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Host suitability and reaction of lettuce cultivars to *Meloidogyne incognita*

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Abstract: Lettuce is one of the most important cultivated vegetable crops globally. However, its production is severely constrained by root-knot nematodes (RKNs, *Meloidogyne* spp.), which cause significant yield losses. There are very limited studies regarding host resistance to RKNs in lettuce. In this study, the responses of a total of 18 commercial lettuce cultivars, representing four distinct types commonly cultivated in Türkiye, Curly-leaf (10), Yedikule/Romaine (3), Lollo Rosso (3), Iceberg (2) were evaluated against *Meloidogyne incognita* under the controlled growth chamber conditions. Seedlings were transplanted into 400 ml pots containing sterile soil and ten days after transplanting, each plant was inoculated with 1000 second-stage juveniles (J2s) of *M. incognita*. Forty-eight days after inoculation, the plants were uprooted to evaluate the number of root galls and egg masses. The gall and egg masses indices and the reproduction rate of the isolate on each plant was calculated. Statistical analysis revealed that, although there were significant differences among cultivars and lettuce types in the evaluated parameters, all 18 cultivars were found to be susceptible to *M. incognita* under the tested conditions. However, lower gall numbers were recorded in iceberg cultivars (Bohça and YT-77), while reduced egg mass production was observed in iceberg cultivars and some curly-leaf cultivars (Elmaria and Yörünge). These findings highlight the need for effective nematode management strategies in lettuce production and emphasize the importance of studies focused on developing resistant cultivars.

Keywords: Lettuce; *Meloidogyne incognita*; Resistance; Root-knot nematode; Testing.

Abbreviations: ANOVA, analysis of variance; EMI, egg mass index; GI, gall index; HSD, honestly significant difference; J2, second-stage juvenile; RF, reproduction factor; RKN, root-knot nematode.

Introduction

Root-knot nematodes (*Meloidogyne* spp.) are one of the most important pests in world. These organisms induce the formation of specialized feeding sites referred to as giant cells, which result in significant disruption to the host plant's vascular system. By obstructing the uptake of water and nutrients, these infestations cause stunted growth, chlorosis, floral abscission, and reduced fruit set; under conditions of high inoculum pressure, severe infections may culminate in plant mortality (Trudgill and Blok, 2001). Furthermore, root penetration by second-stage juveniles (J2s) may facilitate interactions between plants and soil-borne pathogens through root tissue disruption and other nematode-induced physiological changes, potentially leading to increased disease severity and yield losses (Nicol et al., 2011; Jones et al., 2013).

Lettuce (*Lactuca sativa* L.) is one of the most significant leafy vegetables cultivated for nutritional quality in human consumption (Dias-Arieira et al., 2015). While China ranks first in the world in lettuce production, the total production quantity of Türkiye's various lettuce types is 602,848 tons (TUIK, 2024). However, many pests and pathogens cause serious yield losses in lettuce cultivation (Fiorini et al., 2007; Dias-Arieira et al., 2012; Kwon et al., 2020). Root-knot nematodes (RKNs) are one of the most important pests in crops (Jones et al., 2013). They may result in yield losses of up to 100%, depending on the severity of infestation and the susceptibility of the cultivar used (Charchar, 1995; Dias-Arieira et al., 2015; Rabello et al., 2021). In Türkiye, RKNs were reported in lettuce cultivation areas (Akyazı and Ecevit, 2011; Uysal et al., 2017; Aslan and Elekçioğlu, 2022; Uzunoğulları et al., 2022; Yılmaz et al., 2024). As known many management methods are used to control RKNs. Nematicides have long been used as an important component of root-knot nematode management. However, concerns regarding their environmental impact, non-target effects, and potential risks to human health have led to increasing regulatory restrictions and a growing interest in more sustainable management strategies (Nicol et al., 2011). Consequently, alternative control strategies have gained considerable prominence in recent years. The utilization of

resistant cultivars is regarded as a critical alternative control strategy in the management of RKNs (López-Gómez et al., 2016). Therefore, developing of resistant lettuce varieties is very important in management approach. Maluf et al. (2002) investigated the commercial Brazilian lettuce cultivars Grand Rapids and Regina-71 for resistance against *M. incognita* and *M. javanica*; and results showed that Regina-71 was susceptible, whereas Grand Rapids exhibited high tolerance. Furthermore, the study reported that resistance in Grand Rapids is controlled by a single gene with predominantly additive gene effects. For resistant breeding, wild plant species are the most important sources to find resistant genes against pests or diseases. Pedroche et al. (2007) evaluated the response of five lettuce cultivars (Ballon, Gilaben, Great Lakes, Lollo Rosa, and Red Wave) to *M. incognita* under greenhouse conditions following inoculation with 1000 eggs per plant. Based on the resistance index, the cultivars Great Lakes and Gilaben were classified as highly resistant and resistant, respectively. Kaur (2009) inoculated wild lettuce plants (500 lettuce accessions) with 5,000 *M. hapla* eggs per plant under greenhouse conditions and *Lactuca saligna* PI 281876, *L. saligna* PI 491000, and *L. virosa* PI 273579 were identified as highly resistant accessions based on root galling indices formed on the roots. In another study, Diniz et al. (2018) inoculated eight green leaf lettuce inbred lines derived from Brazilian commercial cultivars with 200 J2s of *M. enterolobii*, *M. javanica*, and *M. incognita*. In the study, it was found that two lines (L1 and L2) were moderately resistant and resistant against *M. enterolobii* and *M. incognita* according to gall and egg masses indices, respectively. However, these lines could be classified as resistant based on the number of root galls and egg masses, all lettuce genotypes were ultimately considered susceptible to all three nematode species due to the reproduction factor (RF) of these nematodes. Sgorlon et al. (2018) were tested twenty crispy-leaf lettuce cultivars against RKNs (*M. incognita* race 3, *M. javanica* and *M. enterolobii*) and some cultivars (Veronica, Grand Rapids and Crespa para Verão) were found resistant to the three RKN species. Similarly, Sousa et al. (2019) screened 43 non-commercial genotypes and six commercial cultivars of crisphead lettuce in Brazil for resistance to root-knot nematode, identifying six non-commercial genotypes as resistant to the root-knot nematodes. Vidal et al. (2019) evaluated the resistance of lettuce differential cultivars used for downy mildew race characterization against *M. incognita* and *M. javanica*. While all cultivars were susceptible to *M. incognita*, the cultivars 'Argelès', 'Kibrille', 'Balesta', 'Colorado', 'Design', 'Bartoli', and 'NunDm15' exhibited resistance or high resistance to *M. javanica*, highlighting their potential as sources of combined resistance to both downy mildew and root-knot nematodes in lettuce breeding programs. In another study, Giné et al. (2024) conducted a study in Spain to evaluate the reactions of commercial lettuce cultivars 'Salinas 88' and 'Grand Rapids' against seven *M. javanica* and four *M. incognita* isolates. Their findings indicated that these cultivars were resistant to the most nematode isolates in pot experiments; however, they exhibited slight to moderate resistance under greenhouse conditions. In this study, the host responses of 18 lettuce cultivars grown in Türkiye which unknown resistance to *M. incognita* were investigated under controlled climate chamber conditions.

