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Determination of the soil health status of wheat fields in Tekirdağ, Türkiye, based on nematode diversity*

Türkiye'de Tekirdağ ili buğday tarlalarının toprak sağlık durumunun nematod çeşitliliğine göre belirlenmesi

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Keywords: Nematode fauna, soil food web, Tekirdağ, *Triticum aestivum* L., Türkiye

Anahtar sözcükler: Nematod faunası, toprak besin ağı, Tekirdağ, *Triticum aestivum* L., Türkiye

ABSTRACT

Objective: A study was conducted in wheat cultivation areas in Tekirdağ to estimate the soil health of fields using nematode biodiversity indices.

Material and Methods: In the study, nematode taxa identified in wheat fields were subjected to community and food web analyses and several indices were calculated to determine the health status of soils in sampled areas.

Results and Conclusion Nematodes belonging to 41 genera were identified in wheat fields. The mean values of 10 biodiversity indices calculated in each sampled field were as follows; the Maturity index (MI): 2.26±0.28; the Maturity index MI2-5: 2.32±0.33; the Shannon-Weiner diversity index (H′): 2.03±0.24, the Evennes (J′): 0.90±0.06, the Genera Richness index (GR): 8.32±3.17, the Channel index (CI): 91±20.44; the Basal index (BI): 42.35±12.66; the Enrichment index (EI): 41.93±14.3, the Structure index (SI): 33.6±26.49 and the Plant-parasitic (PPI) index: 2.89±0.17. The nematode faunal indices indicate that 21% of surveyed wheat fields have well-developed and 79% have degraded soil profiles.

ÖZ

Amaç: Tekirdağ ilindeki buğday ekim alanlarında nematod biyoçeşitlilik indeksleri kullanılarak toprak sağlığının tahmin edilmesi için bir çalışma yapılmıştır.

Materyal ve Yöntem: Çalışmada buğday tarlalarında tespit edilen nematod taksonları, örnekleme alanlarındaki toprakların sağlık durumunu belirlemek için komünite ve besin ağı analizlerine tabi tutulmuş ve birçok indeks hesaplanmıştır.

Araştırma Bulguları ve Sonuç: Buğday tarlalarında 41 cinse ait nematod türü teşhis edilmiştir. Örnek alınan tarlaların hesaplanan 10 biyoçeşitlilik indeksinin ortalama değerleri aşağıdaki gibidir; Maturity index (MI): 2.26±0.28; Maturity index MI2-5: 2.32±0.33; Shannon-Weiner diversity index (H′): 2.03±0.24, Evennes (J′): 0.90±0.06, Genera Richness index (GR): 8.32±3.17, Channel index (CI): 91±20.44; Basal index (BI): 42.35±12.66; Enrichment index (EI): 41.93±14.3, Structure index (SI): 33.6±26.49 ve Plant-parasitic (PPI) index: 2.88±0.17. İncelenen buğday tarlalarının nematod fauna indeksleri, tarlaların %21'inin iyi gelişmiş ve %79'unun bozulmuş toprak profillerine sahip olduğunu göstermektedir.

INTRODUCTION

Soil is a substance formed by the disintegration of rocks and organic matter, performing the task of living environment for plants and providing water and nutrients. Mineral substances, water, air, and organic matter comprise the soil volume, and the organic matter consists of humus, plant roots, and soil organisms. There are more than 360.000 living species in the soil (Decaëns et al., 2006). The widespread groups are species in the phylum Protozoa and Nematoda. They are common in all production areas. The phylum Nematoda contains various nematode species, including free-living and plant parasites. There are many nematode species in the soil in terrestrial environments. Nematodes with different trophic groups, such as omnivores, predators, fungivores, and bacterivores, coexist in the soil and play an essential role in forming soil structure with their various functions.

Free-living nematodes feeding on bacteria, algae, fungi, dead organisms, and living tissues constitute 52% of all nematode species on Earth (Freckman, 1988). They have a significant role in the soil environment. Bacterial and fungal feeders do not feed directly on soil organic matter but on bacteria, fungi, algae, and actinomycetes, which play a main role in decomposing plant and animal residues in the carbon cycle. After feeding, they return minerals and other nutrients to the soil accessible to plant roots (Yeates et al., 1993). The main impact of nematodes in soils is the release of available N for plants. For example, bacterivore nematodes can be fed with 40-60% bacterial cells daily. (Lavelle & Spain, 2001). Indeed, bacterivore nematodes in 1 hectare can consume 800 kg of bacterial cells, releasing 20-130 kg of N (Forge & Simard, 2000). Nematodes, which have different feeding habitats due to these functions, can be used as to estimate soil health. For example, an excess of N can be considered in soils with abundant decomposer nematodes. Some nematode species can survive in forms such as cysts in degraded soil conditions, and the high population of these species can indicate that the soil is not well. For this reason, indices such as Shannon-Weiner, Basal, Structure, and Enrichment calculated using the trophic structures, prevalence, and soil density of nematodes are used to determine the physical condition of the soil. The indices also provide information about the soil food web status of fields (Bongers, 1990).

There are also many nematode species in cereal fields. The most harmful are cyst nematodes (*Heterodera* spp.), root lesion nematodes (*Pratylenchus* spp.), and root-knot nematodes (*Meloidogyne* spp.) (Laasli et al, 2022). It is possible to have an idea about the condition of the soil by using the indexes calculated by determining the genus and species, prevalence, and density of these nematodes. Cereals are mostly grown crops worldwide and have been a significant food source for humans throughout history. Cereal growing areas, which cover 57 percent of our country's agricultural lands, provide income to the rural population. The produced crops also are used as food for animals such as livestock (Güneş & Turmuş, 2020). Cereals and cereal products contain vitamins, minerals, carbohydrates, and other nutrients (Topping, 2007; Garg et al., 2021). Wheat is one of the most cultivated plants within cereals due to its good adaptation and good yield under different environmental conditions (Olgun et al., 2013).

