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Original article (Orijinal araştırma)

Distribution and population density of plant parasitic nematodes on cereal production areas of Isparta and Burdur Provinces of Turkey[1]

Türkiye Isparta ve Burdur illeri tahıl üretim alanlarında bitki paraziti nematodların dağılımı ve popülasyon yoğunluğu

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Abstract

Plant parasitic nematodes were systematically surveyed in cereal production areas of Isparta and Burdur Provinces of Turkey in 2016-2017. Nine plant parasitic nematode genera were identified in Isparta and Burdur [*Ditylenchus* (23%)*, Geocenamus* (20%), *Helicotylenchus* (33%)*, Heterodera* (<1%), *Meloidogyne* (3%)*, Pratylenchus* (76%)*, Pratylenchoides* (52%), *Paratylenchus* (41%) and *Tylenchus* (18%)]. *Pratylenchus* spp. was found in 82% and 68% of samples, and *Pratylenchoides* spp. in 55% and 63% samples in Isparta and Burdur Province, respectively. The densities of *Pratylenchus* and *Pratylenchoides* species were higher in Isparta than in Burdur, and were often over the threshold for economic damage. As a result of morphological diagnostic studies, *Pratylenchus crenatus* Loof, 1960, *Pratylenchus neglectus* (Rensch, 1924) Filipjev & Schuurmans-Stekhoven, 1941, *Pratylenchus penetrans* (Cobb, 1917) Filipjev & Schuurmans-Stekhoven, 1941*, Pratylenchus thornei* Sher & Allen, 1953 (Tylenchida: Pratylenchidae)*, Pratylenchoides alkani* Yüksel, 1977, *Pratylenchoides crenicauda* Winslow, 1958, *Pratylenchoides erzurumensis* Yüksel, 1977, *Pratylenchoides leiocauda* Sher, 1970, *Pratylenchoides ritteri* Sher, 1970 and *Pratylenchoides variabilis* Sher, 1970 (Tylenchida: Merliniidae) were identified. *Pratylenchoides* alkani, *P. erzurumensis*, *P. neglectus* and *P. thornei* were the most common species in wheat and barley fields in Burdur and Isparta Provinces.

Keywords: Cereal, population density, *Pratylenchoides* spp., root lesion nematode, survey

Öz

Türkiye'nin Isparta ve Burdur illerinde 2016 ve 2017 yıllarında tahıl üretim alanlarında bitki paraziti nematodların sürveyi sistematik olarak gerçekleştirilmiştir. Burdur ve Isparta illerinde dokuz bitki paraziti nematod cinsi [*Ditylenchus* (%23)*, Geocenamus* (%20), *Helicotylenchus* (%33)*, Heterodera* (<%1), *Meloidogyne* (%3)*, Pratylenchus* (%75,5)*, Pratylenchoides* (52,1%), *Paratylenchus* (41%) and *Tylenchus* (18%)] tespit edilmiştir. *Pratylenchus* spp. Isparta ve Burdur illerinde sırasıyla %82 ve %68 olarak tespit edilirken, *Pratylenchoides* spp. Isparta'da %55 ve Burdur'da %63 olarak bulunmuştur. *Pratylenchus* ve *Pratylenchoides* türleri Isparta İli'nde Burdur İli'nden daha yüksek belirlenmiş ve çoğu tahıl alanında ekonomik zarar seviyesinin üzerinde tespit edilmiştir. Morfolojik teşhis çalışmaları sonucunda, *Pratylenchus crenatus* Loof, 1960, *Pratylenchus neglectus* (Rensch, 1924) Filipjev & Schuurmans-Stekhoven, 1941, *Pratylenchus penetrans* (Cobb, 1917) Filipjev & Schuurmans-Stekhoven, 1941*, Pratylenchus thornei* Sher & Allen, 1953 (Tylenchida: Pratylenchidae)*, Pratylenchoides alkani* Yüksel, 1977, *Pratylenchoides crenicauda* Winslow, 1958, *Pratylenchoides erzurumensis* Yüksel, 1977, *Pratylenchoides leiocauda* Sher, 1970, *Pratylenchoides ritteri* Sher, 1970 ve *Pratylenchoides variabilis* Sher, 1970 (Tylenchida: Merliniidae) tespit edilmiştir. *Pratylenchoides* alkani, *P. erzurumensis*, *P. neglectus* ve *P. thornei* Burdur ve Isparta illerinde buğday ve arpa alanlarında en yaygın türler olarak saptanmıştır.

Anahtar sözcükler: Tahıl, popülasyon yoğunluğu, *Pratylenchoides* spp., kök lezyon nematodu, sürvey

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Introduction

Turkey has approximately 11 Mha under cereal production and the major cereal, wheat, yielding about 20 Mt production annually, followed by barley, maize and rice. Durum wheat production has been reported 73 and 48 Mt in Burdur and Isparta Provinces, respectively (TÜİK, 2020). In Burdur and Isparta Provinces, wheat production excluding durum wheat, was 42 and 32 Mt, respectively (TÜİK, 2020). Additionally, barley production is higher in Burdur Province (112 kt) than Isparta (86 kt) (TÜİK, 2020). Wheat and barley are commonly grown in all agricultural areas of Burdur Province. However, Yalvaç and Şarkikaraağaç Districts of Isparta Province are the prominent wheat and barley production areas.

