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Original article (Orijinal araştırma)

The importance of host weed species for root-knot nematodes, *Meloidogyne* spp. Göldi, 1897 (Tylenchida: Heteroderidae) in banana plantations[1]

Muz üretim plantasyonlarında kök-ur nematodları, *Meloidogyne* spp. Göldi, 1897 (Tylenchida: Heteroderidae) için konukçu yabancı ot türlerinin önemi

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Abstract

Banana is a significant economic source in Türkiye. Root-knot nematodes, *Meloidogyne* spp. Göldi, 1897 (Tylenchida: Heteroderidae) are the important pests in banana fields. This study was conducted from 2021 to 2022 to elucidate the relationship between root-knot nematodes and weed species in bananas in the Mediterranean Region. 2% of the banana production area in Adana, Antalya, Hatay and Mersin were surveyed regularly for this purpose. 1m^2 frames were placed within a 2m radius around banana plants in the sampled areas. The host of root-knot nematodes with weed species identified within the frames was examined. Survey results indicated that *Amaranthus retroflexus* L. (46.34%), *Portulaca oleracea* L. (40.63%), and *Solanum nigrum* L. (37.84%) were the weed species most infected with root-knot nematodes. Furthermore, molecular analyses revealed that *Abutilon theophrasti* Medik., *Amaranthus* spp., *Cucumis melo* var. *agrestis* Naudin., *Erodium cicutarium* (L.) L'Hér. ex Aiton, *Kickxia commutata* (Bernh. ex Rchb.) Fritsch, *Malva* spp., *Mercurialis annua* L., *P. oleracea*, *S. nigrum*, and *Sonchus oleraceus* L. were suitable hosts for root-knot nematodes. This study is an important step in understanding the interaction between root-knot nematodes and weeds in banana. The presence of weed species in agricultural fields should be considered as they may support nematode populations and pose a threat to subsequent crops. Therefore, the implementation of weed control strategies could help producers to control nematode populations.

Keywords: Banana, infection, Mediterranean basin, molecular, nematode-weed relationship

Öz

Muz yetiştiriciliği Türkiye'de ekonomik açıdan önemli bir gelir kaynağıdır. Muz alanlarında kök-ur nematodları, *Meloidogyne* spp. Göldi, 1897 (Tylenchida: Heteroderidae) ise ana zararlıları konumundadır. Akdeniz Bölgesi'nde muz üretiminde kök-ur nematodları ile yabancı ot türleri arasındaki ilişkiyi ortaya koymak amacıyla 2021-2022 yılları arası planlanan bu çalışmada, periyodik çıkışlarla muz üretim alanlarının %2'si (Adana, Antalya, Hatay ve Mersin) gezilmiştir. Örnekleme yapılan alanlarda dikilen muz bitkilerinin 2m'lik çap çevresine 1m^2'lik çerçeveler atılmıştır. Çerçeve içerisinde saptanan yabancı ot türlerinin kök-ur nematodlarıyla olan konukçuluk durumu incelenmiştir. Sürveyler sonunda *Amaranthus retroflexus* L. (46.34%), *Portulaca oleracea* L. (40.63%) ve *Solanum nigrum* L. (37.84%) türlerinin en fazla kök-ur nematoduyla bulaşık olduğu belirlenmiştir. Dahası moleküler yöntemlerle yapılan analizlerde *Abutilon theophrasti* Medik., *Amaranthus* spp., *Cucumis melo* var. *agrestis* Naudin., *Erodium cicutarium* (L.) L'Hér. ex Aiton, *Kickxia commutata* (Bernh. ex Rchb.) Fritsch, *Malva* spp., *Mercurialis annua* L., *P. oleracea*, *S. nigrum* ve *Sonchus oleraceus* L. türlerinin kök-ur nematodları için uygun konukçular olduğu saptanmıştır. Bu çalışma muz üretiminde kök-ur nematodları ile yabancı otlar arasındaki etkileşimi anlamak için önemli bir adımdır. Tarım alanlarında yabancı ot türlerinin bulunması nematod popülasyonlarının yaşamlarını sürdürebileceği ve bir sonraki kültür bitkilerine zarar verebileceği göz önünde bulundurulmalıdır. Bu açıdan nematod popülasyonlarını kontrol altına almada, yabancı ot mücadele stratejilerini uygulamaları konusunda üreticilere rehberlik edebileceği söylenebilmektedir.

Anahtar sözcükler: Muz, bulaşma durumu, Akdeniz havzası, moleküler, nematod-yabancı ot ilişkisi

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Introduction

The banana, *Musa* spp. L., belonging to the Musaceae family, is cultivated in subtropical regions and represents a monocotyledonous, perennial crop. Among non-grain crops worldwide, bananas are the second most produced commodity in terms of trade volume after coffee, cereals, sugar, and cocoa in terms of trade volume (Aurore et al., 2009; Singh et al., 2016). Banana production, an important component of major crop groups in Asia and Africa, serves as a crucial source of income for producers in Türkiye. Initially limited, production has gradually expanded to reach 12 827 hectares with a yield of 883 455 tones in Türkiye (TÜİK, 2022). Banana plantations in the Mediterranean Region occurs both in closed greenhouses and open fields along coastal areas. The varieties most favored by producers include Grand Nain and Azman varieties.