Tekirdağ is among the biggest producers, with a 192.412 ha production area (TUIK, 2021). The nematode community in wheat fields has not been studied in the province. Most previous studies have been aimed at determining plant parasitic nematodes, especially *Heterodera* spp. Additionally, there are limited studies in crop plants focused on evaluating the relationship between nematode diversity and soil health. Therefore, a study was conducted in a wheat field in Tekirdağ to investigate the nematode fauna of wheat fields and to assess soil health and soil food web using nematode-based diversity indices.

MATERIALS and METHODS

Study area information

The study was conducted in nine districts of the Tekirdağ province, located northwest of Türkiye. Sunflower and wheat cultivation are the most common agricultural activities and rural income for several farmers in the province. Wheat was the main crop almost in all districts (Table 1). The surveys were carried out in April-June, 2021. During the field visits, the temperature was between 19-31 °C. The total precipitation was between 0.4-0.7 mm.

Table 1. Wheat production area, districts, and total production in 2021 (TUIK, 2021)

Çizelge 1. *Wheat production area, districts, and total production in 2021 (TUIK, 2021)*

Districts	Total Production Area (ha)	Total Production (ton)	Sampled locations
ÇERKEZKÖY	2.745	14.481	Merkez
ÇORLU	14.500	76.483	Sarılar, Seymen
ERGENE	15.341	83.612	Ahimehmet, Misinli, Velimeşe
HAYRABOLU	37.764	182.588	Soylu, Dambaslar, Susuzmüsellim
KAPAKLI	5.470	28.856	Bahçeağıl, Yanıkağıl
MALKARA	36.789	194.042	İbribey, Evrenbey, Karamurat
MARMARA EREĞLİSİ	7.825	46.093	Türkmenli, Yeniçiftlik, Yakuplu
MURATLI	16.425	96.741	Kırkkepenekli, İnanlı, Arzulu, Yurtbekler
SARAY	16.538	88.686	Büyükyoncalı
SÜLEYMANPAŞA	35.192	194.909	Bıyıkali, Barbaros, Mahramlı, İnecik, Yukarıkılıçlı
ŞARKÖY	3.817	20.127	Beyoğlu, İshaklı

The survey, collection, nematode extraction, and identification

Sampling in 41 wheat fields was conducted by moving in a zigzag pattern between plants, and six subsamples were collected from the rhizosphere of wheat fields at 60 cm soil depth. Nematodes in 100 cm^3 soil samples were extracted by the modified Baermann Funnel method within 24 hours. The extracted nematodes were counted at 10x magnification and identified from nematode slides. The identification of nematodes was conducted by using published polytomous keys (Geraert & Raski, 1987; Loof & Luc, 1990; Brezski, 1991; Castillo & Volvas, 2005, Handoo et al., 2007).

Soil food web and community analysis of nematodes

Nematodes extracted from wheat fields were subjected to several diversity and food web analyses to determine the health status of soils in sampled areas. The Shannon-Weiner diversity index, Evenness, and Richness were calculated to evaluate the diversity index of nematode fauna in fields. The formulas used to calculate the indices were as follows (Pielou, 1966; Neher & Darby, 2009).

Shannon-Weiner index (H′): $H' = -\sum[(pi) \times log(pi)]$

Pielou's evenness index (J′): $J' = H'/ln(S)$

Genera richness index (GR): $GR = S - 1 / lnN$

Pi: the proportion of individuals in genera; S: the number of genera; N: the number of identified nematodes

Maturity (MI), Maturity (MI) 2-5, and plant-parasite (PPI) indices were used to determine the nematode community (Ferris et al., 2001). Food-web conditions of soil were evaluated with Basal (BI), Channel (CI), Enrichment (EI), and Structure (SI) indices calculated as follows

$$MI\ (Maturity\ index) = \sum_{i=1}^{n} v(i) \times f(i)$$

v(i): the c-p of the family (free-living)
f(i): the frequency of free-living family

$$MI\ (Maturiy\ index)\ 2-5 = \sum_{i=1}^{n} v(i) \times f(i)$$

v(i): the c-p value of the 2-5
f(i): the frequency of family

$$PPI\ (Plant-parasitic\ index = \sum vi \times fi$$

The soil food web-based indices, including, were calculated. SI was used to determine food-web quality, EI for enrichment, and BI for disturbance. The following formulas (Ferris et al., 2001) were used;

$Basal\ index\ (BI) = 100 \times \frac{\mathrm{b}}{(\mathrm{e+s+b})}$ $\mathrm{b} = (\mathrm{Ba_2} + \mathrm{Fu_2}) \times \mathrm{W_2}$

Ba_2: bacterivores in c-p2 Fu_2: fungivores in c-p2.

$Channel\ index\ (CI) = \frac{\mathrm{Fu_2 \times W_2}}{\mathrm{Ba_1 \times W_1 + Fu_2 \times W_2}} \times 100$ Ba_1: bacterivores in c-p1 Fu_2: fungivores in c-p2.

$Enrichment\ index\ (EI) = 100 \times \frac{\mathrm{e}}{(\mathrm{e+b})}$ $\mathrm{e} = (\mathrm{Ba_1} \times \mathrm{W_1}) + (\mathrm{Fu_2} + \mathrm{W_2})$

$Structure\ index\ (SI) = 100 \times \frac{\mathrm{s}}{(\mathrm{s+b})}$ $\mathrm{s} = (\mathrm{Ba_n} \times \mathrm{W_n}) + (\mathrm{Fu_n} + \mathrm{W_n}) + (\mathrm{Ca_n} \times \mathrm{W_n}) + (\mathrm{Om_n} \times \mathrm{W_n})$

Ba_n: bacterivore nematodes in all c-p classes Fu_n: fungivore nematodes in all c-p classes Ca_n: carnivore nematodes in all c-p classes Om_n: omnivore nematodes in all c-p classes

Nematode Indicators Joint Analysis (NINJA) was used to prepare the c-p triangle and soil food-web scheme (Sieriebriennikov et al., 2014).