Heterodera avenae Wollenweber, 1924, *Heterodera filipjevi* (Madzhidov, 1981) Stelter, 1984, *Heterodera latipons* Franklin, 1969 (Tylenchida: Heteroderidae), *Pratylenchus thornei* Sher & Allen, 1953 and *Pratylenchus neglectus* (Rensch, 1924) Filipjev & Schuurmans-Stekhoven, 1941 (Tylenchida: Pratylenchidae) are reported as important parasitic nematodes of cereals worldwide (Nicol et al., 2003; Smiley & Nicol, 2009). These nematodes have also been reported on cereal fields in Turkey (Mısırlıoğlu & Pehlivan, 2007; Yavuzaslanoglu et al., 2012, 2020; Dababat et al., 2015; Toktay et al., 2020). Particularly, root lesion nematodes were surveyed and identified on wheat cultivation by researchers in different regions of Turkey (Yıldız, 2007; Yavuzaslanoğlu et al., 2012, 2020; Kasapoğlu et al., 2014; Kasapoğlu Uludamar et al., 2018). İmren et al. (2015) and Yavuzaslanoğlu et al. (2012, 2020), reported that *P. thornei* and *P. neglectus* were found in different densities and mixed population in wheat fields in Turkey. Another migratory endo-ecto parasitic nematode genera, *Pratylenchoides* spp., have been reported in wheat and other plants in Turkey (Yüksel, 1977; Elekcioglu, 1992, 1996; Evlice & Ökten, 2008; İmren & Elekçioğlu, 2008; Yavuzaslanoğlu et al., 2012; Söğüt et al., 2014). Yavuzaslanoğlu et al. (2012), determined 36% prevalence of *Pratylenchoides* spp. in wheat in the Central Anatolia Region in Turkey, and their population density was high in all provinces in this region.

Pratylenchus and *Pratylenchoides* spp. have a migratory endoparasitic feeding behavior (Yeates et al., 1993) and cause brown lesions on the plant roots and loss of root function, and consequently, reduce in plant vigor and yield (Townshend et al., 1989; Agrios, 1997; Jones & Fosu-Nyarko, 2014). Also, root lesion nematodes assist the invasion of soilborne pathogens into plant root tissue and, this interaction increases the importance for such infections (Smiley & Nicol, 2009). It was estimated that *P. thornei* causes up to 62% wheat yield loss in the northern grain region of Australia (Owen et al., 2014). Nicol & Ortiz-Monastterio (2004) reported that cereal cyst and root lesion nematodes yield losses in wheat were 50% on the Central Anatolian Plateau of Turkey.

Research on plant parasitic nematodes in cereal culture of the Lakes Region including Isparta and Burdur Provinces were limited. However, cereal nematodes were surveyed at a limited number of locations in the previous studies (Yavuzaslanoğlu et al., 2012, 2020; Söğüt et al., 2014; Toktay et al., 2020). The objectives of this study are to investigate the distribution and density of plant parasitic nematodes in detail and to determine if they occur as mixed populations in cereal fields in Isparta and Burdur Provinces in Lakes Region of Turkey.

Materials and Methods

Nematode sampling locations

Cereal production fields in Isparta and Burdur Provinces were surveyed in the study. A total of 441 soil and root samples were collected systematically during June-August in the years of 2016 and 2017 from wheat, barley, oat and rye crops. Two hundred and thirty-five samples (124 wheat, 95 barley, 13 oat and 3 rye) were taken from Isparta and 206 samples (111 wheat, 71 barley, 19 oat and 5 rye) from Burdur Province. Samples were collected from the fields adjacent to the roadside with intervals of about 2-5 km (Figure 1). A 5-kg bulk sample consisting of 10-15 subsamples were taken from each field by shovel to 30 cm deep in

a zigzag pattern. The elevation, latitude and longitude for each sampling site were recorded by using the global positioning system.

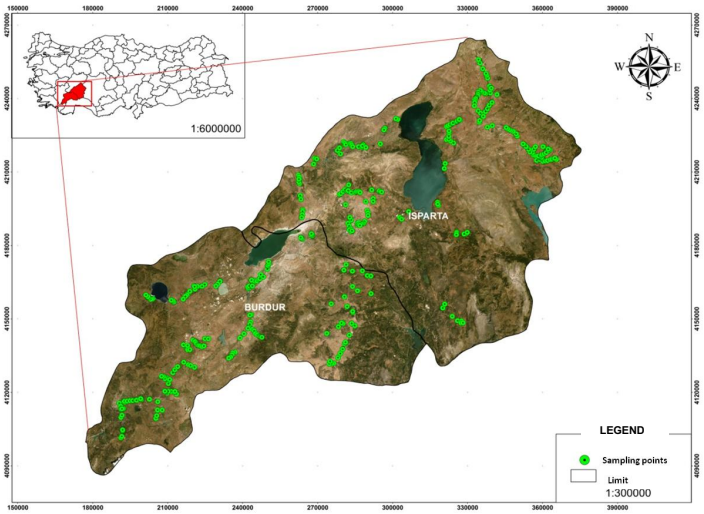

Figure 1. Sampling points in districts of Isparta and Burdur Provinces of Turkey.