Plant-parasitic nematodes are obligate parasites that require a host plant to complete their life cycle. In addition to cultivated plants, weeds that pose challenges to crop production serve as alternative hosts for plant-parasitic nematodes (Bélair & Benoit, 1996; Castillo et al., 2008). Weeds that can act as alternative hosts can be either weak or strong hosts for plant-parasitic nematodes (Hogger & Bird, 1976; Griffin, 1982; Gast et al., 1984). Weeds that favour the development of nematode species can sustain harmful nematode populations, thus perpetuating their persistence and causing damage to crops (Hogger & Estey, 1976; Egunjobi & Bolaji, 1979).

Studies conducted on banana have reported that *Pratylenchus* species attack banana plants in East African countries such as Burundi, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda, with the most prevalent species being *Pratylenchus coffeae* Goodey, 1951 (Tylenchida: Pratylenchidae), and *Pratylenchus goodeyi* Sher & Allen, 1953 (Tylenchida: Pratylenchidae) (Machon & Hunt, 1985; Bridge, 1988; Sarah, 1989; Gowen & Quénéhervé, 1990; Bridge, 1993; Kashaija et al., 1994). Additionally, *Helicotylenchus multicinctus* (Cobb, 1893) Golden, 1956 (Tylenchida: Hoplolaimidae) has been identified as a problem in banana, while *Radopholus similis* (Cobb, 1893) Thorne, 1949 (Tylenchida: Pratylenchidae) is reported to be rare (McSorley & Parrado, 1986). Previous studies in banana fields in Türkiye have found *H. multicinctus*, *Helicotylenchus dihystera* (Cobb, 1893) Sher, 1961 (Tylenchida: Hoplolaimidae), *Meloidogyne incognita* (Kofoid & White, 1919) Chitwood, 1949 (Tylenchida: Heteroderidae), and *Meloidogyne javanica* (Treub, 1885) Chitwood, 1949 (Tylenchida: Heteroderidae) (Gürdemir, 1979; Elekcioğlu, 1992; Elekçioğlu & Uygun, 1994; Özarslandan & Elekcioğlu, 2010; Nacar & Özarslandan, 2021; Kalay Sarı et al., 2023). Surveys in banana greenhouses in the Bozyazı district of Mersin have even shown that *H. multicinctus* has a higher population than *M. incognita* and *M. javanica* (Elekcioğlu et al., 2014). Similarly, Özarslandan & Dinçer (2015) have identified *Helicotylenchus* spp. and *Meloidogyne* spp. in banana fields in the provinces of Antalya, Mersin, and Hatay provinces and reported a higher total nematode count (*Helicotylenchus* spp. + *Meloidogyne* spp.) in August compared to May, based on root and soil samples collected from banana plants.

The identification of these nematode species in banana fields has raised the possibility of weed species acting as hosts. Worldwide, it has been determined that 24 weed species serve as hosts for *R. similis*, 23 for *Helicotylenchus* spp., 13 for *Pratylenchus* spp., 13 for *Haplolaimus seinhorsti* Luc, 1958 (Tylenchida: Hoplolaimidae), 29 for *Meloidogyne* spp., and 24 for *Rotylenchulus reniformis* Linford and Oliveira, 1940 (Tylenchida: Hoplolaimidae) in banana fields (Quénéhervé et al., 2006). Important weed species such as *Amaranthus* spp. (Caryophyllales: Amaranthaceae), *Cucumis* spp. (Cucurbitales: Cucurbitaceae), *Portulaca oleracea* L. (Caryophyllales: Portulacaceae), *Euphorbia* spp. (Malpighiales: Euphorbiaceae), *Solanum nigrum* L. (Solanales: Solanaceae) have been identified as both weak and strong hosts for root-knot nematodes (Kaur et al., 2007; Rich et al., 2008; Singh et al., 2010; Kokalis-Burelle & Rosskopf, 2012; Ntidi et al., 2016). In other studies, it has been revealed that nematodes thrive in *Amaranthus dubius* Mart. Ex Thell, *Colocasia esculenta* (L.) Schott (Alismatales: Araceae), and *Peperomia pellucida* Kunth (Piperales: Piperaceae), while they develop well in *Cleome aculeata* L. (Brassicales: Cleomaceae), *Cyperus* sp. (Poales: Cyperaceae), *Echinochloa colona* (L.) Link (Poales: Poaceae), *Eleusine indica (*L.) Gaertn. (Poales:

Poaceae), *Leptochloa filiformis* P. Beauv. (Poales: Poaceae), *Mimosa pudica* L. (Fabales: Fabaceae), *Phenax sonneratii* (Poir.) Wedd. (Rosales: Urticaceae), *Pilea microphylla* (L.) Liebm. (Rosales: Urticaceae), *Setaria barbata* (Lam.) Kunth (Poales: Poaceae), and *Solanum americanum* Mill. For *Amaranthus spinosus* L., *Cecropia* sp. (Rosales: Urticaceae), *Cleome rutidosperma* DC. (Brassicales: Cleomaceae), *Clidemia hirta* (L.) D.Don (Myrtales: Melastomataceae), *Commelina diffusa* Burm.f. (Commelinales: Commelinaceae), *Euphorbia heterophylla* L., *Laportea aestuans* (L.) Chew (Rosales: Urticaceae), *Mikania micrantha* Kunth (Asterales: Asteraceae), *Paspalum fasciculatum* Willd. Ex Flugge (Poales: Poaceae), *Passiflora* sp. (Malpighiales: Passifloraceae), *Phyllanthus amarus* Schumach. & Thonn. (Malpighiales: Phyllanthaceae), *Solanum torvum* Schltdl., *Urena lobata* L. (Malvales: Malvaceae), *Vernonia cinerea* (L.) Less. (Asterales: Asteraceae), and *Xanthosoma nigrum* (Vell.) Stellfeld (Alismatales: Araceae) are found to have weak nematode development (Quénéhervé et al., 2006). Araya & De Waele (2005) identified nematode species in weeds and banana roots at different soil depths in banana fields and found that weed management was associated with nematode distribution around the roots. Similarly, other studies have elucidated the ability of *Meloidogyne* spp., *H. multicinctus*, *R. similis*, *P. coffeae*, *R. reniformis*, and *H. seinhorsti* nematodes to act as hosts on weeds (Duyck et al., 2009).

Weeds therefore play a crucial role in the survival, development, reproduction, and establishment of plant-parasitic nematodes. Knowledge of alternative hosts is highly beneficial for effective control of plant-parasitic nematodes that cause yield losses in crops. Regular weed control has been reported as an effective technique in reducing nematode populations among various nematode control methods (Quénéhervé et al., 2006). The relationship between root-knot nematodes (*Meloidogyne* spp.) and weeds has been studied in citrus, wheat and vegetables in the Mediterranean region. It was determined that *Amaranthus viridis* L., *Amaranthus retroflexus* L., *Amaranthus albus* L., *Chenopodium album* L. (Caryophyllales: Amaranthaceae), *Cynodon dactylon* (L.) Pers. (Poales: Poaceae), *Cyperus rotundus* L., *Digitaria sanguinalis* (L.) Scop. (Poales: Poaceae), *E. indica*, *Malva sylvestris* L. (Malvales: Malvaceae), *Paspalum paspaloides* Scribn. (Poales: Poaceae), *Physalis angulata* L. (Solanales: Solanaceae), *P. oleracea*, *Setaria verticillata* (L.) P. Beauv. (Poales: Poaceae), *S. nigrum*, *Xanthium strumarium* L. (Asterales: Asteraceae), *Chenopodium* sp., and *Trifolium* sp. (Fabales: Fabaceae) weed species could serve as hosts for root-knot nematodes, *Meloidogyne arenaria* Neal, 1889 (Tylenchida: Heteroderidae); 8%, *M. incognita*; 44%, and *M. javanica*; 48% (Ercan, 2009).

There is no detailed study on the relationship between root-knot nematodes (Meloidogyne spp.), the main pests of banana fields in Türkiye, and weeds. The aim of this study is to fill this gap by conducting a survey in banana production areas, focusing on the root-knot nematodes causing problems and identifying weed species that could act as hosts. The study also aims to determine the family distribution of weed species in relation to root-knot nematodes. In addition, molecular methods are used to confirm the presence of root-knot nematodes on specific weed species and to elucidate their host status. The infection status of root-knot nematodes in weeds has been determined in banana plantations in the Mediterranean Region.

Materials and Methods

Between 2021 and 2022, survey studies were conducted in the provinces of Adana, Antalya, Hatay, and Mersin in the Mediterranean Region to determine the relationship between root-knot nematodes and weeds in open and greenhouse banana plantations. In the Mediterranean Region, a total plantation area of 11,154.4 hectares was recorded in 2020 (TUIK, 2023). Employing the sampling method proposed by Bora & Karaca (1970), approximately 2% of the total production area, equivalent to 180.8 hectares of banana plantations, was investigated. Additionally, for species identification purposes, various laboratory chemicals and materials, an incubator, a freezer, an oven, a PCR machine, electrophoresis equipment, DNA isolation kits, a gel imaging system, and PCR materials were employed as consumables in the diagnostic process of root-knot nematodes.

Root-knot nematodes (*Meloidogyne* spp.) identified on weed species

In the sampled banana production area, transects were established along the diagonals of the plantation area. Ten frames of 1 m^2 each were randomly placed around the banana plants, and the dominant weed species within these frames were identified (Odum, 1971). Once the dominant species in the banana field had been identified, nematological sampling was carried out by collecting roots from the prominent weed species within a radius of approximately 2 m around randomly selected banana plants. At least one species of weed belonging to three different root-knot nematode orientations was tested in the banana sampling area. Weeds were pulled from the soil surface, and plant species with evidence of galls on roots were identified, thereby recording weed species capable of hosting root-knot nematodes (Ercan, 2009). Surveys in banana production areas were conducted throughout the year with periodic intervals (Nkoa et al., 2015).