Results

The lettuce cultivars were evaluated within their respective horticultural groups (Curly-leaf, Yedikule/Romaine, Lollo Rosso, and Iceberg) to allow meaningful comparisons among commercially relevant cultivars of similar type. Two iceberg lettuce cultivars were evaluated for their response to the *Meloidogyne incognita* G7 isolate. Although numerical differences were detected between two cultivars in terms of number of galls, gall index, number of J2s in the soil, and reproductive factor (RF) these differences were not statistically significant (P>0.05). Similarly, no significant differences were observed regarding the number of egg masses, egg mass index, number of galls per gram of root, number of egg masses per gram of root, and root fresh weight (P>0.05). Despite the variations observed in certain parameters, both cultivars were classified as susceptible (Table 2, Fig. 1, Fig. 2).

Table 2. Response of iceberg lettuce cultivars to *Meloidogyne incognita* G7 isolate based on nematode infection parameters

Cultivar	Galls plant^{-1}	Egg masses plant^{-1}	GI (0–5)	EMI (0–5)	J2s in pot soil	Galls root g^{-1}	Egg masses root g^{-1}	Root fresh weight (g)	RF
Bohça	42.7 ±5.10 a	12.2 ± 2.56 a	3.9 ±0.10 a	2.5 ±0.22 a	1156 ±61.81 a	6.191 ±0.56 a	1.755 ±0.32 a	6.835 ± 0.38 a	1.156 ±0.06 a
YT-77	35.2 ±2.62 a	10.9 ±1.59 a	3.7 ±0.15 a	2.4 ±0.22 a	1058 ± 46.51 a	5.901 ±0.66 a	1.792 ±0.29 a	6.384 ±0.53 a	1.058 ±0.04 a
P value	0.18	0.67	0.28	0.75	0.22	0.74	0.93	0.50	0.22

The columns in the table were evaluated among themselves, and according to the T-test, values showing the same letter are statistically indistinguishable from each other according to P≤0.05. ± indicates the standard error. Gall index and egg masses index were evaluated according to a 0-5 scale (Hartman and Sasser, 1985). RF = Final population (Pf) / Initial population (Pi) GI: gall index; EMI: egg mass index; J2: second-stage juvenile.

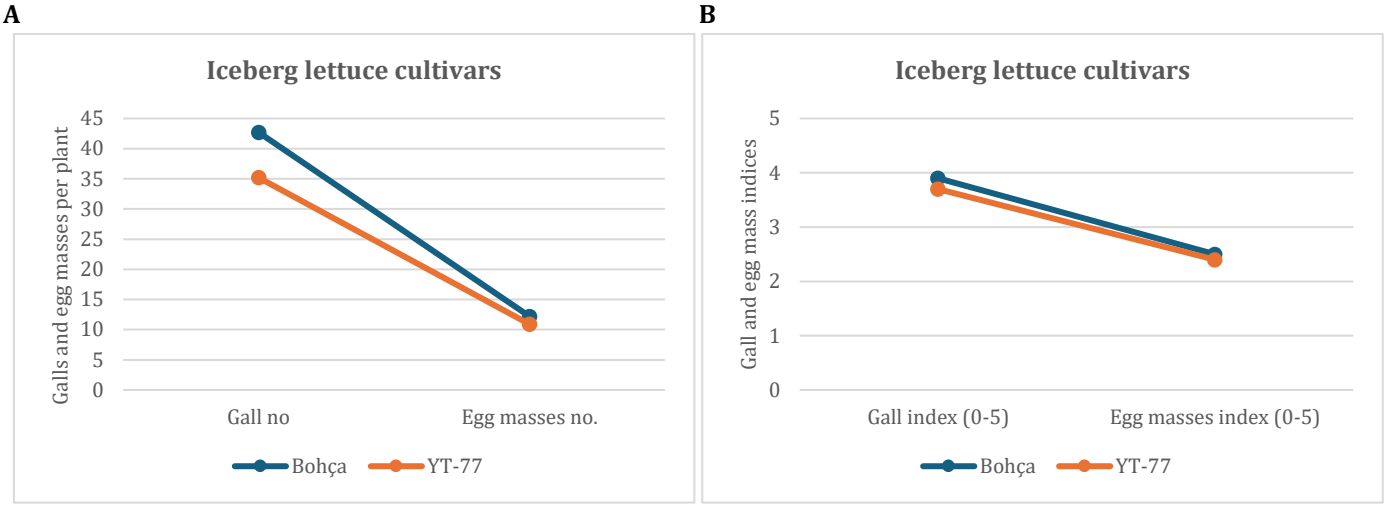


Fig. 1. The number of galls and egg masses (A) and gall and egg masses indices (B) of *Meloidogyne incognita* G7 isolate on Iceberg lettuce cultivars

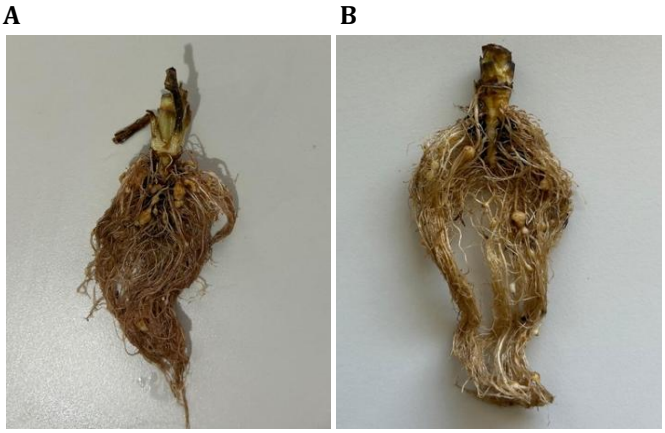


Fig. 2. The galls by *M. incognita* G7 isolate on Bohça (A) and YT-77 (B) Iceberg lettuce cultivars

Ten curly-leaf lettuce cultivars were tested with *M. incognita*. The highest number of galls was detected in Frisady (106.1), while the lowest was observed in Fiyonk (58.8). There was significant difference among these curly-leaf lettuce cultivars (P≤0.05). The highest egg masses were identified in Kiloma (50.2), while the lowest egg masses were in Elmaria (6.9) (Fig. 3, Fig. 4). Significant differences were observed between them (P≤0.05). When compared based on the gall index (GI), the highest value was recorded in Kiloma (4.7), whereas the lowest values (4) were determined in Elmaria, Yörünge, Kıvanç, Fiyonk, and Kanaryole, indicating a statistically significant variation among them (P≤0.05) (Fig. 3, Fig. 4). In terms of the egg mass index, the highest rates were found in Kiloma (3.8) and Mikaela (3.8), while the lowest was in Elmaria (1.4), showing significant statistical differences among the cultivars (P≤0.05). According to egg-mass index Elmaria was classified as resistant (Hartman and Sasser, 1985). In analysis of J2 populations from soil, the highest density occurred in Frisady (1978) and the lowest in Kiloma (1314), with significant differences between cultivars. The number of galls per gram of root was the highest in Kiloma (14.723), while the number of galls was the lowest in Kanaryole (7.404). Similarly, the number of egg masses per gram of root was the highest in Kiloma (7.307) and the lowest in Elmaria (0.98). (Table 3).