Nematode extraction, population estimation and species identification

Migratory nematodes were extracted from 100 g dry soil and 10 g fresh root from each sample using a modified Baermann funnel technique (Whitehead & Hemming, 1965; Hooper, 1986a). Soil moisture content was measured by drying 10 g of soil from each sample in oven at 90°C for 2 d. Roots removed from sample placed in a separate dish and soil adhering to the roots gently removed. Each root sample was examined under a stereomicroscope for evidence of root galls (*Meloidogyne* spp.) or cyst nematodes (*Heterodera* spp.). The roots were then finely chopped with a scissors in a dish. All chopped roots were mixed thoroughly and 10 g placed on a labeled sieve and water added. After an extraction period of 48 h, the sieve was removed and roots tissue discarded. The same process was repeated for soil samples. The resultant nematode suspensions were placed in measuring cylinders for 8 h to settle, the supernatant discarded, and the concentrated nematodes transferred to 15-ml tubes. Nematodes were counted to genera under the light microscope at 100x magnification. The nematode counts from the soil and root samples were converted to the number of nematodes 100 g of dry soil and 10 g fresh root.

Heterodera cysts were extracted by using the modified Fenwick can method from 250 g dry soil under constant water flow (Fenwick, 1940; Stirling et al., 1999). The numbers of cyst, with or without eggs, were counted under a dissecting microscope at 20x magnification. Permanent slides were prepared according to published procedures (Hooper, 1986b). Nematode species were morphologically identified using morphology and morphometric characters according to Baldwin et al. (1983) and Castillo & Vovlas (2007) under the light microscope. Identification of the specimens was performed by the senior author.

Visualization of migratory endoparasitic nematodes

Inverse distance weighting method with ArcGIS 10.2 software was used for mapping distribution and population densities of *Pratylenchus* and *Pratylenchoides* spp. in 23 districts of Isparta and Burdur Provinces.

Population densities (number/100 g of dry soil and 10 g fresh root) of *Pratylenchus* and *Pratylenchoides* spp. were analyzed the SPSS (version 20.0) program. The Kruskal-Wallis test was used because the number of samples taken on district was not homogeneous and the data obtained were non-parametric. For statistical lettering, Tamhane's T2 multiple comparison test was applied in ANOVA analysis.

Results

Incidence of plant parasitic nematodes

Nine plant parasitic nematode genera were recorded, *Ditylenchus* (23% of samples)*, Geocenamus* (20%), *Helicotylenchus* (33%)*, Heterodera* (<1%), *Meloidogyne* (3%)*, Pratylenchus* (76%)*, Pratylenchoides* (52%), *Paratylenchus* (41%) and *Tylenchus* (18%). *Pratylenchus* and *Pratylenchoides* spp. were found in the study as important plant parasitic nematodes in cereal fields of Isparta and Burdur Provinces. *Pratylenchus* spp. was found to be 82% and 68% of samples, and *Pratylenchoides* spp. in 55% and 63% of samples from Isparta and Burdur Provinces, respectively.

In a few soil samples, second stage juveniles (J2s) of cyst and root-knot nematodes were found and these samples were examined under a stereomicroscope, however, no galls, egg masses and cysts were found in the roots. Cyst nematode larvae were found in one wheat soil sample from Isparta Central District (20 J2s/100 g soil) and two barley soil samples (20-40 J2s/100 g soil) from Keçiborlu District. In addition, J2s of *Meloidogyne* spp. were found in seven wheat root samples (4 in Burdur Province and 3 in Isparta Province), two oat (Burdur Province) and one barley (Burdur Province) by the modified Baermann funnel technique. The soil density of these samples varied between 20 and 240 J2s/100 g soil.

Pratylenchus species by morphological identification

Pratylenchus crenatus Loof, 1960, *P. neglectus*, *Pratylenchus penetrans* (Cobb, 1917) Filipjev & Schuurmans-Stekhoven, 1941 and *P. thornei* (Tylenchida: Pratylenchidae), root lesion nematodes species, were identified morphologically in samples from cereal fields of Burdur and Isparta Provinces. *Pratylenchus thornei* and *P. neglectus* were found 35% and 35% of all samples from Burdur Province, followed by *P. penetrans* at 10% and *P. crenatus* at 8%. Root lesion nematode species were found in mixed populations in 11% of samples from Burdur Province, with 4% being mixtures of *P. penetrans* and *P. thornei*. *Pratylenchus thornei* was the most common species in the cereal fields in Isparta Province being found in 63% of samples and the least common species was *P. crenatus* at 3%. *Pratylenchus neglectus* and *P. penetrans* were found in 13% and 12% samples from Isparta Province. Mixed populations of *Pratylenchus* spp. occurred at 9% in Isparta, which was less than in Burdur.

Pratylenchoides species by morphological identification

Pratylenchoides alkani Yüksel 1977, *Pratylenchoides crenicauda* Winslow, 1958, *Pratylenchoides erzurumensis* Yüksel, 1977, *Pratylenchoides leiocauda* Sher, 1970, *Pratylenchoides ritteri* Sher, 1970 and *Pratylenchoides variabilis* Sher, 1970 (Tylenchida: Merliniidae) were identified from the samples from both Burdur and Isparta Provinces. The most common species were *P. alkani* (40% of samples) and *P. erzurumensis* (31%) in Burdur Province, followed by *P. variabilis* at 18% and *P. crenicauda* at 5.4%. *Pratylenchoides alkani* was the most common species in Isparta Province at 45% and the least common species was *P. leiocauda* at 6%. *Pratylenchoides erzurumensis, P. variabilis* and *P. ritteri* were found at 19%, 12% and 14%, respectively in Isparta Province. Mixed *Pratylenchoides* populations were found 6% and 5% of samples from in Burdur and Isparta Provinces, respectively.