Molecular diagnosis through laboratory studies

During the survey, weed species with nematode-infected and gall-forming roots were sampled, and subsequently transported to the laboratory. In the surveyed banana plantations, the weed species predominantly present at the sampling points were initially examined, and root samples were collected. Commonly recognized weed species from these samples were documented, while unidentified ones were identified using the Flora of Turkey (Davis, 1965-1989) guide. For molecular diagnosis of root-knot nematodes, DNA isolation was performed using Thermo DNA isolation kit from egg masses. Species identification of the isolated DNA samples was conducted using general and specific primers as specified in Table 1 (Blok et al., 1997; Courtright et al., 2000; Zijlstra et al., 2000; Tesarova et al., 2003).

Table 1. Primers and PCR programs to be used for the identification of root-knot nematodes

Primer	Sequence	Length	Target Nematodes	Programs	References
194 195	TTAACTTGCCAGATCGGACG TCTAATGAGCCGTACGC	720 bp	5S-18S Ribosome region	Preheat 95°C-5 min. 95°C for 1 min. 50°C for 30 sec. 72°C for 1 min. 35 cycles 72°C for 7 min.	Blok et al., 1997
Fjav Rjav	GGTGCGCGATTGAACTGAGC CAGGCCCTTCAGTGGAACTATAC	720 bp	*M. javanica* specific SCAR	Preheat 95°C-5 min. 95°C for 1 min. 64°C for 45 sec. 72°C for 2 min. 35 cycles 72°C for 10 min.	Zijlstra et al., 2000
Far Rar	TCGGCGATAGAGGTAAATGAC TCGGCGATAGACACTACAAACT	420 bp	*M. arenaria* specific SCAR	Preheat 95°C-5 min. 95°C for 1 min. 61°C for 45 sec. 72°C for 2 min. 35 cycles 72°C for 10 min.	Zijlstra et al., 2000
SEC-F SEC-R	GGGCAAGTAAGGATGCTCTG GCACCTCTTTCATAGCCACG	502 bp	*M. incognita*	Preheat 95°C-5 min. 95°C for 1 min. 56°C for 45 sec. 72°C for 2 min. 35 cycles 72°C for 10 min.	Tesarova et al., 2003
D2 D3	ACAAGTACCGTGAGGGAAAGTTG TCCTCGGAAGGAACCAGCTACTA	758-784 bp	General	Preheat 94°C-4 min. 94°C for 30 sec. 55°C for 1 min. 72°C for 1 min. 30 cycles 72°C for 10 min.	Courtright et al., 2000

Species identification from the DNA obtained after isolation was conducted using the classical PCR method with DreamTaq Green PCR Master mix. The PCR reaction was prepared using 1V PCR Master Mix (DreamTaq DNA Polymerase, 2X DreamTaq Green buffer, dNTPs, 4 mM MgCl2), 1V d2H2O, and 0.4 µM of each primer. The mixture was supplemented with 1 µl of DNA, and the reaction was carried out to a

final volume of 25 µl. Samples displaying a 720 bp band in PCR with general primers underwent specific primer PCR for *M. javanica*, *M. arenaria*, and *M. incognita* species. Samples producing bands of different lengths with primers specific to these species were subjected to PCR with the general D2/D3 primers for species diagnosis and sent for sequence analysis.

Visualization of molecularly identified nematode species through agarose gel electrophoresis method

For agarose gel electrophoresis of PCR, buffer was used to prepare the agarose gel. Six microlitres of loading buffer and 10 microlitres of PCR product mixture were pipetted into wells of the prepared agarose gel. The PCR products were electrophoresed and then ethidium bromide was applied for 15 minutes to visualise the bands. After washing the stained gel with distilled water, the bands were examined and photographed under ultraviolet light in a transilluminator (Sambrook et al., 1989).

Results

Infection status of root-knot nematodes (*Meloidogyne* spp.) on weed species in banana

When examining the banana plantations, both under cover and in open fields, in the Mediterranean Region, a total of 151 sampling fields were surveyed, covering 50.8 hectares in Mersin, 46.2 hectares in Antalya, 8.2 hectares in Hatay, and 75.6 hectares in Adana. Specifically, the districts of Akdeniz and Erdemli in Mersin, Alanya and Gazipaşa in Antalya, Arsuz and Erzin in Hatay, and Ceyhan and Yüreğir in Adana were investigated, revealing the highest nematode infections in weed populations. The proportion of nematode infections in weeds was found to be 44.54% in covered banana plantations and 34.79% in open fields (Table 2).