Table 3. Response of curly-leaf lettuce cultivars to *Meloidogyne incognita* G7 isolate based on nematode infection parameters

Cultivar	Galls plant^{-1}	Egg masses plant^{-1}	GI (0–5)	EMI (0–5)	J2s in pot soil	Galls root g^{-1}	Egg masses root g^{-1}	Root fresh weight (g)	RF
Elmaria	75.3 ±8.2 abc	6.9 ±2.5 e	4 ±0.14 b	1.4 ±0.3 c	1610 ±125 ab	10.7 ±1.27 abc	0.98 ±0.33 c	7.18 ±0.25 ab	1.61 ±0.12 ab
Mikaela	97.1 ±10.10 ab	49.2 ±8.49 ab	4.5 ±0.16 ab	3.8 ±0.2 a	1606 ± 93.85 ab	12.841 ±1.76 ab	6.733 ±1.58 ab	7.893 ±0.44 ab	1.606 ±0.09 ab
Frisady	106.1 ±10.17 a	42.4 ±8.52 abc	4.5 ±0.16 ab	3.6 ±0.22 a	1978 ±236.67 a	12.634 ±0.63 ab	4.739 ±0.62 abc	8.435 ±0.71 a	1.978 ±0.23 a
Kiloma	102.8 ±6.09 ab	50.2 ±5.59 a	4.7 ±0.15 a	3.8 ±0.13 a	1314 ±108.04 b	14.723 ±1.34 a	7.307 ±1.03 a	7.34 ±0.47 ab	1.314 ±0.10 b

Cultivar	Galls plant^{-1}	Egg masses plant^{-1}	GI (0–5)	EMI (0–5)	J2s in pot soil	Galls root g^{-1}	Egg masses root g^{-1}	Root fresh weight (g)	RF
Tropicana	71.7 ±7.29 bc	37.2 ±6.23 abcd	4.1 ±0.1 b	3.6 ±0.16 a	1390 ±64.17 b	10.792 ±0.68 abc	5.475 ±0.60 abc	6.668 ±0.60 ab	1.39 ±0.06 b
Yörünge	61.3 ±3.39 c	14.6 ±2.46 de	4 ±0 b	2.6 ±0.22 b	1617 ±101.17ab	8.443 ±0.61 bc	2.041 ±0.36 bc	7.37 ±0.27 ab	1.617 ±0.10 ab
Papyon	96.9 ±7.90 ab	22.6 ±4.39 cde	4.4 ±0.17 ab	3.1 ±0.27 ab	1458 ±116.52 ab	14.616 ±1.16a	3.412 ±0.67 abc	6.708 ±0.40 abc	1.458 ± 0.11ab
Kıvanç	64.1 ±3.04 c	26.7 ±2.70 bcde	4 ±0 b	3.3 ±0.15 ab	1388 ±67.01b	12.299 ±1.08abc	5.238 ±0.78 abc	5.441 ±0.33 c	1.388 ± 0.06 b
Fiyonk	58.8 ±4.39 c	24 ±3.16 cde	4 ±0 b	3.2 ±0.13 ab	1500 ±130.26 ab	10.325 ±1.3 abc	4.277 ±0.76 abc	6.223 ±0.59 abc	1.5 ±0.13 ab
Kanaryole	60 ± 4.74 c	19 ±2.56 de	4 ±0 b	2.9 ±0.1 ab	1440 ±67.19 ab	7.404 ±0.54 c	2.316 ±0.26 abc	8.128 ±0.30 ab	1.44 ±0.06 ab

The columns in the table were evaluated among themselves, and according to the Tukey's HSD test, values showing the same letter are statistically indistinguishable from each other according to P≤0.05. ± indicates the standard error. Gall index and egg masses index were evaluated according to a 0-5 scale (Hartman and Sasser, 1985). RF = Final population (Pf) / Initial population (Pi) GI: gall index; EMI: egg mass index; J2: second-stage juvenile.

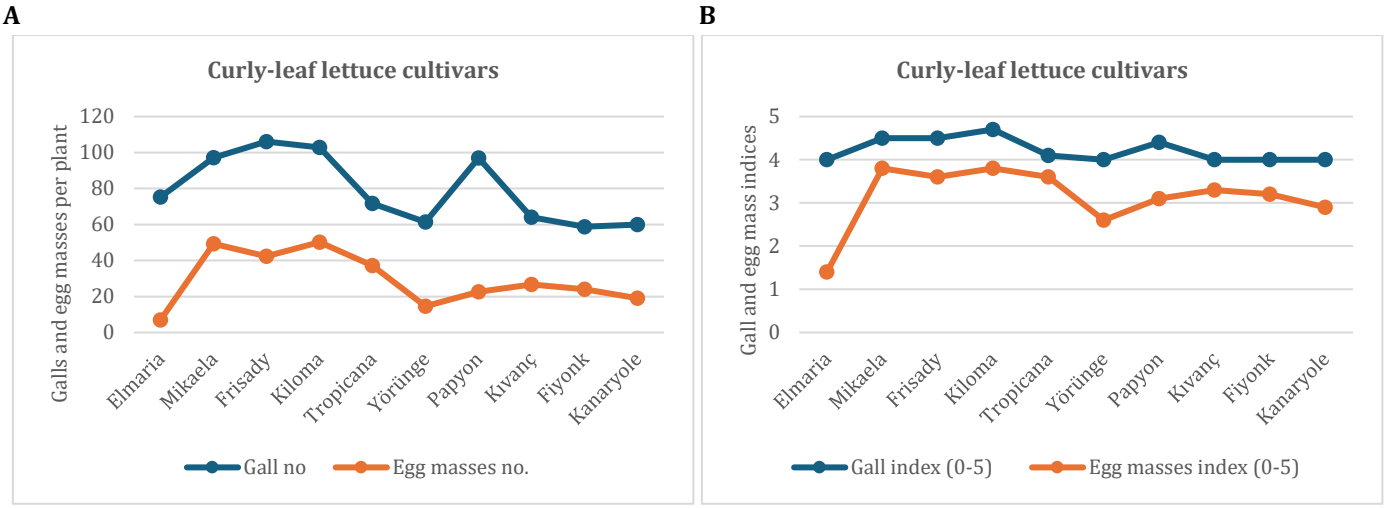


Fig. 3. The number of galls and egg masses (A) and gall and egg masses indices (B) of *Meloidogyne incognita* G7 isolate on Curly-leaf lettuce cultivars

Three Yedikule lettuce cultivars were evaluated in this study. Based on the statistical analyses, no significant differences were observed among the cultivars in terms of gall number, gall index, J2 populations in the soil and reproduction factor (P>0.05). However, regarding the number of egg masses, the highest value was recorded in the Mozole cultivar (48.1), while the lowest was found in YT-39 (28.9), and there was significant difference among them (P≤0.05) (Fig. 5, Fig. 6). In terms of the egg mass index, the highest value was observed in Mozole (4.0) and the lowest in YT-39 (3.4) and significant differences were observed among cultivars (P≤0.05) (Fig. 5, Fig. 6). Based on the number of galls per gram of root, the highest value was identified in Presidental (17.9) and the lowest in YT-39 (11.13), indicating a significant difference between them (P≤0.05). Similarly, for the number of egg masses per gram of root, the highest rate was found in Mozole (6.806), while the lowest was in YT-39 (3.515) and a significant difference was detected (P≤0.05). When evaluated for fresh root weight, the highest value was recorded in YT-39 (8.449) and the lowest in Presidential (6.034). Results showed three Yedikule cultivars classified as susceptible (Table 4).