Incidence of *Pratylenchus* and *Pratylenchoides* species in cereal species in Isparta and Burdur Provinces

The incidence of *Pratylenchus* and *Pratylenchoides* spp. in districts of Burdur and Isparta Provinces are given in Tables 1 and 2. *Pratylenchus neglectus* and *P. thornei* was more common in wheat in both Burdur and Isparta Provinces than other root lesion nematode species (Table 1; 2). *Pratylenchus thornei* was more common in barley in the two provinces. *Pratylenchus penetrans* was found at low frequency in seven districts (Bucak, Burdur Central, Ağlasun, Tefenni, Karamanlı, Yeşilova and Kemer) of Burdur Province and nine districts (Gönen, Atabey, Isparta Central, Gelendost, Uluborlu, Senirkent, Şarkikaraağaç, Yalvaç and Eğirdir) of Isparta Province (Table 1;2). *Pratylenchus crenatus* was found in Gölhisar, Central, Tefenni,

Yeşilova and Kemer Districts of Burdur Province (Table 1) and Yalvaç, Şarkikaraağaç, Gelendost, Gönen and Central Districts of Isparta Province (Table 2). *Pratylenchus thornei* was more common in oat in two Provinces (Tables 1 & 2).

Table 1. Incidence (%) of *Pratylenchus* and *Pratylenchoides* species in cereal fields in districts of Burdur Province

District	Cereal	Samples No	*Pratylenchus*				*Pratylenchoides*					
			Pc	Pn	Pp	Pt	Pa	Prc	Pe	Pl	Pr	Pv
Ağlasun	Wheat	7	-	71	14	-	40	20	-	-	-	40
	Barley	2	-	-	50	50	-	-	100	-	-	-
	Rye	2	-	-	-	100	-	-	100	-	-	-
Bucak	Wheat	16	-	50	6	12	67	-	-	-	-	33
	Barley	4	-	50	25	25	50	-	-	-	-	-
	Oat	4	-	-	-	100	-	-	75	-	-	-
Central (Burdur)	Wheat	14	14	50	14	29	-	57	-	-	-	43
	Barley	13	-	7	33	60	-	-	77	-	-	-
	Oat	5	20	20	-	60	80	-	-	-	-	-
Çavdır	Wheat	4	-	100	-	-	100	-	-	-	-	-
	Barley	2	-	-	-	100	100	-	-	-	-	-
	Oat	1	-	-	-	100	100	-	-	-	-	-
Çeltikçi	Wheat	3	-	-	-	67	67	-	-	-	-	-
	Barley	4	-	-	-	100	100	-	-	-	-	-
	Oat	1	-	-	-	-	-	-	-	-	-	-
Dirmil	Wheat	5	-	80	-	-	60	-	20	-	-	-
	Barley	1	-	-	-	100	-	-	100	-	-	-
	Oat	1	-	100	-	-	-	-	100	-	-	-
	Rye	1	-	100	-	-	100	-	-	-	-	-
Gölhisar	Wheat	14	-	79	-	21	36	-	64	-	-	-
	Barley	5	20	-	-	80	-	50	-	-	-	50
	Oat	1	-	-	-	-	-	-	-	-	-	-
Karamanlı	Wheat	10	-	100	-	-	50	-	-	-	-	-
	Barley	7	-	-	38	63	-	-	-	-	-	57
	Oat	1	-	-	-	100	100	-	-	-	-	-
Kemer	Wheat	13	29	57	7	7	-	-	31	-	-	-
	Barley	11	45	-	18	27	-	-	46	-	-	-
Tefenni	Wheat	12	12	44	6	38	-	-	58	-	-	-
	Barley	11	14	-	14	71	57	14	-	-	-	29
	Oat	3	33	-	-	67	-	-	-	-	-	67
	Rye	2	-	-	-	100	50	-	-	-	-	-
Yeşilova	Wheat	14	-	71	-	29	43	-	-	-	-	57
	Barley	11	15	8	23	54	82	-	-	-	-	-
	Oat	2	-	-	50	50	-	-	100	-	-	-

Pc, *Pratylenchus crenatus*; Pn, *Pratylenchus neglectus*; Pp, *Pratylenchus penetrans*; Pt, *Pratylenchus thornei*; Pa, *Pratylenchoides alkani*; Pcr, *Pratylenchoides crenicauda;* Pe, *Pratylenchoides erzurumensis;* Pl, *Pratylenchoides leiocauda;* Pr, *Pratylenchoides ritteri*; and Pv, *Pratylenchoides variabilis*.