Table 2. Infection status of root-knot nematodes (*Meloidogyne* spp.) in weed populations examined in covered and open banana production in the Mediterranean Region for 2021-2022

		Covered banana				Open field banana			
Provinces	Districts	Studied area (ha)	Studied area (number)	Infected area (number)	Infection (%)	Studied area (ha)	Studied area (number)	Infected area (number)	Infection (%)
Mersin	Akdeniz	5.0	5	5	100.00				
	Anamur	10.9	20	4	20.00	0.6	2	0	-
	Aydıncık	0.7	2	1	50.00				
	Bozyazı	2.9	8	1	12.50	0.7	3	0	-
	Erdemli	9.8	16	13	81.25	1.0	2	0	-
	Silifke	7.5	10	6	60.00				
	Tarsus	11.7	7	4	57.15				
Antalya	Alanya	4.6	5	2	40.00	25.5	13	8	61.54
	Gazipaşa	2.0	2	1	50.00	3.6	3	0	-
	Manavgat	10.5	6	0	-				
Hatay	Arsuz	4.2	10	7	70.00				
	Erzin	4.0	4	3	75.00				
Adana	Ceyhan	2.3	1	1	100.00				
	İmamoğlu	2.1	2	0	-				
	Karataş	38.4	14	3	21.43				
	Sarıçam	1.6	2	0	-				
	Seyhan	7.5	5	2	40.00				
	Yumurtalık	9.7	5	1	20.00				
	Yüreğir	14.0	4	3	75.00				
	TOTAL	149.4 ha	128	57	44.54	31.4 ha	23	8	34.79

As a result of survey studies conducted in banana production areas, it was determined that out of a total of 1617 examined weed numbers, roots of 300 weeds (18.55%) were infected with root-knot nematodes. On plant family, the highest infection rates with root-knot nematodes were observed in Amaranthaceae (33.59%), Apiaceae (33.33%), Geraniaceae (33.33%), Malvaceae (32.41%), Portulacaceae (33.85%), and Solanaceae (22.45%). Among the 24 plant families surveyed, nematode infection was identified in 13 families (Table 3).

Table 3. Distribution of weeds examined in banana production areas of the Mediterranean Region according to plant families and infected status of plant families with root-knot nematodes (*Meloidogyne* spp.) for 2021-2022

Family	Weed species (number)	Proportion (%)	Studied weeds (number)	Infected weeds (number)	Infected proportion (%)
Amaranthaceae	5	9.62	393	132	33.59
Apiaceae	1	1.92	3	1	33.33
Asteraceae	3	5.77	171	8	4.68
Boraginaceae	2	3.85	24	1	4.17
Brassicaceae	3	5.77	54	0	0.00
Caryophyllaceae	1	1.92	12	1	8.33
Convolvulaceae	2	3.85	15	0	0.00
Cucurbitaceae	1	1.92	18	2	11.11
Cyperaceae	1	1.92	21	0	0.00
Equisetaceae	1	1.92	3	0	0.00
Euphorbiaceae	6	11.54	81	15	18.52
Fabaceae	1	1.92	21	0	0.00
Geraniaceae	1	1.92	3	1	33.33
Malvaceae	2	3.85	108	35	32.41
Oxalidaceae	1	1.92	63	0	0.00
Papaveraceae	1	1.92	6	0	0.00
Plantaginaceae	3	5.77	12	1	8.33
Poaceae	8	15.38	144	5	3.47
Polygonaceae	1	1.92	3	0	0.00
Portulacaceae	1	1.92	192	65	33.85
Primulaceae	1	1.92	3	0	0.00
Ranunculaceae	1	1.92	9	0	0.00
Solanaceae	2	3.85	147	33	22.45
Urticaceae	3	5.77	111	0	0.00
TOTAL	52 species	100.00	1617 weeds	300 weeds	18.55

Surveys conducted in banana production areas examined 52 different weed species within a total of 151 areas for both open-field and covered plantations. Among these, the most extensively studied weed species are *A. retroflexus*, *P. oleracea*, *S. nigrum*, *Malva* spp. (Malvales: Malvaceae), and *Conyza* spp. (Asterales: Asteraceae). The number of weed species sampled in banana production areas is thought to be directly related to the root-knot nematode infections in the weed roots, resulting in more accurate results. In this context, when evaluating at the area-based infection of root-knot nematodes, *A. retroflexus* was determined to have an infection rate of 46.34%, *P. oleracea* 40.63%, and *S. nigrum* 37.84%, establishing them as the dominant species within the surveyed areas. Based on the formation of galls in the roots of weed species, *A. retroflexus*, *P. oleracea*, and *S. nigrum* were recorded with the highest infection rates, at 40.65%, 33.85%, and 22.52%, respectively. Additionally, the highest root-knot nematode infections were identified in *Malva* spp. (32.38%), *Mercurialis annua* L. (Malpighiales: Euphorbiaceae) (26.67%), *P. angulata* (22.22%), *A. viridis* (36.67%), *A. spinosus* (41.67%), *Abutilon theophrasti* Medik. (Malvales: Malvaceae) (33.33%), *Erodium cicutarium* (L.) L'Hér. ex Aiton (Geraniales: Geraniaceae) (33.33%), *E. heterophylla* (66.67%), *Kickxia commutata* (Bernh. ex Rchb.) Fritsch (Lamiales: Plantaginaceae) (33.33%), and *Visnaga daucoides* Gaertn. (Apiales: Apiaceae) (33.33%). A total of 22 weed species were found to be infected with root-knot nematodes (Table 4).