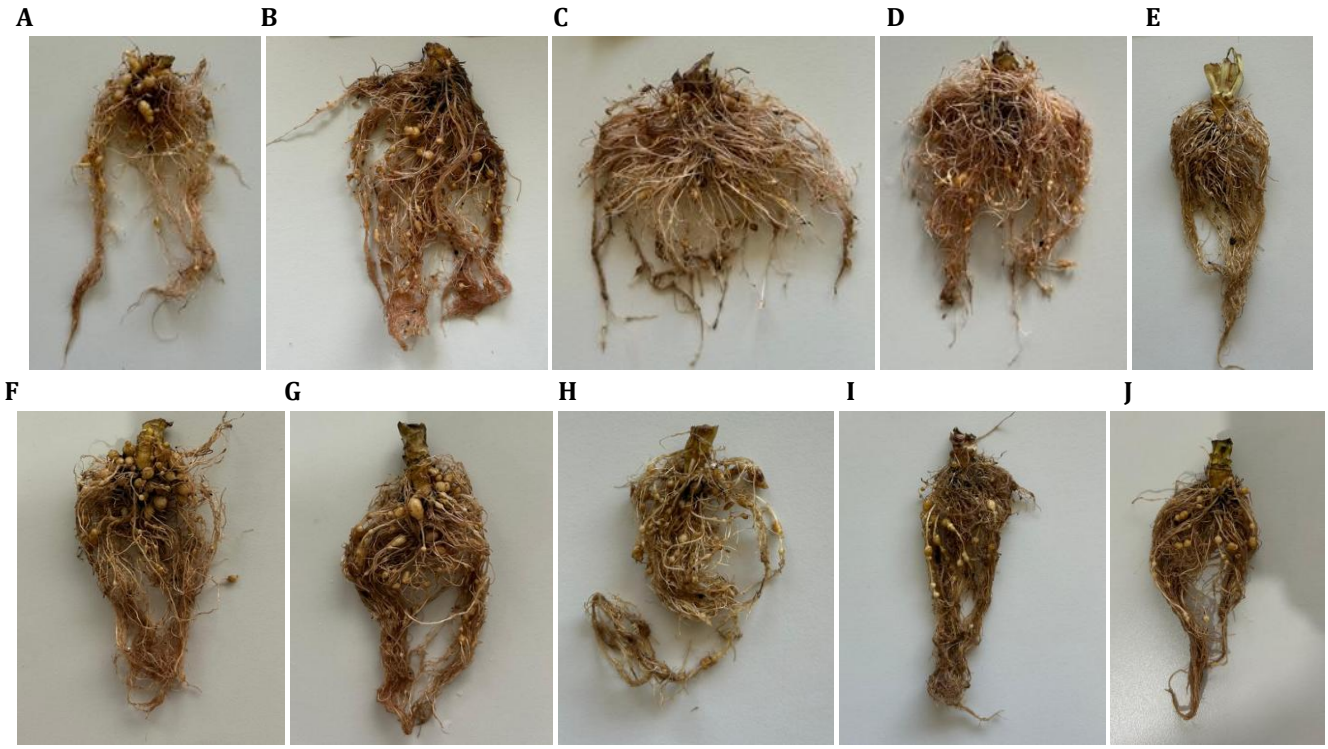


Fig. 4. The galls by *M. incognita* G7 isolate on Elmaria (A), Mikaela (B), Frisady (C), Kiloma (D), Tropicana (E), Yörünge (F), Papyon (G), Kıvanç (H), Fiyonk (I), Kanaryole (J) Curly-leaf lettuce cultivars

Table 4. Response of Yedikule lettuce cultivars to *Meloidogyne incognita* G7 isolate based on nematode infection parameters

Cultivar	Galls plant^{-1}	Egg masses plant^{-1}	GI (0–5)	EMI (0–5)	J2s in pot soil	Galls root g^{-1}	Egg masses root g^{-1}	Root fresh weight (g)	RF
YT-39	91.9 ±9.95 a	28.9 ±3 b	4.3 ±0.15 a	3.4 ±0.16 b	1886 ±61.17 a	11.132 ±1.40 b	3.515 ±0.43 b	8.449 ±0.35 a	1.886 ±0.06 a
Mozole	90.7 ±3.37 a	48.1 ±2.99 a	4.2 ±0.13 a	4 ±0 a	1898 ±67.42 a	12.86 ±0.66 b	6.806 ±0.45 a	7.17 ±0.35 ab	1.898 ±0.06 a
Presidential	108 ±3.53 a	30.9 ±2.08 b	4.7 ±0.15 a	3.6 ±0.16 ab	1712 ±41.11 a	17.9 ±1.33 a	5.475 ±0.59 a	6.034 ±0.52 b	1.712 ±0.04 a

The columns in the table were evaluated among themselves, and according to the Tukey's HSD test, values showing the same letter are statistically indistinguishable from each other according to P≤0.05. ± indicates the standard error. Gall index and egg masses index were evaluated according to a 0-5 scale (Hartman and Sasser, 1985). RF = Final population (Pf) / Initial population (Pi) GI: gall index; EMI: egg mass index; J2: second-stage juvenile.

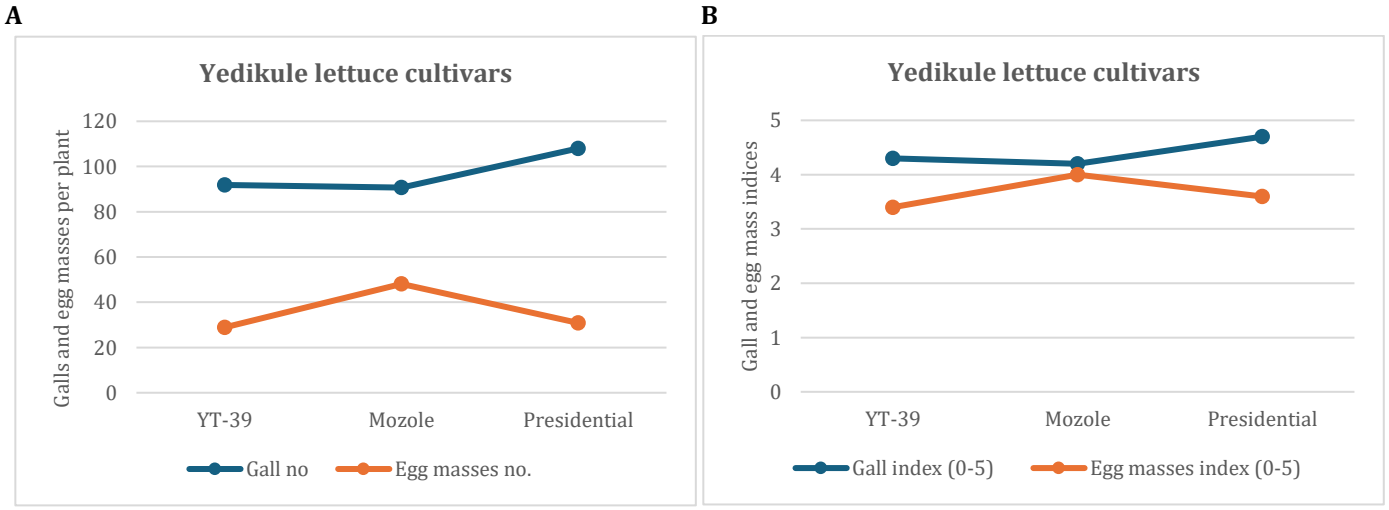


Fig. 5. The number of galls and egg masses (A) and gall and egg masses indices (B) of *Meloidogyne incognita* G7 isolate on Yedikule lettuce cultivars