Pratylenchoides alkani and *P. erzurumensis* were more common in wheat and barley in both Burdur and Isparta Provinces than other *Pratylenchoides* spp. (Tables 1 and 2). *Pratylenchoides leiocauda* and *P. ritteri* were not found in then samples from Burdur Province (Table 1). *Pratylenchoides leiocauda* was found in barley samples from Gelendost and Sütçüler Districts, and wheat and barley samples from Atabey Districts of Isparta Province (Table 2). *Pratylenchoides ritteri* was found wheat and barley samples from four districts (Central, Uluborlu, Yalvaç and Şarkikaraağaç) (Table 2). *Pratylenchoides crenicauda* was found in two wheat (Tefenni, Gölhisar) and two barley samples (Ağlasun and Central) in Burdur Province (Table 1) and in only one district (Yalvaç) in Isparta Province (Table 2). Rye samples only had *P. alkani,* oat samples had *P.* alkani and *P. erzurumensis* (Tables 1 & 2), but *P. variabilis* was only found in oat sample from Tefenni (Table 1).

Table 2. Incidence (%) of *Pratylenchus* and *Pratylenchoides* species in cereal fields in districts of Isparta Province

District	Cereal	Samples No	*Pratylenchus*				*Pratylenchoides*					
			Pc	Pn	Pp	Pt	Pa	Prc	Pe	Pl	Pr	Pv
Aksu	Wheat	5	-	-	-	80	40	-	-	-	-	-
	Barley	1	-	-	-	100	-	-	-	-	-	-
Atabey	Wheat	1	-	-	100	-	-	-	-	100	-	-
	Barley	6	-	17	-	83	-	-	-	66	-	-
	Oat	1	-	-	-	100	100	-	-	-	-	-
	Rye	1	-	-	-	100	100	-	-	-	-	-
Central (Isparta)	Wheat	15	-	6	24	71	-	-	-	-	44	56
	Barley	8	12	12	-	75	-	-	-	-	-	62
	Oat	1	-	-	-	-	100	-	-	-	-	-
Eğirdir	Wheat	5	-	-	20	80	-	-	60	-	-	40
	Barley	1	-	-	-	100	-	-	-	-	-	-
Gelendost	Wheat	14	7	14	14	57	50	-	-	-	-	-
	Barley	5	-	-	40	60	-	-	-	40	-	-
	Oat	1	-	-	-	100	100	-	-	-	-	-
Gönen	Wheat	5	-	-	-	100	100	-	-	-	-	-
	Barley	9	11	-	-	89	88	-	-	-	-	-
	Oat	3	-	-	33	67	100	-	-	-	-	-
Keçiborlu	Wheat	6	-	33	-	67	100	-	-	-	-	-
	Barley	7	-	14	-	86	43	-	-	-	-	-
Senirkent	Wheat	9	-	-	-	22	40	-	-	-	-	-
	Barley	7	-	-	14	57	60	-	-	-	-	-
Sütçüler	Wheat	5	-	20	-	40	60	-	-	-	-	-
	Barley	2	-	50	-	50	50	-	-	50	-	-
Şarkikaraağaç	Wheat	29	3	17	14	48	50	-	19	-	23	8
	Barley	14	-	27	13	60	36	-	64	-	-	-
	Rye	2	-	-	-	50	-	-	50	-	-	-
Uluborlu	Wheat	7	-	-	14	57	-	-	-	-	42	-
	Barley	5	-	-	20	60	-	-	-	-	40	-
Yalvaç	Wheat	23	4	19	19	58	-	12	75	-	6	6
	Barley	30	12	24	9	55	56	-	33	-	11	-
	Oat	7	-	-	14	71	-	-	71	-	-	-

Pc, *Pratylenchus crenatus*; Pn, *Pratylenchus neglectus*; Pp, *Pratylenchus penetrans*; Pt, *Pratylenchus thornei*; Pa, *Pratylenchoides alkani*; Pcr, *Pratylenchoides crenicauda;* Pe, *Pratylenchoides erzurumensis;* Pl, *Pratylenchoides leiocauda;* Pr, *Pratylenchoides ritteri*; and Pv, *Pratylenchoides variabilis*.

Population density of *Pratylenchus* and *Pratylenchoides* spp. in cereal fields in Burdur and Isparta Provinces

The lowest *Pratylenchus* spp. root densities were found in Dirmil, Gölhisar, Çeltikçi, Ağlasun, Bucak and Kemer Districts and the highest was found in Çavdar and Central District of Burdur Province (Table 3). The differences between the *Pratylenchus* spp. soil densities were not statistically significant in districts of Burdur Province ($p \geq 0.05$). There was no statistically significant difference between districts of Burdur Provinces in terms of root and soil density of *Pratylenchoides* spp. (Table 3).

In Isparta Province, lower *Pratylenchus* spp. root densities were found in Sütçüler, Senirkent, Gelendost, Gönen and Keçiborlu Districts and higher densities in Şarkikaraağaç, Eğirdir, Yalvaç and Uluborlu Districts (Table 4). Lower *Pratylenchus* spp. soil densities were found in Eğirdir, Aksu and Senirkent Districts and higher densities in Şarkikaraağaç, Yalvaç, Isparta Central, Gelendost, Gönen, Atabey and Keçiborlu Districts. The lower *Pratylenchoides* spp. root densities were found in Uluborlu and Gelendost District but these were not found significantly different to Isparta Central and Senirkent Districts. The average of *Pratylenchoides* spp. soil densities was lower in Eğirdir, Aksu, Sütçüler, and Senirkent Districts than in Isparta central, Uluborlu, Gelendost, Gönen and Atabey Districts but these were not significantly different (Table 4).

