheng et al. 2012; Kembo et al. 2022). The diversity of nematodes in various biotopes may be influenced by several factors, including organic residues, nitrogen (N_2) content, vegetation period, and seasonal changes (Ferris et al. 1996; Puneet and Irfan 2017; Obed et al. 2017).

	A (above ground part)	B (root)**	C (0–15 cm layer)	D (15–30 cm layer)
Simpson_1-D	0.8612	0.9537	0.9881	0.9875
Shannon_H	2.633	3.49	4.431	4.382
Menhinick	3.87	5.96	9.165	8.944
Margalef	5.347	9.17	18.73	18.03
Berger–Parker	0.05882	0.02632	0.0119	0.0125

Table 3. *Diversity indices of nematode communities in different habitats*

Note: ** The number of root nematode individuals found in the root system was excluded from the calculations of ecological indices.

In the ecological composition of the studied fauna, herbivorous and bacterivorous nematodes were the most abundant groups, with the dominance of bacterivores observed in other studies as well (Rawhat et al. 2021). However, variations in the distribution of nematodes belonging to different trophic groups were evident across the biotopes. The above-ground parts of the plants had the fewest species, primarily composed of plant-associated nematodes, confirming the findings of prior research (Yetaes 1987; Zhao et al. 2022). Notably, the presence of fungus-eating nematodes (such as *Aphelenchus avenae*, *Paraphelenchus pseudoparietinus*, *Aphelenchoides bicaudatus*, and *A. parietinus*) in the above-ground plant tissues was a unique finding, indicating a strong trophic connection with fungi (Lamondia and Timper 2016; Zhang et al. 2020). This association suggests the onset of decaying processes within this plant region. Additionally, some of these species (e.g., members of the genus *Aphelenchoides*) are also categorized as herbivorous nematodes (Wheler and Crow 2020). Other studies indicate significant environmental differences that affect nematode communities, which may stem from variances in soil type, annual precipitation, and vegetation cover (Keshava and Shwetha 2023).

An increase in the diversity of species was observed within the tomato root system. While the presence of herbivorous nematodes is typical in root environments, the rising numbers of bacterivorous and fungal hyphae-feeding nematodes were noteworthy. Nematode species that feed on bacteria and fungal hyphae constituted 47.2% of the root nematode fauna, which can be attributed to significant infections by root-knot nematodes (RKN). Previous studies have demonstrated that many bacteria exist in symbiosis with *Meloidogyne* parasites (Yi et al. 2015), creating favorable conditions for bacterivorous nematodes to thrive in RKN-infected roots. Furthermore, rotting processes in RKN-infected roots, often involving fungal action, contribute to an increase in populations of fungal-feeding nematodes (Briar et al. 2023; Jagdale et al. 2021).

In the 0–15 cm layer of the rhizosphere, the greatest diversity of phytonematodes (in terms of species and individuals) was found. This diversity is mainly due to the prevalence of free-living nematodes. The conditions in this layer, such as protection from sunlight provided by plant foliage (Rawhat et al. 2021), enhanced root development, and favorable soil characteristics (Kim et al. 2017), facilitate good aeration. Additionally, higher levels of humus (organic residues) along with abundant bacterial biomass (Jiang et al. 2017) play a crucial role in supporting free-living nematode populations (Čerevková and Renèo 2009; Patrícia et al. 2017; Pan et al. 2020). The richness of nematode diversity in the 0–15 cm soil layer is primarily attributed to bacteriotrophs, omnivores, and those that feed on fungal hyphae, while herbivorous nematodes were predominantly represented by ectoparasitic forms.

The diversity of free-living nematodes in the 15–30 cm soil layer was nearly identical to that in the upper layer (0–15 cm). However, in the lower layer, there was a significant decrease in both the number of species and individuals of nematodes that feed on fungal hyphae (Fig. 2). This decline can be attributed to the low humus content in this layer, which is necessary for fungal growth in the soils of the research area (Nomozov and Turdimetov 2016). Among the plant-eating nematodes, ectoparasitic species remained dominant.

Overall, the reduction in species diversity and individual richness of nematodes observed in the upper layer (0–15 cm, see Tables 2 and 3) is likely linked to decreasing temperature and moisture levels as soil depth increases (Bakonyi et al. 2007; Rawhat et al. 2021).

In summary, the diversity of nematodes across different biotopes is primarily associated with their trophic characteristics. Consequently, the Jaccard index indicates that the faunal composition of plants closely resembles that of the above-ground and root systems, as well as between the 0–15 cm and 15–30 cm soil layers (Fig. 4).

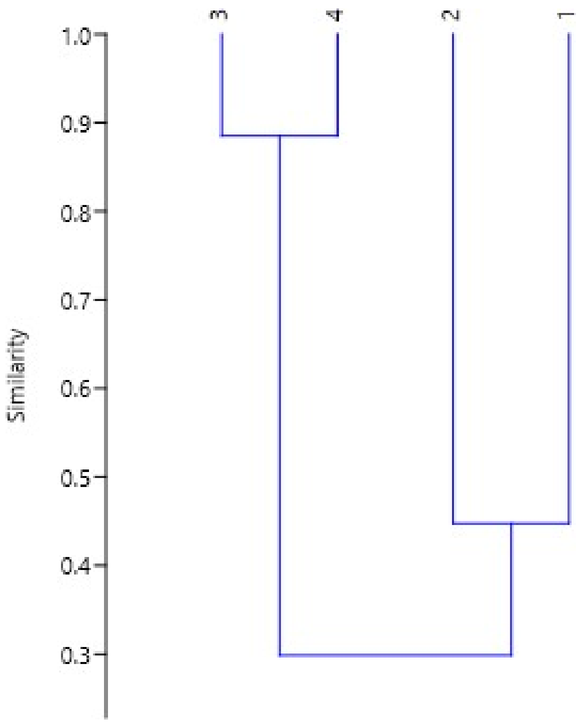

Figure 4. *The degree of similarity in faunal composition across biotopes assessed using the Jaccard index with the UPGMA method. 1 – 0–15 cm soil layer; 2 – 15–30 cm soil layer; 3 – above-ground part of the plant; 4 – root system.*

Conclusions

When examining nematode diversity across different biotopes, the highest diversity was found in the upper layers of the rhizosphere soil, which was anticipated. However, the ecological diversity of nematodes exhibited unique characteristics across the various biotopes. The distribution of different ecological groups of nematodes was found to depend on various ecological factors, including humus content, pH, soil aeration, and trophic characteristics.

It is important to note that this study does not overlook the influence of agricultural practices, particularly the application of mineral fertilizers, the concentration of natural mineral salts in the soil, and the presence of heavy elements on nematode community formation. Given that this is the first study of its kind in the area, further research is warranted to explore the roles of mineral salts and heavy elements in shaping the nematode community.

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