RESULTS AND DISCUSSION

Nematodes belonging to 41 genera were extracted from wheat fields in Tekirdağ. The identified genera were divided into free-livings (Bacterivore, fungivore, omnivore, and predator) and plant parasitics (Figure 1). Free-living species predominate in 95.12 % of the sampled fields.

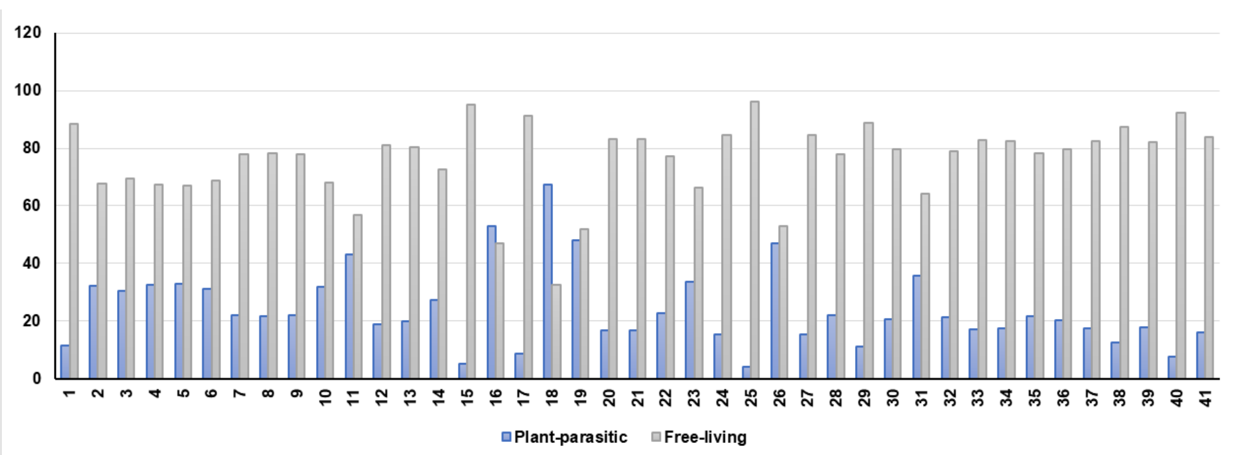

Figure 1. The % proportion of free-living and plant parasitic nematodes in 41 wheat fields in Tekirdağ.

Şekil 1. *Tekirdağ'da 41 buğday tarlasında serbest yaşayan ve bitki paraziti nematodların oranı.*

Free-living nematodes in wheat fields

In this study, free-living nematode species from 23 genera, 11 suborders, and 15 families were identified in wheat fields (Table 2). The proportion of bacterivores, omnivores, predators, and fungivores among all identified fauna was 24.4%, 17%, 7.3%, and 7.3%, respectively. Fungivores were found to predominate in wheat-growing areas. Fungivorous nematodes took first place in the number of species in the soils of some fields, constituting 56.5-90.6% of all identified nematodes (Figure 2). Omnivores and predator species were detected in 26.8% of the fields. The population of omnivores was higher than predators.

Table 2. Taxonomic classification, c-p values, frequency of occurrence of free-living nematodes in 41 wheat fields in Tekirdağ

Çizelge 2. *Tekirdağ'da 41 buğday tarlasında serbest yaşayan nematodların taksonomik sınıflandırması, c-p değerleri, ve bulunma sıklığı*

Genera/species	Feeding habitat	c-p class	Suborder	Families	Frequency of occurrence (%)
Acrobeles Linstow, 1877	Bacterivore	2	Cephalobina	Cephalobidae	56.0
Alaimus de Man, 1880		4	Dorylaimina	Alaimidae	17.0
Achromadora Cobb,1913		3	Chromadorina	Achromadoridae	4.9
Acrobeloides Cobb, 1924		2	Cephalobina	Cephalobidae	70.7
Cervidellus Thorne, 1937		2	Cephalobina	Cephalobidae	19.5
Cephalobus Bastian, 1865		2	Rhabditina	Rhabditidae	58.5
Monhystera Bastian, 1865		2	Monhysterina	Monhysteridae	17.0
Plectus Bastian, 1865		2	Chromadorina	Plectidae	4.9
Rhabditis Dujardin, 1845		1	Rhabditina	Rhabditidae	26.8
Wilsonema Cobb, 1913		2	Chromadorina	Plectidae	2.4
Aphelenchus Bastian, 1865	Fungaivore	2	Aphelenchina	Aphelenchidae	61.0
Aphelenchoides Fischer, 1984		2	Aphelenchina	Aphelenchioididae	70.7
Ditylenchus Filipjev, 1936		2	Tylenchina	Anguinidae	82.9
Allodorylaimus Andrássy, 1986	Omnivores	4	Dorylaimina	Qudsianematidae	2.4
Aporcelaimellus Heyns, 1965		5	Dorylaimina	Aporcelaimidae	7.3
Aporcelinus Andrássy, 2009		5	Dorylaimina	Aporcelaimidae	2.4
Dorylaimus Dujardin, 1845		4	Dorylaimina	Dorylaimidae	39.0
Eudorylaimus Andrássy, 1959		4	Dorylaimina	Qudsianematidae	7.3
Mesodorylaimus Andrássy, 1959		5	Dorylaimina	Dorylaimidae	46.3
Prodorylaimus Andrássy, 1959		5	Dorylaimina	Dorylaimidae	2.4
Clarkus Jairajpuri, 1970	Predators	4	Mononchina	Mononchidae	2.4
Seinura Fuchs, 1931		4	Aphelenchina	Aphelenchioididae	2.4
Tripyla Bastian, 1865		3	Tripylina	Tripylidae	7.3