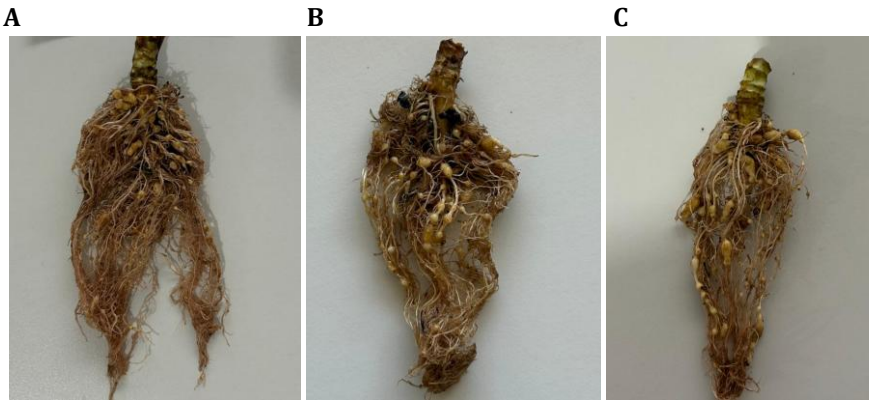


Fig. 6. The galls by *M. incognita* G7 isolate on YT-39 (A), Mozole (B) and Presidential (C) Yedikule lettuce cultivars

Three Lollo Rosso lettuce cultivars were subjected to testing with *M. incognita*. While the cultivars were found to be statistically similar in terms of the number of galls per gram of root and the number of egg masses per gram of root significant statistical differences were observed in other parameters (P≤0.05). Regarding the number of galls, the highest value was recorded in Tuska (108.9), while the lowest was in Motif (53.5) (Fig. 7, Fig. 8). Similarly, the number of egg masses is the highest in Tuska (75.5) and the lowest in Motif (33.1) and there were significant differences between cultivars (P≤0.05) (Fig. 7). In terms of the gall index, the highest value was determined in Tuska (4.6) and the lowest in Motif (4). For the egg mass index, the values ranged from a high of 4.3 in Tuska to a low of 3.6 in Motif; significant differences were found among cultivars (P≤0.05) (Fig. 7). Analysis of J2s in soil, the highest value was observed in Lea (2894), while the lowest was recorded in Motif (1598). Statistical analysis indicated that there was significant difference between Lea and Motif. Furthermore, root fresh weights were highest in Tuska (6.291) and lowest in Motif (3.964) and showing statistical significance among cultivars The reproduction value was found to be highest in the Lea cultivar (2.894) and lowest in Motif (1.598) and there was significant difference between cultivars (P≤0.05) Based on all evaluated parameters, the cultivars were classified as susceptible against *M. incognita* G7 isolate (Table 5).

Table 5. Response of Lollo Rosso lettuce cultivars to *Meloidogyne incognita* G7 isolate based on nematode infection parameters

Cultivar	Galls plant^{-1}	Egg masses plant^{-1}	GI (0–5)	EMI (0–5)	J2s in pot soil	Galls root g^{-1}	Egg masses root g^{-1}	Root fresh weight (g)	RF
Lea	89 ±11.16 ab	59.3 ±5.67 a	4.4 ±0.22 ab	4 ±0 ab	2894 ±132.50 a	17.593 ±2.14 a	11.594 ±0.92 a	5.131 ±0.31 ab	2.894 ±0.13 a
Tuska	108.9 ±13.75 a	75.5 ±10.17 a	4.6 ±0.16 a	4.3 ± 0.15 a	1995 ±143.66 b	20.089 ±3.84 a	14.223 ±3.31 a	6.291 ±0.70 a	1.995 ±0.14 b
Motif	53.5 ±3.13 b	33.1 ±2.63 b	4 ±0 b	3.6 ±0.16 b	1598 ±46.99 b	14.277 ±1.40 a	8.945 ±1.09 a	3.964 ±0.28 b	1.598 ±0.04 b

The columns in the table were evaluated among themselves, and according to the Tukey's HSD test, values showing the same letter are statistically indistinguishable from each other according to P≤0.05. ± indicates the standard error. Gall index and egg masses index were evaluated according to a 0-5 scale (Hartman and Sasser, 1985). RF = Final population (Pf) / Initial population (Pi) GI: gall index; EMI: egg mass index; J2: second-stage juvenile.

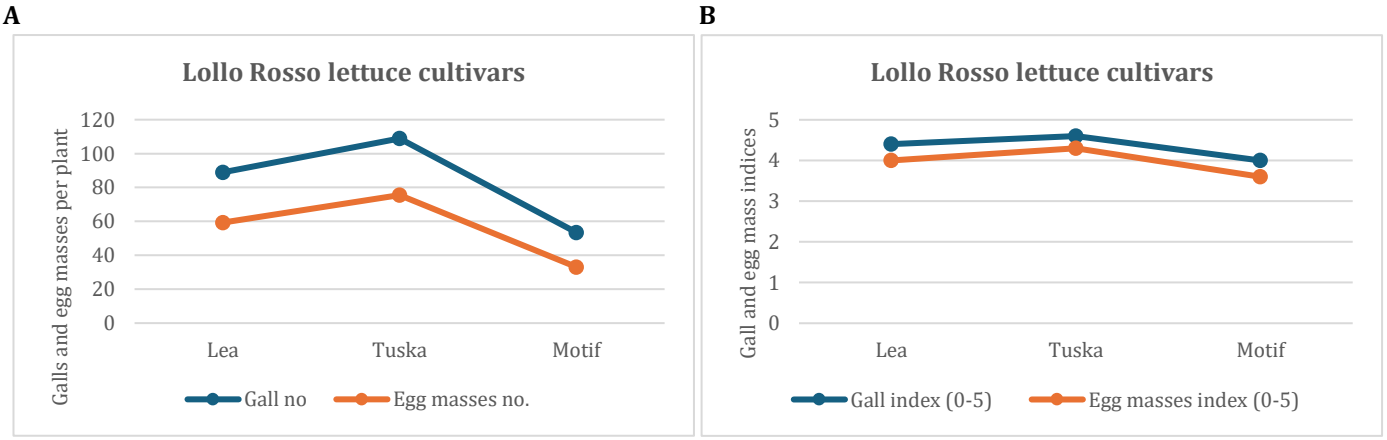


Fig. 7. The number of galls and egg masses (A) and gall and egg masses indices (B) of *Meloidogyne incognita* G7 isolate on Lollo Rosso lettuce cultivars

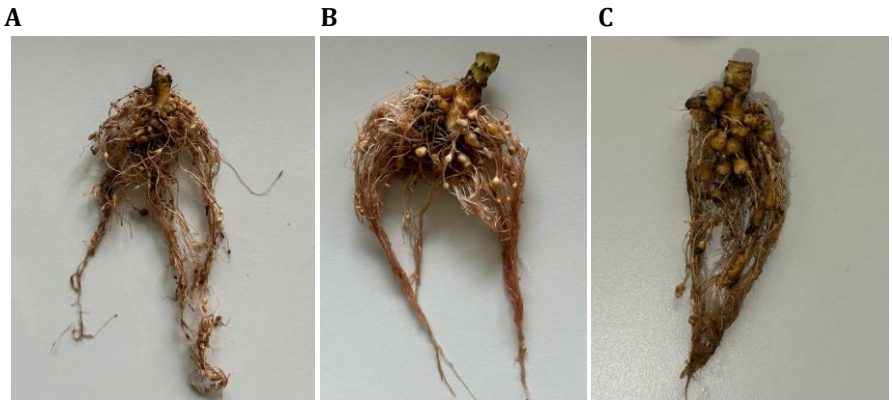


Fig. 8. The galls by *M. incognita* G7 isolate on Lea (A), Tuska (B) and Motif (C) Lollo Rosso lettuce cultivars

Discussion

Lettuce cultivation is subject to significant yield reductions worldwide due to biotic stresses. Root-knot nematodes (RKNs) are one of the most important pests causing damage to lettuce cultivars (Koleva and Mitova, 2021; Maluf et al., 2002). In many countries, lettuce is grown in rotation with other vegetables including tomato, pepper, cucumber, eggplant etc., particularly during the cold months of season (Rabello et al., 2021). Therefore, the damage caused by RKNs in lettuce cultivations have been increased, leading to significant yield losses and reduced marketable quality. Consequently, developing effective management strategies against RKNs is needed for sustainable lettuce production. Among these strategies, the development of resistant cultivars is notable and applicable solution.