Table 4. Percentage of root-knot nematode (Meloidogyne spp.) infection in weed species examined in banana production areas in the Mediterranean Region during 2021-2022

Weed species	Family	EPPO Codes	Field (number)	Infected field (number)	*Infected proportion (%)	Weeds (number)	Infected weeds (number)	**Infected proportion (%)
Amaranthus retroflexus L.	Amaranthaceae	AMARE	82	38	46.34	246	100	40.65
Portulaca oleracea L.	Portulacaceae	POROL	64	26	40.63	192	65	33.85
Solanum nigrum L.	Solanaceae	SOLNI	37	14	37.84	111	25	22.52
Malva spp.	Malvaceae	MALSS	35	15	42.86	105	34	32.38
Conyza spp.	Asteraceae	CNDSS	33	0	0.00	99	0	0.00
Chenopodium album L.	Amaranthaceae	CHEAL	24	4	16.67	72	9	12.50
Oxalis corniculata L.	Oxalidaceae	OXACO	21	0	0.00	63	0	0.00
Sonchus oleraceus L.	Asteraceae	SONOL	19	4	21.05	57	8	14.04
Pilea microphylla (L.) Liebm.	Urticaceae	PILMI	18	0	0.00	54	0	0.00
Echinochloa crus-galli (L.) P.Beauv.	Poaceae	ECHCG	16	1	6.25	48	2	4.17
Cardamine occulta Hornem.	Brassicaceae	1CARG	15	0	0.00	45	0	0.00
Mercurialis annua L.	Euphorbiaceae	MERAN	15	5	33.33	45	12	26.67
Parietaria judaica L.	Urticaceae	PAIDI	14	0	0.00	42	0	0.00
Setaria verticillata (L.) P.Beauv.	Poaceae	SETVE	13	1	7.69	39	3	7.69
Physalis angulata L.	Solanaceae	PHYAN	12	3	25.00	36	8	22.22
Amaranthus viridis L.	Amaranthaceae	AMAVI	10	5	50.00	30	11	36.67
Amaranthus spinosus L.	Amaranthaceae	AMASP	8	4	50.00	24	10	41.67
Amaranthus albus L.	Amaranthaceae	AMAAL	7	1	14.29	21	2	9.52
Heliotropium europaeum L.	Boraginaceae	HEOEU	7	1	14.29	21	1	4.76
Cyperus rotundus L.	Cyperaceae	CYPRO	7	0	0.00	21	0	0.00
Digitaria sanguinalis (L.) Scop.	Poaceae	DIGSA	7	0	0.00	21	0	0.00
Euphorbia nutans Lag.	Euphorbiaceae	EPHNU	7	0	0.00	21	0	0.00
Melilotus officinalis (L.) Pall.	Fabaceae	MEUOF	7	0	0.00	21	0	0.00
Cucumis melo var. *agrestis* Naudin.	Cucurbitaceae	CUMMG	6	2	33.33	18	2	11.11
Senecio vernalis Waldst. & Kit.	Asteraceae	SENVE	5	0	0.00	15	0	0.00
Urtica urens L.	Urticaceae	URTUR	5	0	0.00	15	0	0.00
Stellaria media (L.) Vill.	Caryophyllaceae	STEME	4	1	25.00	12	1	8.33
Convolvulus arvensis L.	Convolvulaceae	CONAR	4	0	0.00	12	0	0.00
Setaria viridis (L.) P.Beauv.	Poaceae	SETVI	4	0	0.00	12	0	0.00
Sorghum halepense (L.) Pers.	Poaceae	SORHA	4	0	0.00	12	0	0.00
Ranunculus muricatus L.	Ranunculaceae	RANMU	3	0	0.00	9	0	0.00
*Chrozophora tinctoria (*L.) A.Juss.	Euphorbiaceae	CRZTI	2	1	50.00	6	1	16.67
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	CAPBP	2	0	0.00	6	0	0.00
Echinochloa colonum (L.) Link	Poaceae	ECHCO	2	0	0.00	6	0	0.00
Fumaria officinalis L.	Papaveraceae	FUMOF	2	0	0.00	6	0	0.00
Veronica arvensis L.	Plantaginaceae	VERAR	2	0	0.00	6	0	0.00
Abutilon theophrasti Medik.	Malvaceae	ABUTH	1	1	100.00	3	1	33.33
Erodium cicutarium (L.) L'Hér. ex Aiton	Geraniaceae	EROCI	1	1	100.00	3	1	33.33
Euphorbia heterophylla L.	Euphorbiaceae	EPHHL	1	1	100.00	3	2	66.67
Kickxia commutata (Bernh. ex Rchb.) Fritsch	Plantaginaceae	KICCO	1	1	100.00	3	1	33.33
Visnaga daucoides Gaertn.	Apiaceae	AMIVI	1	1	100.00	3	1	33.33
Anagallis arvensis L.	Primulaceae	ANGAR	1	0	0.00	3	0	0.00
Dactyloctenium aegyptium (L.) Willd.	Poaceae	DTTAE	1	0	0.00	3	0	0.00
Eleusine indica (L.) Gaertn.	Poaceae	ELEIN	1	0	0.00	3	0	0.00