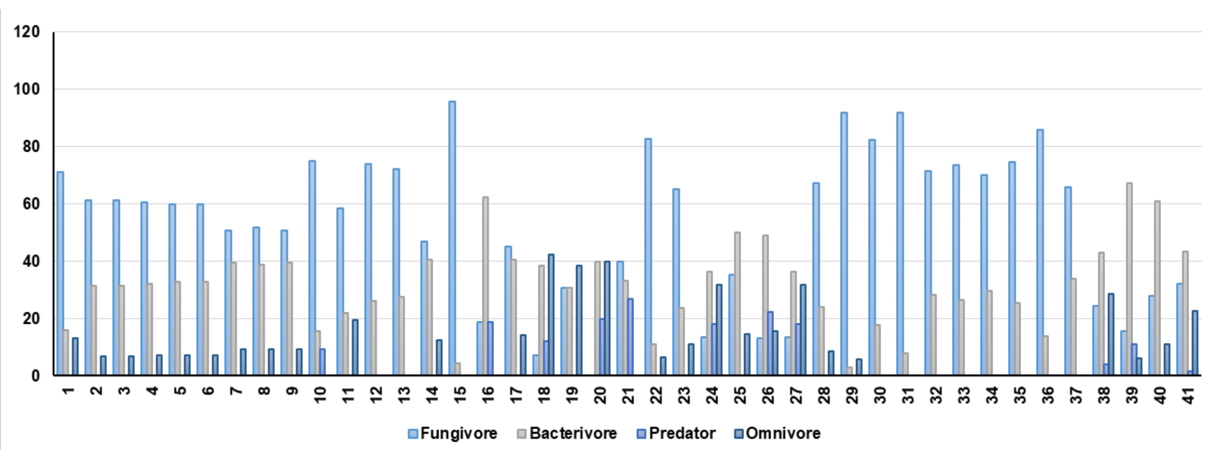

Figure 2. The % proportion of fungivore, bacterivore, omnivore, and predator nematodes in 41 wheat fields in Tekirdağ.

Şekil 2. *Tekirdağ'da 41 buğday tarlasında fungivor, bakterivor, omnivor ve predatör nematodların % oranı.*

Fungivore *Aphelenchus* Bastian, 1865 (61%), *Ditylenchus* Filipjev, 1936 (82.9%), and *Aphelenchoides* Fischer, 1984 (70.7%), as well as bacterivore *Cephalobus* Bastian, 1865 (58.5 %), were frequent genera in wheat fields. Except for *Mesodorylaimus* Andrássy, 1959 (46.3%), omnivores and predators were rare and not abundant.

Plant parasitic nematodes recovered from wheat soils belonged to two suborders, 10 families and 17 genera (Table 3). Based on feeding strategy, nematodes were categorized as ectoparasite (14 genera), migratory endoparasite (1 genus), sedentary endoparasite (1 genus), and semi-endoparasite (1 genus). Ectoparasites dominated almost all (38 of 41) fields. Species with different feeding strategies coexisted in 23 soil samples. Only ectoparasite species were found in 16 fields. (Figure 3).

Table 3. Taxonomic classification, c-p values, frequency of occurrence, and abundance of plant-parasitic nematodes in wheat fields in Tekirdağ (M1: Ectoparasite M2: Migratory endoparasite M3: Semi-endoparasite M4: Sedentary endoparasite RHF: Root hair feeder)

Çizelge 3. *Tekirdağ ili buğday tarlalarında bitki paraziti nematodların taksonomik sınıflandırması, c-p değerleri, bulunma sıklıkları ve yoğunlukları (M1: Ektoparazit M2: Gezici endoparazit M3: Yarı endoparazit M4: Sabit endoparazit RHF: Kök emici tüyleri ile beslenenler)*

Genera	Feeding habitat	Feeding strategy	c-p class	Suborder	Families	Frequency of Occurrence (%)
Bitylenchus Filipjev, 1934		M1	3	Tylenchina	Dolichodoridae	2.4
Boleodorus Thorne, 1941		M1/RHF	2	Tylenchina	Boleodorinae	12.2
Coslenchus Siddiqi, 1978		M1/RHF	2	Tylenchina	Tylenchidae	17.0
Criconema Hofmanner and Menzel, 1914		M1	3	Tylenchina	Criconematidae	2.4
Filenchus Andrassy, 1954		M1/RHF	2	Tylenchina	Tylenchidae	78.0
Geocenamus Thorne & Malek, 1968		M1	3	Tylenchina	Merliniidae	41.4
Helicotylenchus Steiner, 1945		M1	3	Tylenchina	Hoplolaimidae	4.9
Heterodera Schmidt, 1871		M4	3	Tylenchina	Heteroderidae	26.8
Paratylenchus Micoletzky, 1922	Plant-parasitic	M1	3	Tylenchina	Paratylenchidae	4.9
Paratrophurus Arias, 1970		M1	3	Tylenchina	Telotylenchidae	2.4
Pratylenchus Filipjev, 1936		M2	3	Tylenchina	Pratylenchidae	14.6
Pratylenchoides Winslow, 1958		M3	3	Tylenchina	Pratylenchidae	17.0
Psilenchus de Man, 1921		M1/RHF	2	Tylenchina	Boleodorinae	2.4
Rotylenchus Filipjev, 1934		M1	3	Tylenchina	Hoplolaimidae	4.9
Sakia Khan, 1964		M1/RHF	2	Tylenchina	Boleodorinae	2.4
Tylenchorhynchus Cobb, 1913		M1	3	Tylenchina	Belonolaimidae	48.8
Xiphinema Cobb, 1913		M1	5	Dorylaimina	Longidoridae	2.4