The development of new lettuce cultivars requires prolonged and labour-intensive breeding process. Therefore, determining the resistance levels of commercial lettuce cultivars to RKNs is a crucial approach for sustainable agriculture. In the present study, the responses of different lettuce cultivars grown in Türkiye were investigated against *M. incognita*. Therefore, ten curly, two iceberg, three Yedikule/Romaine, and three Lollo Rosso commercial cultivars were screened to determine whether they are resistant or no against *M. incognita*, focusing on parameters including the number of egg masses and galls, galling indices, and the reproduction rates of J2s. Based on these phenotypic evaluations, all tested cultivars were classified as susceptible to the G7 isolate of *M. incognita* under the conditions of this study. Although all lettuce cultivars were classified as susceptible based on reproduction factor (RF > 1), considerable variation was observed among cultivars in terms of egg mass production and nematode reproduction. For instance, Elmaria supported markedly fewer egg masses compared to Kiloma, while Motif showed substantially lower reproduction than Tuska. In addition, Elmaria exhibited low egg mass production and was classified as resistant according to the egg-mass index; however, because its reproduction factor exceeded 1, it was not considered resistant overall. These within-group differences suggest that even among susceptible cultivars, host suitability varies significantly, which may have practical implications for nematode population build-up under field conditions. Such variation could be important for integrated management strategies, where selecting less suitable hosts may help reduce long-term nematode pressure. Maluf et al. (2002) evaluated the curly lettuce cultivar 'Grand Rapids' and the butterhead type 'Regina-71' against *M. javanica* as resistant and susceptible, respectively. On the other hand, the susceptible response of the lettuce cultivar Lollo Rosso observed in our study is in agreement with the findings of Pedroche et al. (2007), who reported the cultivar Lollo Rosa as exhibiting an intermediate/susceptible reaction to *Meloidogyne incognita*. This similarity suggests that red loose-leaf lettuce cultivars of the Lollo type may generally exhibit limited resistance to *M. incognita*. Similarly, Diniz et al. (2018) assessed eight green leaf lettuce lines in Brazil against RKN species (*M. enterolobii*, *M. incognita*, and *M. javanica*). The plants were categorized as susceptible based on the reproduction factor (RF), while they exhibited moderate resistance according to gall and egg mass indices. These findings emphasize that the determination of resistance or susceptibility is highly dependent on the parameters utilized; specifically, egg mass and gall indices are often considered more definitive indicators of resistance levels. In another study, screening of lettuce germplasm identified the *L. sativa* accessions PI 508476 and PI 419140 as consistently resistant to root-knot nematodes (Kaur, 2009). Additionally, wild *Lactuca* accessions belonging to *L. saligna* and *L. virosa* were also reported as resistant. These cultivated and wild genetic resources are valuable for breeding programs aimed at improving resistance to RKNs. The use of resistant lettuce cultivars is an important strategy for RKN management in lettuce production. Our results were compared with those reported by Sousa et al. (2019), who evaluated total 49 crisphead lettuce cv. responses to root-knot nematodes. Although both studies identified susceptibility in several lettuce cultivars, differences in nematode reproduction and host reaction may be associated with cultivar characteristics, environmental conditions, and variability among nematode populations. Vidal et al. (2019), evaluated lettuce cultivars revealed that all genotypes were susceptible to *M. incognita*, whereas seven cultivars (Argelès, Kibrille, Balesta, Colorado, Design, Bartoli, and NunDm15) showed resistance to *M. javanica*. In our study, all tested lettuce cultivars were likewise found to be susceptible to *M. incognita*, confirming the limited availability of effective resistance against this nematode species in lettuce germplasm. Giné et al. (2024) investigated the reactions of commercially available lettuce cultivars in Spain namely Regina 71 (susceptible), Salinas 88, and Grand Rapids against *Meloidogyne incognita* and *M. javanica*. Results showed that Salinas 88 and Grand Rapids displayed significantly lower rates of galls and egg masses compared to the susceptible control and were classified as resistant. The discrepancy between our findings and those reported by Giné et al. (2024) may be attributed to differences in virulence among *M. incognita* isolates. In the present study, evaluations were conducted using a single isolate (G7), whereas nematode

populations from different geographical origins may vary in their pathogenicity and ability to overcome host resistance. Therefore, the susceptibility responses observed should be interpreted as being specific to the G7 isolate rather than representative of all *M. incognita* populations. Further studies involving multiple isolates and populations are needed to better characterize the resistance responses of lettuce germplasm. From a practical perspective, the present findings suggest that lettuce production systems remain highly vulnerable to *M. incognita*, particularly in protected cultivation systems where nematode pressure can accumulate over time. In Turkish vegetable production systems, where intensive greenhouse cultivation and short rotation cycles are common, this may have important implications for crop rotation strategies, especially in lettuce–tomato or lettuce–pepper production sequences. Therefore, even cultivars exhibiting relatively lower nematode reproduction should be considered in the context of integrated nematode management rather than as sources of resistance.

Materials and methods

Plant materials and nematode isolate

Lettuce cultivars used in this study are listed in Table 1. Plant testing was carried out using the *Meloidogyne incognita* G7 isolate described by Devran and Söğüt (2009). The isolate has been maintained as a pure culture in Devran's laboratory since 2008. The *M. incognita* G7 isolate was re-confirmed using the species-specific primer pairs IncK14F/IncK14R and MincF/MincR following the protocols of Randig et al. (2002) and Devran et al. (2018).

Table 1. Lettuce cultivars used in this study

Lettuce Type	Cultivar	Company
Curly-leaf (green leaf)	Kiloma	AG Seed
	Mikaela	AG Seed
	Elmaria	AG Seed
	Frisady	AG Seed
	Tropicana	AG Seed
	Kanaryole	Syngenta
	Kıvanç	Yuksel Seeds
	Papyon	Yuksel Seeds
	Yörünge	Yuksel Seeds
	Fiyonk	Yuksel Seeds
Yedikule (Romaine)	Presidential	Syngenta
	YT-39	Yuksel Seeds
	Mozole	Yuksel Seeds
Lollo Rosso (red leaf)	Lea	AG Seed
	Tuska	AG Seed
	Motif	Yuksel Seeds
Iceberg	YT-77	Yuksel Seeds
	Bohça	Yuksel Seeds

Nematode inoculum

Meloidogyne incognita G7 isolate was multiplied on the susceptible pepper cv. Safran F1. Egg masses on the pepper roots were collected under a stereomicroscope and transferred to a sieve for the hatching. The egg masses were incubated at 27± 2 °C to obtain second-stage juveniles (J2s). Following incubation, the J2s were counted under the microscope at 10× magnification and prepared in a suspension at an inoculation density of 1000 J2s per plant. Freshly collected J2s were maintained at +4 °C and used for plant inoculation within 48 h.