Table 3. Soil and root density of *Pratylenchus* and *Pratylenchoides* species in cereal samples from districts of Burdur Province

Districts	Samples No	*Pratylenchus*		*Pratylenchoides*	
		Mean rank			
		Root density (10 g fresh root)	Soil density (100 g dry soil)	Root density (10 g fresh root)	Soil density (100 g dry soil)
Ağlasun	11	76,4 b*	72,1 a	114,5 a	138,5 a
Bucak	24	55,9 b	70,0 a	118,5 a	132,7 a
Central (Burdur)	32	138,6 a	106,7 a	113,2 a	94,7 a
Çavdır	7	146,5 a	127,5 a	148,5 a	98,7 a
Çeltikçi	8	100,6 b	90,0 a	139,1 a	145,2 a
Dirmil	11	76,4 b	72,1 a	114,5 a	138,5 a
Gölhisar	19	97,9 b	87,0 a	110,6 a	84,1 a
Karamanlı	18	133,2 ab	148,2 a	92,1 a	97,6 a
Kemer	24	53,9 b	81,7 a	73,3 a	84,5 a
Tefenni	28	134,3 ab	123,0 a	96,5 a	99,6 a
Yeşilova	27	123,6 ab	145,1 a	95,5 a	98,0 a

* There is no significant difference between the means followed by the same letter with a column based on Tamhane's T2 multiple comparison test.

Table 4. Soil and root density of *Pratylenchus* and *Pratylenchoides* species cereal samples from districts of Isparta Province

Districts	Samples No	*Pratylenchus*		*Pratylenchoides*	
		Mean rank			
		Root density (10 g fresh root)	Soil density (100 g dry soil)	Root density (10 g fresh root)	Soil density (100 g dry soil)
Aksu	6	118,1 ab*	56,5 b	108,0 ab	62,5 b
Atabey	9	115,3 ab	125,5 a	151,2 a	109,4 ab
Central (Isparta)	24	122,3 ab	128,5 a	99,5 ab	112,9 ab
Eğirdir	6	140,7 a	56,5 b	141,4 a	92,0 b
Gelendost	20	68,7 b	136,3 a	96,4 b	118,1 ab
Gönen	17	109,4 b	155,8 a	167,4 a	118,2 ab
Keçiborlu	13	101,5 b	159,6 a	121,6 a	142,9 a
Senirkent	16	85,4 b	45,2 b	103,4 ab	85,8 b
Sütçüler	7	76,2 b	89,8 ab	121,9 a	91,7 b
Şarkikaraağaç	43	140,3 a	115,3 a	139,1 a	129,7 a
Uluborlu	12	130,0 a	103,2 ab	68,4 b	107,0 ab
Yalvaç	60	128,0 a	122,7 a	105,6 a	125,4 a

* There is no significant difference between the means followed by the same letter with a column based on Tamhane's T2 multiple comparison test.

Root population densities of *Pratylenchus* spp. ranged between 1,000 and 2,000 nematodes/10 g fresh root in 19 samples and between 2,000 and 3,000 nematodes/10 g root in 12 samples in Burdur Province. *Pratylenchus* spp. had over 3,000 nematodes/10 g root in Central, Tefenni and Yeşilova Districts. *Pratylenchus* spp. had higher root densities in Isparta than Burdur Province. Root densities were over the 70,000 nematodes/10 g fresh root in two samples in Central District of Isparta. Also, 19 samples in Isparta had *Pratylenchus* spp. between 40,000 and 60,000 nematodes/ 10 g fresh roots. The root density of *Pratylenchus* spp. were ranged between 1,000 and 2,000 individuals/10 g fresh root in 29 samples, 2,000 and 3,000 nematodes/10 g fresh root in 24 samples, 4,000 and 5,000 nematodes/10 g fresh root in 17 samples, 6,000 and 7,000 nematodes/10 g fresh root in 12 samples and 8,000 and 9,000 nematodes/10 g fresh root at five samples from Isparta (Figure 2).

Soil densities of *Pratylenchus* spp. were generally between 0 and 100 nematodes/100 g dry soil in Burdur and Isparta Province. *Pratylenchus* spp. densities where higher in Tefenni District with 3,000 and Karamanlı District with 2,800 nematodes/100 g dry soil in Burdur Province. The densities were between 1,000 and 2,000 nematodes/100 g dry soil in nine samples in Tefenni, Karamanlı, Yeşilova and Kemer Districts in Burdur Province. *Pratylenchus* spp. had over 3,000 nematodes/100 dry g soil in three samples from Isparta Province. Four samples contained 2,480, 2,000, 1,000 and 1,100 nematodes in 100 g dry soil in Central, Keçiborlu, Yalvaç and Şarkikaraağaç Districts, respectively (Figure 3).

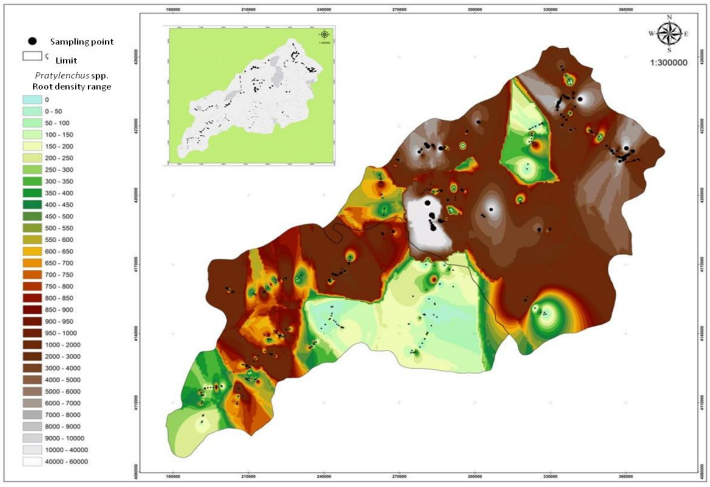

Figure 2. Root population density of *Pratylenchus* spp. at the sampling points in Burdur and Isparta Provinces.