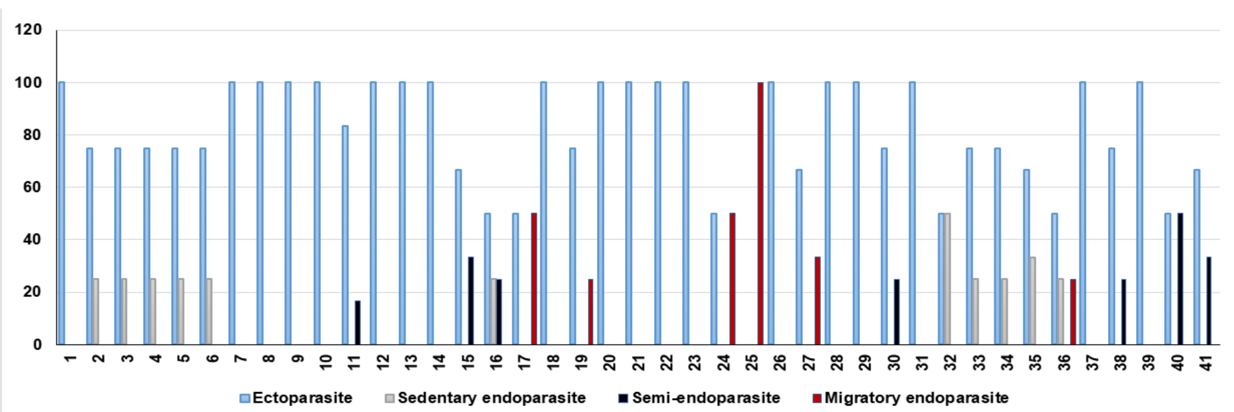

Figure 3. The % proportion of plant-parasitic nematodes based on feeding strategy in 41 wheat fields in Tekirdağ.

Şekil 3. *Tekirdağ'da 41 buğday tarlasında bitki paraziti nematodların beslenme şekli bakımından % oranı.*

Filenchus Andrassy, 1954 (78%), *Tylenchorhynchus* Cobb, 1913 (48.8%) and *Geocenamus* Thorne & Malek, 1968 (41.4%) were the most frequent and abundant (up to 111 individuals in 100 cm^3 soil) in sampled areas. The population of lesion nematode *Pratylenchus* Filipjev, 1936, *Pratylenchoides* Winslow, 1958, dagger nematode *Xiphinema* Cobb, 1913, and ring nematode *Criconema* Hofmanner and Menzel, 1914 were under economic damage threshold in all fields (1-10 individual/ 100 cm^3 soil). Cyst nematode *Heterodera* Schmidt, 1871 was found in 26.8% of the samples, and the mean population of second-stage juveniles in 100 cm^3 soil was 8.1 (8-10).

The extracted free-living and plant parasitic nematodes belonged to five colonizer-persister groups. Among all nematodes, one genus belonged to c-p1, 15 to c-p2, 12 to c-p3, six to c-p4, and five to c-p5. Generally, the c-p2 and c-p3 groups were dominant in all fields, and rare occurrences of c-p1 (e.g. Rhabditis Dujardin, 1845), c-p4 (e.g. Allodorylaimus Andrássy, 1986) and c-p5 (e.g. Aporcelinus Andrássy, 2009) group species were observed. At the same time, c-p2 group nematodes were more dominant than c-p3 in all areas except three wheat fields, and c-p3 nematodes were prominent in one field. (Figure 4).

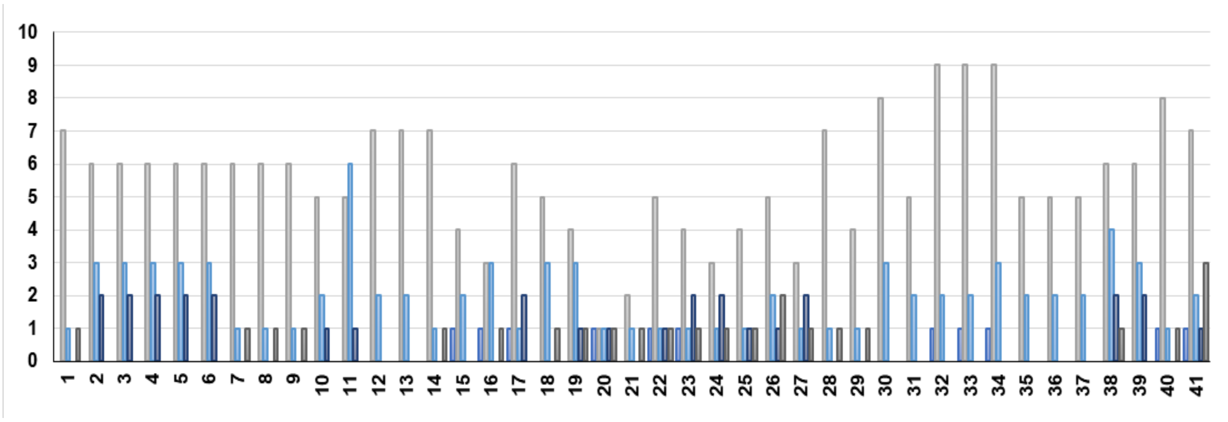

Figure 4. The number of free-living and plant-parasitic nematodes based on c-p values in 41 wheat fields in Tekirdağ.

Şekil 4. *Tekirdağ'da 41 buğday tarlasında c-p değerlerine göre serbest yaşayan ve bitki paraziti nematod sayısı.*

Nematode diversity in wheat fields in Tekirdağ

The nematode diversity of all surveyed wheat fields maintains 3 to 14 genera of free-living and plant-parasitic nematodes. The average of the Shannon-Weiner diversity index (H′) was calculated as 2.03±0.24 (1.35-2.42), and similar values in some fields showed the existence of species in similar numbers and population densities. The mean of Evenness (J′) value was between 0.90±0.06 (0.73-0.99), and the Genera Richness (GR) was 8.32±3.17 (4-14) (Figure 5). The number of different plant-parasitic genera was not high in the wheat fields, suggesting that it was due to the host status of the wheat plant.