Testing plants with Meloidogyne incognita

Lettuce seedlings with 5 cm were transplanted into 400 mL plastic pots filled with sterilized sandy soil. 10 days after transplantation, each plant was inoculated with infective 1000 J2s which were introduced into 2–3 cm deep holes near the stems (Devran et al., 2016). An inoculation density of 1000 J2s per plant was selected because it is commonly used in controlled host-suitability and resistance-screening studies involving lettuce (Vidal et al., 2019) and other vegetable crops

(Devran et al., 2016; Öçal et al., 2018; Sargın and Devran, 2021). The pots were kept in a growth chamber under controlled conditions including at 24±1 °C, 60±5% humidity, and 16:8 h (light:dark) photoperiod. Each treatment was arranged in a completely randomized design with five replicates, and the experiment was conducted twice, resulting in a total of ten replicates (n = 10).

Evaluation

Forty-eight days post-inoculations, the plants were removed from the pots. The roots were carefully washed under tap water and recorded. Then roots were weighed and recorded. The roots of the plants were stained with Phloxine B (Merck) (0.15 g/L) to the visibility of egg masses (Daykin and Hussey, 1985). The roots were evaluated using root parameters (fresh root weight, the number of gall and egg masses, the number of galls and egg masses per gram of root) and assessed according to the gall and egg masses indices described by Hartman and Sasser (1985). According to the rating scale of Hartman and Sasser (1985), gall index (GI) and egg mass index (EMI) values were assessed on a 0–5 scale, where 0 = no galls or egg masses, 1 = 1–2, 2 = 3–10, 3 = 11–30, 4 = 31–100, and 5 = more than 100 galls or egg masses per root system. Based on these ratings, plants with GI or EMI values ≤ 2 were considered resistant, whereas those with values > 2 were considered susceptible. Nematodes from the soil were extracted using the modified Baermann Funnel technique (Hooper, 1986). Additionally, the reproduction factor (RF) was calculated using the final population of second-stage juveniles (J2) recovered from soil relative to the initial inoculum density (Pi = 1000 J2 per plant) (Oostenbrink, 1966). The final host status classification was based on the reproduction factor (RF), where RF > 1 indicated susceptibility and RF ≤ 1 indicated resistance.

Data analysis

Data were analyzed using analysis of variance (ANOVA) based on a completely randomized design. The experimental unit was an individual pot containing a single plant. Response variables included the number of galls, egg masses, and second-stage juveniles (J2s) in the soil, as well as gall and egg mass indices and the reproduction factor (RF). Prior to analysis, data were checked for normality and homogeneity of variance assumptions. For cultivar groups containing three or more cultivars, mean comparisons were performed using Tukey's Honestly Significant Difference (HSD) test at $P \leq 0.05$. Since the iceberg group consisted of only two cultivars, comparisons were performed using Student's t-test. All statistical analyses were conducted using SAS software (version 9.00).

Conclusion

In conclusion, the deployment of resistant lettuce cultivars is a primary management approach to RKNs. However, there are limited resistant commercial lettuce cultivars in the world. Therefore, it is imperative to evaluate the resistance profiles of new genotypes against common RKN species prior to commercial release. Identifying resistant or tolerant cultivars and integrating them into agricultural practices is essential for sustainable nematode management. In our study, all tested cultivars were classified as susceptible to the G7 isolate of *M. incognita* based on these phenotypic evaluations under the pot experiment conditions. Although all lettuce cultivars were classified as susceptible, considerable variation was observed among cultivars in terms of the number of galls, egg mass production, and nematode reproduction. In particular, lower gall numbers were recorded in iceberg cultivars (Bohça and YT-77), while reduced egg mass production was observed in iceberg cultivars, and some curly-leaf cultivars (Elmaria and Yörünge). Therefore, the relatively lower galling and nematode reproduction observed in the iceberg cultivars suggest that these genotypes may be considered as potential candidates for further evaluation under field conditions to assess their performance in more complex agro-ecosystems.

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Author contributions

MOK carried out experimental procedures and collected data, GU carried out statistical analyses, helped plant testing and wrote and edited the manuscript, ZD conceived and designed the study and wrote and edited the manuscript. Authors read and approved the final manuscript.

Conflict of interest

The authors declare no conflict of interest and that the research complies with ethical standards. This research does not involve any human participants and/or animals.

References

Akyazı F, Ecevit O (2011) Identification and distribution of root-knot nematode species (*Meloidogyne* spp.) in vegetable fields in Tokat province. Anadolu J Agric Sci. 26(1):1–9. https://doi.org/10.7161/ANAJAS.2011.26.1.1-9

Aslan A, Elekçioğlu İH (2022) Biochemical and molecular identification of root-knot nematodes in greenhouse vegetable areas of Eastern Mediterranean Region (Turkey). Turk J Entomol. 46(1):115–127. https://doi.org/10.16970/entoted.1055181

Charchar JM (1995) *Meloidogyne* em hortaliças. In: Congresso Internacional de Nematologia Tropical; XIX Congresso da Sociedade Brasileira de Nematologia; XXVII Encontro Anual da Organização dos Nematologistas da América Tropical, Rio Quente. Programa e anais. SBN/ONTA, Rio Quente, p. 149–153.

Daykin ME, Hussey RS (1985) Staining and histopathological techniques in nematology. In: Barker KR, Carter CC, Sasser JN (eds) An advanced treatise on *Meloidogyne*, vol. II: Methodology. North Carolina State University Graphics, Raleigh, NC, p. 39–48.