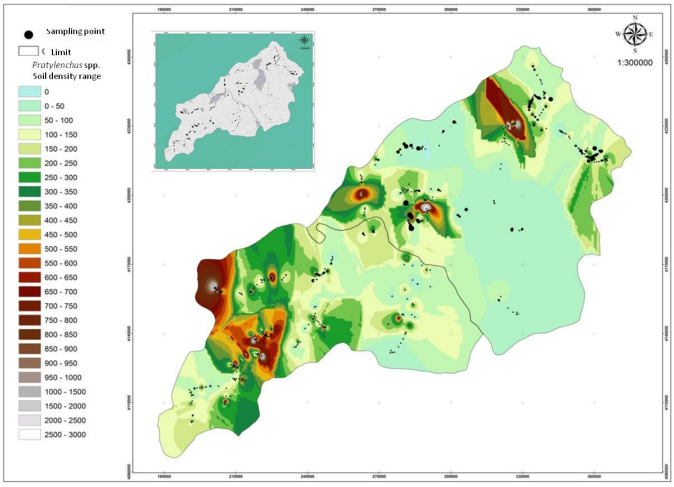

Figure 3. Soil population density of *Pratylenchus* spp. at the sampling points in Burdur and Isparta Provinces.

Root density of *Pratylenchoides* spp. ranged between 600 and 6,000 nematodes/10 g fresh root in Isparta Province. However, root density was over 10,000 nematodes/10 g fresh root in several locations. *Pratylenchoides* spp. had between 6,000 and 10,000 nematodes/10 g fresh root in one sample in Senirkent, two samples in Yalvaç and four samples in Şarkikaraağaç Districts in Isparta Province. Density of *Pratylenchoides* was lower in Burdur Province than Isparta. The density ranged between 1,000 and 2,000 nematodes/10 g fresh root at nine samples and between 2,000 and 3,000 nematodes/10 g fresh root densities at six samples in Burdur Province. The highest root densities were found in two samples with 3,580 and 3,060 nematodes/10 g fresh root in Bucak and Central Districts, respectively.

Pratylenchoides spp. had lower densities in soil than roots in all samples. The higher population densities of *Pratylenchoides* spp. in Isparta were in one sample from Gelendost, one sample from Central and two samples from Keçiborlu Districts with 1600, 1800, 2200 and 2860 nematodes/100 g dry soil, respectively. In Burdur, *Pratylenchoides* spp. had highest population density in soil in four samples in Karamanlı, Tefenni, Kemer and Bucak Districts with 2,580, 1,200, 1,200 and 1,060 nematodes/100 g dry soil, respectively (Figure 4).

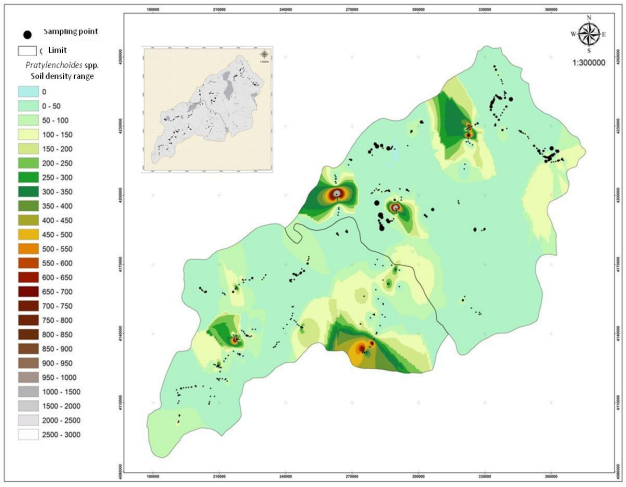

Figure 4. Soil population density of *Pratylenchoides* spp. at the sampling points in Burdur and Isparta Provinces.