Table 4. Continued

Weed species	Family	EPPO Codes	Field (number)	Infected field (number)	*Infected proportion (%)	Weeds (number)	Infected weeds (number)	**Infected proportion (%)
Equisetum arvense L.	Equisetaceae	EQUAR	1	0	0.00	3	0	0.00
Euphorbia helioscopia L.	Euphorbiaceae	EPHHE	1	0	0.00	3	0	0.00
Euphorbia prostrata Aiton	Euphorbiaceae	EPHPT	1	0	0.00	3	0	0.00
Ipomoea spp.	Convolvulaceae	IPOSS	1	0	0.00	3	0	0.00
Lithospermum arvense L.	Boraginaceae	LITAR	1	0	0.00	3	0	0.00
Polygonum aviculare L.	Polygonaceae	POLAV	1	0	0.00	3	0	0.00
Sinapis arvensis L.	Brassicaceae	SINAR	1	0	0.00	3	0	0.00
Veronica montana L.	Plantaginaceae	VERMO	1	0	0.00	3	0	0.00

* The higher number of samples from the surveyed of banana production area, the more accurate infection rate of root-knot nematodes (*Meloidogyne* spp.) shows in weed species.
** The greater the number of weed species sampled in the surveyed areas, the more accurately the infection rate of root-knot nematodes (*Meloidogyne* spp.) shows on weeds.

The host status of root-knot nematodes (*Meloidogyne* spp.) assessed through molecular methods

During the surveys, samples were taken from the roots of weeds growing within a 2 m radius of the banana plants. These samples, exhibiting galls on the roots, were taken to the laboratory. The roots of the weeds studied were subjected to molecular analysis to identify the species of root-knot nematodes. As a result, the host situation of *M. javanica*, *M. incognita* and *M. arenaria* nematodes on different weed species was revealed (Figure 1).

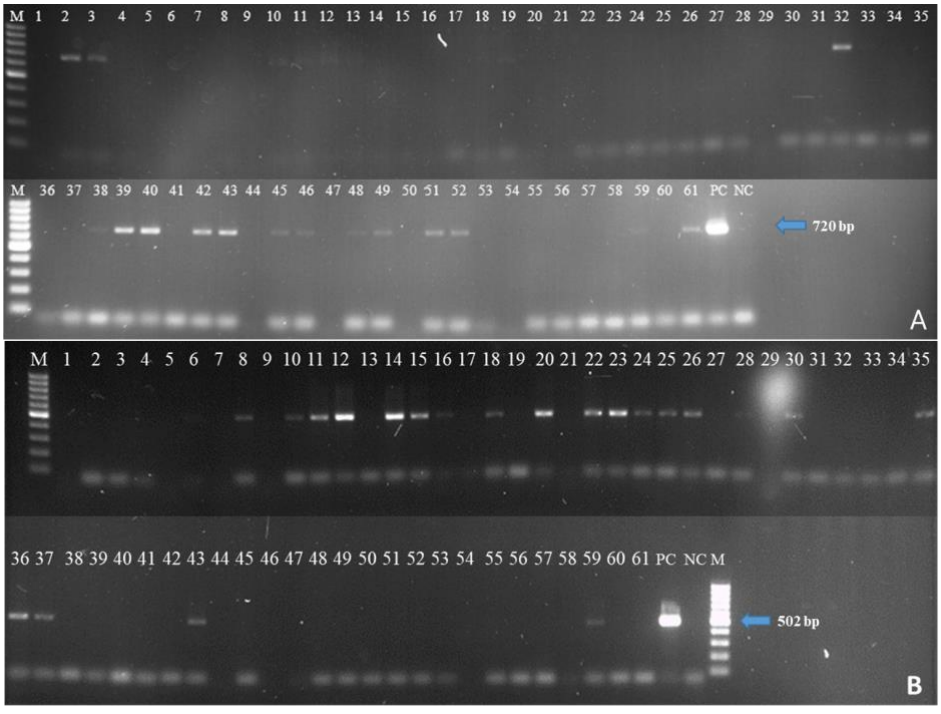

Figure 1. Molecular identification of *Meloidogyne* species in weed roots during surveys (*Meloidogyne javanica* (A); *Meloidogyne incognita* (B)) (M: Molecular marker, 1-61: DNAs obtained from weed roots, PC: Positive control, NC: Negative control).

After molecular studies, root-knot nematodes in the roots of weed samples evaluated in laboratory, such as *A. theophrasti*, *A. albus*, *A. retroflexus*, *A. spinosus*, *A. viridis*, *K. commutata*, *Malva neglecta* Wallr. (Malvales: Malvaceae), *M. sylvestris*, *M. annua*, *P. oleracea*, *S. nigrum*, and *Sonchus oleraceus* L., (Asterales: Asteraceae) were successfully diagnosed through molecular analyses. However, despite the formation of galls on the roots of other weed species collected from the field, molecular analysis did not show any results, as the diagnoses were based on the evaluation of nematode egg masses in weed roots.