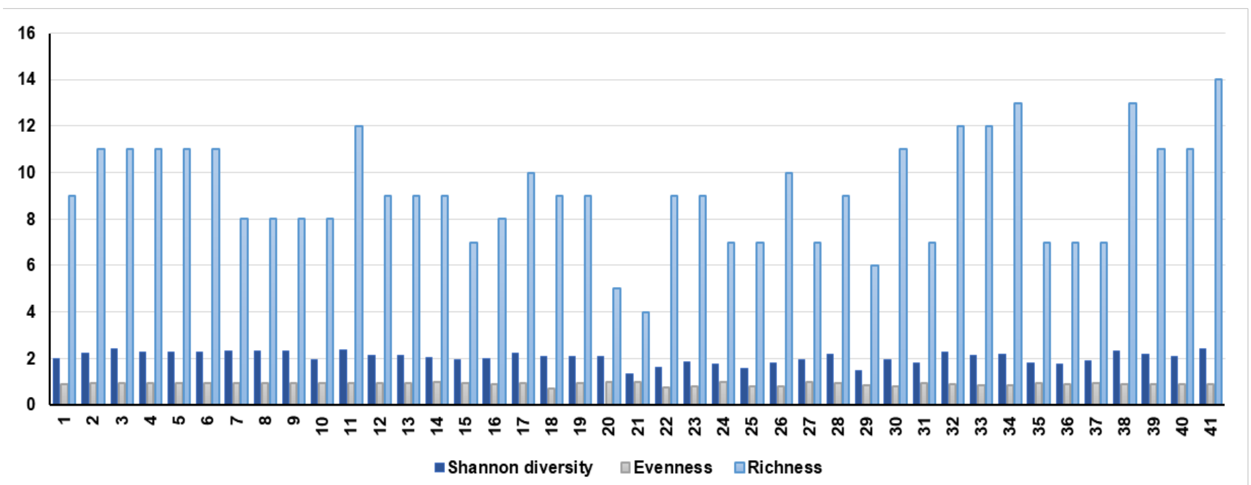

Figure 5. The Shannon-Weiner diversity index (H′), the Evenness (J′), and the Genera Richness (GR) values in 41 wheat fields in Tekirdağ.

Şekil 5. *Tekirdağ'da 41 buğday tarlasının Shannon-Weiner diversity index (H′), Evenness (J′), ve Genera Richness (GR) değerleri.*

Nematode community analysis and estimation of the soil health status of wheat fields in Tekirdağ

The nematode maturity and soil food web-based indices were calculated for the surveyed wheat field. The average of the Maturity index (MI) value was 2.26±0.28 (1.97-2.96); the Maturity index MI2-5 value was 2.32±0.33 (2-3.12), and the PPI value was 2.88±0.17 (2.29-3.0) (Figure 6). Except for six fields with an MI value of >2.5, most fields had values between 2-2.3, and low values indicate soil disruption and enrichment of nutrients. The MI value increased in soils, maintaining the higher number of omnivore nematodes like *Mesodorylaimus* spp. In areas with a PPI value of 3, the number of plant-parasitic genera from the c-p3 group was higher.

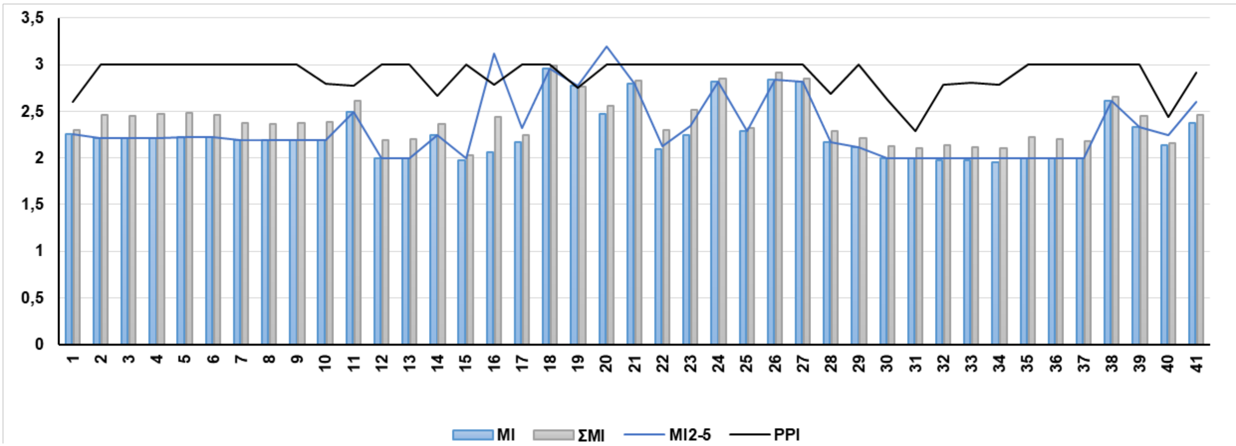

Figure 6. The Maturity Index (MI), the Maturity Index (MI) 2-5, and the Plant-parasitic Index (PPI) values of 41 wheat fields in Tekirdağ.

Şekil 6. *Tekirdağ'da 41 buğday tarlasının Maturity Index (MI), the Maturity Index (MI)2-5 ve Plant-parasitic Index (PPI) değerleri.*

The soil food web-related indices Channel (CI), Enrichment (EI), Basal (BI), and Structure (SI) were calculated for all sampled fields. The SI index took the values between 0 (excessively degraded) and 100 (well structured). The average SI value was 33.6±26.49 (0-81.05) and showed great variations, calculated as >50 in 11 and <50 in 30 fields. The EI value was 41.93±14.3 (13.64-87.50). The average BI value was 42.35±12.66 (8.51-60.26). The CI value was 91±20.44 (8.57-100) (Figure 7).