Discussion

In this study, nine genera of plant parasitic nematode species were found in cereal fields in Burdur and Isparta Provinces of Turkey. *Pratylenchus* and *Pratylenchoides* were found to be the two most common plant parasitic genera. *Pratylenchus thornei* and *P. neglectus* were common; however, *P. penetrans* and *P. crenatus* were also found in Isparta and Burdur. Some lesion nematode species were found in mixed populations. The other important finding was that *Pratylenchoides* spp. occurred at high density in some cereal sample roots and soils. In addition, *P. alkani* and *P. erzurumensis* were common in cereal fields in Isparta and Burdur Provinces. While *P. leiocauda* and *P. ritteri* were found in Isparta, they were not found in Burdur Province. *Pratylenchoides* spp. was found mixed populations with *Pratylenchus* spp. in both Provinces. *Pratylenchus thornei*, *Pratylenchus fallax* Seinhorst, 1968*, P. crenatus, P. neglectus* and *P. penetrans* have been reported in cereal fields in the Eastern Mediterranean region, Central Anatolia Region and Southeastern Anatolia of Turkey (Elekcioglu & Gözel, 1998; Yıldırım et al., 2007; Yavuzaslanoğlu et al., 2012; Öcal & Elekcioğlu, 2015). Kasapoğlu Uludamar et al. (2018) identified *P. neglectus, P. thornei* and *P. alkani* in soil from barley and wheat fields in Adıyaman. While *P. neglectus* has been reported to be widely distributed in Bolu Province (Dababat et al., 2019), *P. thornei* was more common in Konya and Karaman Provinces (Yavuzaslanoğlu et al., 2020). Yavuzaslanoğlu et al. (2012) identified *P. alkani*, *P. erzurumensis*, *P. variabilis*, *P. crenicauda* and *P. ritteri* from soil samples from Central Anatolian Plateau. As a result, *Pratylenchus* and *Pratylenchoides* spp. identified in the present study are potentially of economic importance for cereal production in Isparta and Burdur Provinces.

The results of this study showed that distribution, incidence and population density of *Pratylenchus* and *Pratylenchoides* spp. varied. In previous studies, researchers noted that there are several factors thought to contribute to this variation including cereal species, cultivar, soil type, pH, organic matter, fallow, planting times and tillage practices (Sundararaju & Jeyabaskaran, 2003; Castillo & Vovlas, 2007; Govaerts et al., 2008; Thompson et al., 2008; Collins et al., 2011). In our study, *Pratylenchus* and *Pratylenchoides* spp. had high densities in root and soil in both Burdur and Isparta Provinces. Also, *Pratylenchoides* spp. densities were higher than *Pratylenchus* spp. in some samples and these two migratory endoparasitic nematodes were found mixed population in many samples. *Pratylenchus* spp. densities were found at over 1,000 nematodes/100 g soil in 11 samples from Burdur and in seven samples from Isparta, which is over the economic threshold level proposed by Dickerson et al. (2000). Dickerson et al. (2000) calculated economic damage threshold level for control of root lesion nematodes at 250 nematodes/100 g of soil in wheat fields. Moreover, Van Gundy et al. (1974) reported that the threshold level of lesion nematode was

42 nematodes/100 g soil. Yavuzaslanoğlu et al. (2012) reported that *Pratylenchus* spp. densities of at most 274, 140, 119, 113, 69 and 52 nematodes/100 g soils, Konya, Niğde, Kırşehir, Sivas, Denizli and Eskişehir Provinces, respectively, and also found *Pratylenchoides* spp. at high density of soil from cereal fields of Central Anatolia where it ranged between 133 and 749 nematodes/100 g soil. In addition, Dababat et al. (2019) found for 12% of samples collected from five districts in Bolu Province that, on average, *P. neglectus* were at 155 nematodes/100 g soil, while 12% of samples had more than 250 nematodes/100 g soil. Yavuzaslanoğlu et al. (2020) found that a higher density of nematodes in Karapınar, Kadınhanı, Selçuklu and Cihanbeyli Districts of Konya Province; a mean of 14 ± 14, 13 ± 8, 16 ± 16 and 9 ± 4 nematodes/100 g dry soil, respectively while *Pratylenchoides* spp. was found only one district at a low density with a mean of 5 ± 5 nematodes/100 g dry soil in Konya Province. The reason for higher density of *Pratylenchus* spp. in present study than in others studies in Turkey could be due to sampling time. In previous studies, the sampling time was between March and April (Yavuzaslanoğlu et al., 2012, 2020). Sampling times were delayed due to late cereal planting and a particularly wet spring in Isparta and Burdur Provinces in 2016 and 2017. Also, Söğüt et al. (2011) collected from 198 samples in 15 districts in the Lakes Region between May and June in 2008-2010 and *P. thornei, P. neglectus, P. crenatus* and *P. alkani* were determined in the region. It was found that *Pratylenchus* spp. had over the economic threshold levels in soil and roots in June-August in 2016 and 2017, and caused serious yield loss in Burdur and Isparta Provinces.

Cereal cyst nematodes were not found in the roots in present study. This may be because with high densities of *Pratylenchu*s and *Pratylenchoides* spp. cyst nematodes may not be able to compete effectively. It might also have been a result of the ecological conditions of the Isparta and Burdur Provinces. In addition, crop rotation is successfully practicing in cereal fields in Isparta and Burdur Provinces. The changing soil conditions and host plant are effective in reducing the incidence and population densities of the main damaging plant parasitic nematode species (Sundararaju & Jeyabaskaran, 2003; Collins et al., 2011). Toktay et al. (2020) reported that the fields where cyst nematodes were not found were generally rotated with other crops. Also, climate change and global warming affect spatial distribution and damage potential of pathogens and pests (Morgan & Wall, 2009).

In conclusion, it appears necessary to work on control strategies for *Pratylenchus* and *Pratylenchoides* species in order to increase yields in Isparta and Burdur Provinces. In addition, the incidence of these nematodes in other host plants involving crop rotation should be investigated. Several researchers and CIMMYT in Turkey have been focusing on host reactions of wheat lines and cultivars to improve resistance. Also, some future studies should focus on the economic significance of *Pratylenchoides* in cereals as there have been no studies of host reactions to *Pratylenchoides* spp. This is needed to improve integrated control strategies in cereal fields.

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