Discussion

In banana production, it has been reported that the growth of weeds prevents the initial development of banana seedlings, and some weeds also act as hosts for diseases and pests (Isaac et al., 2007; Fongod et al., 2010). Knowing the distribution, community status and floristic richness of the weed flora in open field and greenhouse banana plantations prevent yield losses. It is also important to understand which pests these weed species have as hosts. In countries with significant banana plantations, such as Colombia and Brazil, weed species have been reported to cause problems and damage crop production (Moura Filho et al., 2015; Quintero-Pertúz et al., 2020). In the banana fields of Türkiye, 68 weed species from 25 families have been identified, with Poaceae, Amaranthaceae and Euphorbiaceae being the top three. The weed species identified for banana fields were similar to those identified in surveys of weed roots for root-knot nematodes in banana fields. In fact, *Cardamine occulta* Hornem., *Amaranthus* spp., *P. oleracea*, *Conyza* spp., and *Oxalis corniculata* L. were among the most common weed species (Torun et al., 2023). Specifically, the interaction and host status of *Meloidogyne* spp., one of the main problems in banana production in the Mediterranean Region of Türkiye, with weeds, have been revealed by this study (Elekcioğlu et al., 2014; Özarslandan & Dinçer, 2015; Nacar & Özarslandan, 2021; Kalay Sarı et al., 2023).

The study found that *A. albus*, *A. retroflexus*, *A. spinosus*, *A. viridis*, *Cucumis melo* var. *agrestis* Naudin. (Cucurbitales: Cucurbitaceae), *P. oleracea* and *S. nigrum* are suitable hosts for the nematode species *M. javanica* and *M. incognita*. In fact, similar studies around the world have identified *M. javanica* and *M. incognita* as hosts for these weed species (Jain et al., 1983; Quénéhervé et al., 2006; Kaur et al., 2007; Brito et al., 2008; Rich et al., 2008; Singh et al., 2010; Kokalis-Burelle & Rosskopf, 2012; Faske, 2013; Ntidi et al., 2016). Similarly, in recent surveys, only *M. javanica* was found in the roots of *E. cicutarium*, *K. commutata*, and *S. oleraceus*, while only *M. incognita* was observed in the roots of *A. theophrasti*, *M. sylvestris*, *M. neglecta*, and *M. annua* (Goodey et al., 1965; Rich et al., 2008; Akyazı & Felek, 2022). The results of this study on host status are consistent with many other studies in the literature. Although root-knot nematodes are a known problem in banana fields (Sudha & Prabhoo, 1983; Saeed et al., 1988). The study of nematode infections in weed roots showed that *M. arenaria* did not act as a host in any weed species when analysed by molecular methods. However, this does not imply a lack of potential host interactions, as the presence of specific nematode species may vary depending on banana varieties, cultivars, and growing conditions. Because nematode populations always interact with plants (De Waele & Davide, 1999). Other studies have reported that nematode infected weed species do not act as hosts all the time or do not reproduce for other nematode species such as *R. similis*, *H. multicinctus* and *P. goodeyi* (Tedford & Fortnum, 1988; Quénéhervé et al., 2006). Despite some similarities observed in studies on weed species, it has been suggested that the major banana nematodes sometimes have a limited host range in these areas, infecting only a few plants depending on environmental conditions (Blake, 1972).

Consequently, weeds are potential reservoirs that can contribute to the rapid establishment of root-knot nematodes in bananas. A total of 151 sampling points were surveyed in the Mediterranean region, including indoor and outdoor production areas in Mersin, Antalya, Hatay and Adana. Surveys showed that the highest levels of root-knot nematode infection occurred in weeds of the Amaranthaceae, Apiaceae, Geraniaceae, Malvaceae, Portulacaceae and Solanaceae families. However, other studies have reported nematode development in prominent plant families such as Euphorbiaceae, Poaceae, and Solanaceae (Araya & De Waele, 2005; Quénéhervé et al., 2006; Duyck et al., 2009; Gebremichael, 2015). Regarding banana yield, it has been reported that if low population levels of *Meloidogyne* species observed on

Amaranthus sp., *S. nigrum*, *Crassocephalum crepidioides* (Benth.) S. Moore (Asterales: Asteraceae), *Commelina benghalensis* L. (Commelinales: Commelinaceae) and *E. indica* are not effectively managed, significant yield losses in bananas could occur in the future (Jonathan & Rajendran, 2000).

Weed control is a recommended management practice in banana plantations. Failure to control weeds can lead to an increase in nematode populations. Compared to open fields, daily irrigation, farm manures, and high humidity in greenhouses contribute to the population of weeds, thereby supporting the continued life cycle of nematode populations. In general, banana plantations have a rich exotic weed flora. It is therefore believed that integrated weed management (IWM), which involves the control of weed populations can reduce nematode densities. It is also considered that weed management indirectly plays an effective role in nematode management.

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