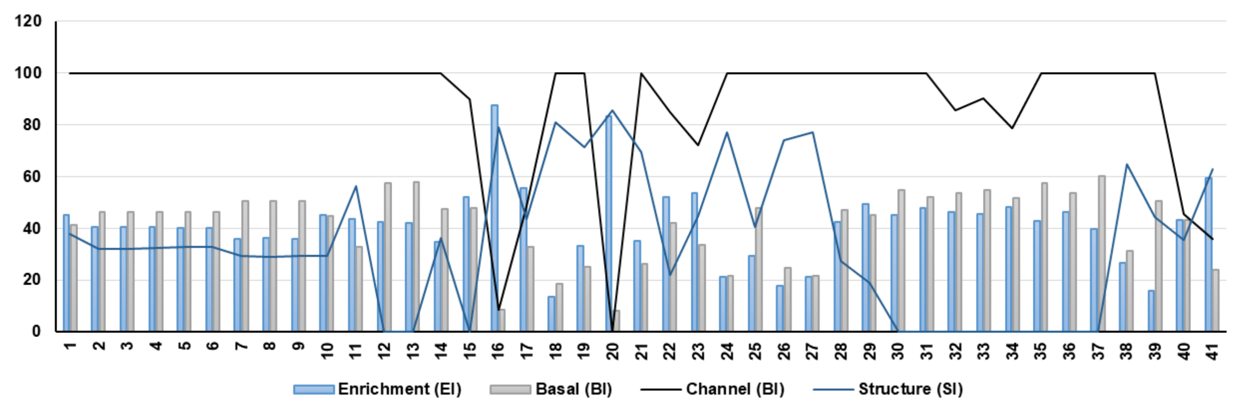

Figure 7. The Enrichment Index (EI), Basal Index (BI), Channel Index (CI), and Structure Index (SI) values of 41 wheat fields in Tekirdağ.

Şekil 7. *Tekirdağ'da 41 buğday tarlasının* Enrichment Index (EI), Basal Index(BI), Channel Index (CI) ve Structure Index (SI) *değerleri.*

The c-p triangle plot confirmed that most nematodes in wheat fields belonged to the c-p2 and c-p3-5 classes (Figure 8A). Most of the fields showed stressed characteristics. The soil food-web graph represents the replacement of the fields under four quadrats. Four were in quadrate A, 3 in quadrate B, 7 in quadrate C, and 27 in quadrate D. According to Figure 8B, 31 fields were disturbed and stressed, and 10 were maturing or matured.

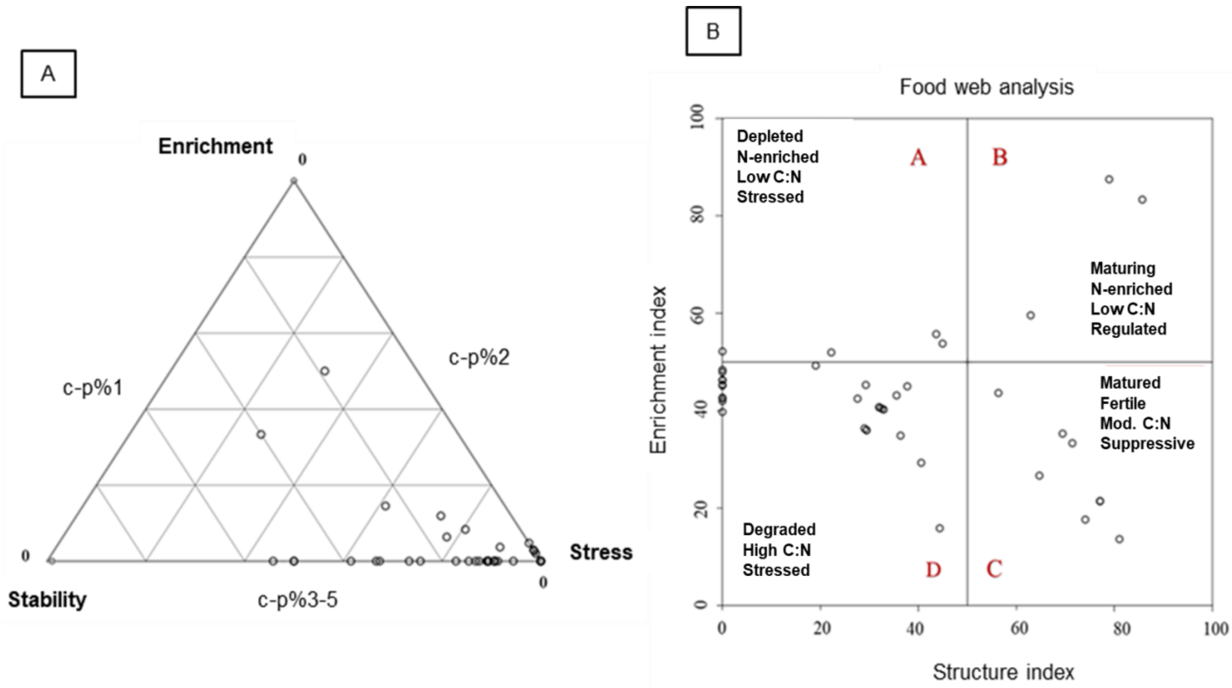

Figure 8. A. c-p triangle representing nematodes with c-p1, c-p2 and c-p3-5 values. B. Soil food web analysis representing enrichment and structure conditions in sampled wheat soils in Tekirdağ.

Figure 8. *A. c-p1, c-p2 ve c-p3-5 değerlerine sahip nematodları temsil eden c-p üçgeni. B. Tekirdağ'da örneklenen buğday topraklarındaki zenginleşmeyi ve yapısal koşulları temsil eden toprak besin ağı analizi.*

Soil organisms are a key component in determining the food web's status in the soil. Especially fungivores, bacterivores, and predator nematodes affect the food web and the nutrient content of the soil. Nematode diversity represents soil characteristics. Nematodes' consumption of soil organic residues significantly increases available N, P, and other elements. The rate of other elements, such as N, C, and P, is high, especially in areas with high bacterivore nematodes in the c-p1 and c-p2 classes (Sanchez-Moreno, 2018). For instance, *Acrobeloides*, a bacterivore species, exhibit a higher rate of copper resistance, and their abundance promotes soil resilience against copper. It has been reported that the number of omnivore and predator nematodes is reduced or eliminated from nematode communities in soil with high Cu and Zn concentrations. Again, since c-p1 group nematodes are lowly tolerant to the stress of chemicals and pollutants, their abundance in the soil can provide information about the heavy metal status of the soil (Bongers et al., 1997). For these reasons determining biotic agents' principally nematodes, diversity, and abundance in the soil is important in regulating soil productivity (Ara Khanum et al., 2022).