Devran Z, Söğüt MA (2009) Distribution and identification of root-knot nematodes from Turkey. J Nematol. 41(2):128–133. https://pmc.ncbi.nlm.nih.gov/articles/PMC3365313/
Devran Z, Mıstanoğlu İ, Özalp T (2016) Response of tomato seedlings with different number of true leaves to *Meloidogyne incognita* (Kofoid & White, 1919) Chitwood, 1949. Turk J Entomol. 40(4):377–383. https://dergipark.org.tr/en/pub/entoted/article/287082 *
Devran Z, Mıstanoğlu İ, Özalp T (2017) Occurrence of mixed populations of root-knot nematodes in vegetable greenhouses in Turkey, as determined by PCR screening. J Plant Dis Prot. 124(6):617–630. https://doi.org/10.1007/s41348-017-0113-9
Devran Z, Polat İ, Mıstanoğlu İ, Baysal Ö (2018) A novel multiplex PCR tool for simultaneous detection of three root-knot nematodes. Australas Plant Pathol. 47(4):389–392. https://doi.org/10.1007/s13313-018-0570-z
Dias-Arieira CR, Cunha TPL, Chiamolera FM, Puerari HH, Biela F, Santana SM (2012) Reaction of vegetables and aromatic plants to *Meloidogyne javanica* and *M. incognita*. Hortic Bras. 30(2):322–326. https://doi.org/10.1590/S0102-05362012000200023
Dias-Arieira CR, Mattei D, Puerari HH, Ribeiro RCF (2015) Use of organic amendments in the management of root-knot nematode in lettuce. Hortic Bras. 33(4):488–492. https://doi.org/10.1590/S0102-053620150000400013
Diniz GMM, Candido WS, Rabelo HO, Marín MV, Braz LT, Soares PLM (2018) Reaction of green leaf lettuce genotypes to three species of root-knot nematodes according to two evaluation methods. Nematropica. 48(1):1–4. https://hdl.handle.net/11449/228600
Fiorini CVA, Gomes LAA, Libânio RA, Maluf WR, Campos VP, Licursi V, Moretto P, de Souza LA, Fiorini IVA (2007) Identificação de famílias F2:3 de alface homozigotas resistentes aos nematóides das galhas. Hortic Bras. 25(4):509–513. https://doi.org/10.1590/S0102-05362007000400004
Giné A, Sanz-Prieto A, Gomes LAA, Expósito A, Escudero N, Sorribas FJ (2024) Host suitability of lettuce and bean germplasm for *Meloidogyne incognita* and *M. javanica* isolates from Spain. Plants. 13(1):38. https://doi.org/10.3390/plants13010038
Hartman KM, Sasser JN (1985) Identification of *Meloidogyne* species on the basis of differential host test and perineal-pattern morphology. In: Barker KR, Carter CC, Sasser JN (eds) An advanced treatise on *Meloidogyne*, vol. II: Methodology. North Carolina State University Graphics, Raleigh, NC, p. 69–77.
Hooper DJ (1986) Extraction of free-living stages from soil. In: Southey JF (ed) Laboratory methods for work with plant and soil nematodes, 6th edn. Her Majesty's Stationery Office, London, p. 5–30.
Jones JT, Haegeman A, Danchin EGJ, Gaur HS, Helder J, Jones MGK, Kikuchi T, Manzanilla-López R, Palomares-Rius JE, Wesemael WML, Perry RN (2013) Top 10 plant-parasitic nematodes in molecular plant pathology. Mol Plant Pathol. 14(9):946–961. https://doi.org/10.1111/mpp.12057
Kaur P (2009) Resistance to northern root-knot nematode (*Meloidogyne hapla* Chitwood) in lettuce (*Lactuca sativa* L.). PhD thesis, University of Rhode Island. https://doi.org/10.23860/diss-2307
Koleva L, Mitova I (2021) Effect of mixed crops on soil plant parasitic nematodes in lettuce cultivation (*Lactuca sativa* L.). Indian J Agric Res. 55(6):756–760. https://doi.org/10.18805/IJARe.A-622
Kwon G, Seo J, Park S, Kang H, Park N, Cho I (2020) Searching for rotationable vegetables for *Paratylenchus projectus* in lettuce greenhouse. Res Plant Dis. 26(4):272–278. https://doi.org/10.5423/RPD.2020.26.4.272
López-Gómez M, Talavera M, Verdejo-Lucas S (2016) Differential reproduction of *Meloidogyne incognita* and *M. javanica* in watermelon cultivars and cucurbit rootstocks. Plant Pathol. 65(1):145–153. https://doi.org/10.1111/ppa.12394
Maluf WR, Azevedo SM, Gomes LAA, de Oliveira ACB (2002) Inheritance of resistance to the root-knot nematode *Meloidogyne javanica* in lettuce. Genet Mol Res. 1(1):64–71. https://doi.org/10.4238/vol1-1gmr006
Nicol JM, Turner SJ, Coyne DL, den Nijs L, Hockland S, Maafi ZT (2011) Current nematode threats to world agriculture. In: Jones J, Gheysen G, Fenoll C (eds) Genomics and molecular genetics of plant-nematode interactions. Springer, Dordrecht, p. 21–43. https://doi.org/10.1007/978-94-007-0434-3_2
Öçal S, Özalp T, Devran Z (2018) Reaction of wild eggplant *Solanum torvum* to different species of root-knot nematodes from Turkey. J Plant Dis Prot. 125(6):577–580. https://doi.org/10.1007/s41348-018-0167-3
Oostenbrink M (1966) Major characteristics of the relation between nematodes and plants. Meded Landbouwhogesch Wageningen. 66(4):1–46. https://edepot.wur.nl/284956
Pedroche NB, Villanueva LM, De Waele D (2007) Response of five lettuce cultivars to root-knot nematode, *Meloidogyne incognita*. Commun Agric Appl Biol Sci. 72(3):659–666. https://pubmed.ncbi.nlm.nih.gov/18399501/
Rabello LKC, Gonçalves ÂO, da Cruz TP, Zinger FD, de Jesus Júnior WC, Rodrigues LL, de Souza AF, Moraes WB, Alves FR (2021) Quantification of damage and yield losses caused by root-knot nematode in lettuce in Brazil. Idesia. 39(2):121–130. https://doi.org/10.4067/S0718-34292021000200121
Randig O, Bongiovanni M, Carneiro RMDG, Castagnone-Sereno P (2002) Genetic diversity of root-knot nematodes from Brazil and development of SCAR markers specific for the coffee-damaging species. Genome. 45(5):862–870. https://doi.org/10.1139/g02-054
Sargın S, Devran Z (2021) Degree of resistance of *Solanum torvum* cultivars to Mi-1.2-virulent and avirulent isolates of *Meloidogyne incognita*, *Meloidogyne javanica*, and *Meloidogyne luci*. J Nematol. 53:1–7. https://doi.org/10.21307/jofnem-2021-068
Sgorlon LFF, Silva EHC, Soares RS, Borges HO, Diniz GMM, Braz LT, Soares PLM (2018) Host status of crispy-leaf lettuce cultivars to root-knot nematodes. Biosci J. 34(5):1319–1325. https://doi.org/10.14393/BJ-v34n5a2018-39387
Sousa LA, Jacinto ACP, Silveira AJ, Castoldi R, Maciel GM, Beloti IF (2019) Agronomic potential of biofortified crisphead lettuce (*Lactuca sativa*) and its reaction to root-knot nematodes. Aust J Crop Sci. 13(5):773–779. https://doi.org/10.21475/ajcs.19.13.05.p1565
Trudgill DL, Blok VC (2001) Apomictic, polyphagous root-knot nematodes: exceptionally successful and damaging biotrophic root pathogens. Annu Rev Phytopathol. 39:53–77. https://doi.org/10.1146/annurev.phyto.39.1.53
TUIK (Turkish Statistical Institute) (2024) Vegetable production quantities. https://data.tuik.gov.tr/Search/Search?text=sebze
Uysal G, Söğüt MA, Elekçioğlu İH (2017) Identification and distribution of root-knot nematode species (*Meloidogyne* spp.) in vegetable growing areas of Lakes Region in Turkey. Turk J Entomol. 41(1):105–122. https://doi.org/10.16970/ted.91225
Uzunoğulları N, Hantaş C, Dura O, Tunalı N, Hephızlı Göksel P, Polat Z, Sönmez İ (2022) Determination of the diseases and pests in leafy vegetables in Marmara Region. Bahçe. 51(1):45–54. https://doi.org/10.53471/bahce.1038755
Vidal RL, Soares RS, Kobayashi BF, Franco CA, Marin MV, Soares PLM, Maldonado-Junior W, Braz LT (2019) Resistance of lettuce downy mildew's differential cultivars to root-knot nematodes. Chil J Agric Res. 79(2):174–180. https://doi.org/10.4067/S0718-58392019000200174
Wille CN, Gomes CB, Minotto E, Nascimento JS (2019) Potential of aqueous extracts of basidiomycetes to control root-knot nematodes on lettuce. Hortic Bras. 37(1):54–59. https://doi.org/10.1590/S0102-053620190108
Yılmaz A, Çakmak T, Gözel U (2024) First record of *Meloidogyne javanica* (Treub, 1885) (Chitwood, 1949) on lettuce (*Lactuca sativa* L.) growing areas in the Southern Marmara Region. KSU J Agric Nat. 27(5):1055–1060. https://doi.org/10.18016/ksutarimdoga.vi.1334097