The nematode diversity in wheat fields in Tekirdağ constitutes 41 genera of nematodes with different feeding strategies and habitats. Free-living non-plant-parasitic belonged to 23 genera, and plant parasitic to 18 genera. The dominant species in survey areas were bacterivore and fungivore nematodes. Among all functional guilds, most of the identified nematodes belonged to c-p2. Conversely, nematodes from the c-p group were common.

Researchers in many provinces, such as Bolu, Sakarya, Isparta, Burdur, and Adıyaman in our country, previously found the genera such as *Heterodera* spp, *Pratylenchus* spp, *Helicotylenchus* spp. that we detected. But still, their population densities differed from area to region (Yıldız et al., 2017; Kasapoğlu Uludamar, 2018; Göze Özdemir et al., 2022, Keçeci et al., 2022). *H. avenae* belonging to *Heterodera* can cause 15-90% and *H. filipjevi* 20.4-24.8% yield loss in wheat (Hassan et al., 2010; Karimipourd Fard et al., 2018). In *Pratylenchus* species, *P. thornei* causes a 65% yield decrease (Owen et al., 2021). In studies conducted in Türkiye, *Heterodera flipjevi* caused nearly 40.5% yield loss in wheat (İmren et al., 2020).

In our study, species such as *Acrobeloides* (70.7%)*, Aphelenchoides* (70.7%), and *Ditylenchus* (81%) were common in Tekirdağ, and similarly, in a study by Yıldız et al. (2017) in Bolu, these two species were found to be the most common with 92.7% and 72.1% occurrence, respectively. Like our study, many nematode species were identified in wheat fields in several countries. In Morocco, 33 genera of nematodes from different trophic groups were reported (Laasli et al., 2022).

The values of nematode diversity based on several indices were calculated in fields to determine the conditions of the soil food web, soil degradation, and providers of organic material decomposition. Shannon diversity index (H′) value in wheat fields in Tekirdağ was above 2 in 19 fields and below 2 in 22 fields. Low values such as 1.35, 1.42, 1.43, and 1.56 were calculated in some areas. In these fields, nematode abundance and genera richness were generally low. According to Hodda et al. (2009), as in Tekirdağ, the low diversity of nematodes is due to the degraded soil, and many agricultural areas in the world are in this situation. Additionally, wheat host plants may affect the nematode diversity, promote the multiplication of some genera and suppress others. Low Maturity index (MI) values calculated according to free-living nematodes also indicate soil stress and disturbance. Plant parasitic index (PPI) value is low in poor soil conditions with c-p2 group nematodes in the field (Bongers et al., 1990). In Tekirdağ, while the MI value was below 2.5 in 34 fields, the PPI value was generally determined as 3 and calculated below this value in only 14 fields. Our H′ (2.03+0.24), MI (2.26+0.28), and PPI (2.88+0.17) values quietly fit with values (H′: 2.52+0.0; MI: 2.37+0.1; PPI: 2.51+0.0) calculated in wheat fields in Bolu by (Yıldız et al., 2017).

The soil-food web-related indices in Tekirdağ, representing food web conditions and the status of bacterivores and fungivores in decomposition, were calculated. The Enrichment Index (EI) indicates soil nutrient enrichment (Ferris, 2001). In this study, the EI values of 13.64, 15.87, and 17.65 calculated for three fields were very low and indicated soil depletion. On the other hand, soils were considered highly enriched in two fields with very high values of 87.33 and 83.5. On the other hand, according to Ferris (2001) Structure Index (SI), which gives information about the presence of c-p 1-5 nematodes in soils and its contribution to soil structure, took the value of 0 in 11 fields in Tekirdağ and in these fields omnivores and predators were not found. SI levels between 0-30 indicate a degraded soil food-web chain (Sanchez-Moreno & Ferris, 2018). Basal (BI) and Channel (CI) indices that give information about the conditions of the soil food web and organic residue decomposition pathway were also calculated and the values were 91±20.44 and 42.35±12.66 CI values of >50, representing the dominance of fungivore nematodes, and <50 represent the dominance of bacterivore nematodes in the decomposition of organic material in the soil (Du Preez et al., 2022). Accordingly, it can be considered that there was mostly bacterial decomposition in 5 fields and fungal decomposition in 36 fields in Tekirdağ. In our study, the BI value was 50 and above in 13 fields and 30 and below in 9 fields. When the BI value is >50, the soils are considered to have poor soil food-web conditions (Sanchez-Moreno & Ferris, 2018). In the c-p triangle, the sampling fields were generally concentrated in the stress region. In the Soil food-web scheme, the sampling areas in Tekirdağ were included in the 4 Quadrats in parallel with the above-mentioned index values. More than half of the fields were located in Quadrat D. Here; there are disturbed environments with a high C: N ratio, and fungal decomposition is prominent (Ferris et al., 2001). On the other hand, *Aphelenchus, Aphelenchoides* and *Ditylenchus* were highly distributed in wheat fields located in Quadrat D. Only seven fields had biologically and physiologically matured well-developed soil characteristics.

CONCLUSION

In this study, in wheat fields in Tekirdağ province, nematode biodiversity was investigated. The prevalence of nematode genera was determined, and taxonomic classification was made. *Heterodera* and *Pratylenchus*, the most harmful genera of wheat, were extracted from several locations. With the indices calculated based on the determined nematode biodiversity, information was obtained about the food web status of the soil and the soil environmental conditions. Most of the sampled wheat fields showed some degree of disturbed environment features.

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