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Original article (Orijinal araştırma)

Resistance of some Turkish garlic genotypes and landraces against stem and bulb nematode, *Ditylenchus dipsaci* (Kühn, 1857) Filipjev, 1936 (Rhabditida: Anguinidae)[1]

Bazı yerel sarımsak genotip ve köy çeşitlerinin soğan sak nematoduna, *Ditylenchus dipsaci* (Kühn, 1857) Filipjev, 1936 (Rhabditida: Anguinidae) karşı dayanıklılıklarının belirlenmesi

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Abstract

Ditylenchus dipsaci (Kühn, 1857) Filipjev, 1936 (Rhabditida: Anguinidae) is one of the destructive agents of garlic and reduces yield and market value. One of the most practical and eco-friendly methods for nematode management is using resistant varieties. In the study, two endemic garlic species, *Allium tuncelianum* (Kolman) Ozhatay, Mathew & Siraneci and *Allium macrochaetum* subsp. *macrochaetum* Boiss. & Hausskn. (Alliaceae: Amaryllidaceae), 10 mutant and 32 landraces garlic genotypes, *Allium sativum* L. (Alliaceae: Amaryllidaceae) were investigated for their resistance reactions to *D. dipsaci* and effect of *D. dipsaci* on some plant growth parameters. All experiments were conducted at Atatürk Horticultural Central Research Institute in 2019-2020. None of the genotypes was found resistant to *D. dipsaci,* and reproduction factors, which ranged from 2.6 to 12.7, were grouped from susceptible to highly susceptible. The Tunceli garlic genotype had the lowest reproduction factor (2.6), 36.6% less than the highly susceptible Muğla6 genotype. Alata1, Muğla1, Muğla7 and Kula genotypes had the lowest decrease rate with nematode treatment at least in one of the plant growth parameters. The genotypes that had lower nematode multiplication and displayed better development under nematode infestation in this study are recommended for the field infested with *D. dipsaci* as sources for garlic breeding.

Keywords: Endemic garlic species, garlic landraces, garlic mutant clones, plant parasitic nematode

Öz

Ditylenchus dipsaci (Kühn, 1857) Filipjev, 1936 (Rhabditida: Anguinidae) sarımsakta zarar yapan en önemli etmenlerden biri olup verimi ve pazar değerini düşürmektedir. Nematod mücadelesinde en pratik ve çevre dostu yöntemlerden biri dayanıklı çeşitlerin kullanılmasıdır. Bu çalışmada iki endemik sarımsak türü, *Allium tuncelianum* (Kolman) Özhatay, Matthew & Siraneci ve *Allium macrochaetum* subsp. *macrochaetum* Boiss. & Hausskn. (Alliaceae: Amaryllidaceae), 10 mutant ve 32 yerel sarımsak, *Allium sativum* L. (Alliaceae: Amaryllidaceae), genotipinin *D. dipsaci*'ye karşı dayanıklılık durumları ve *D. dipsaci*'nin bazı bitki büyüme parametreleri üzerine etkisi belirlenmiştir. Tüm denemeler 2019-2020 yıllarında Atatürk Bahçe Kültürleri Merkez Araştırma Enstitüsü'nde yürütülmüştür. Genotiplerin hiçbiri *D. dipsaci*'ye dayanıklı bulunmamış ve üreme faktörleri 2.6 ile 12.7 arasında değişerek duyarlıdan çok duyarlıya doğru gruplanmıştır. En düşük üreme faktörü (2.6), yüksek hassas Muğla6 genotipinden %36.6 daha az olarak Tunceli sarımsak genotipinde belirlenmiştir. Alata1, Muğla1, Muğla7 ve Kula yerel genotiplerinde soğan sak nematodu uygulaması sonucunda bitki büyüme parametrelerinin en az birinde en düşük etki belirlenmiştir. Bu çalışmada nematodun üreme faktörünün düşük tespit edildiği ve nematod zararı altında daha iyi gelişme gösteren genotipler, *D. dipsaci* ile bulaşık alanlar için sarımsak ıslah materyali olarak önerilmektedir.

Anahtar sözcükler: Yerel sarımsak genotipleri, endemik sarımsak türleri, mutant sarımsak klonları, bitki paraziti nematodlar

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Introduction

Garlic, *Allium sativum* L. (Alliaceae: Amaryllidaceae) has an important role in human nutrition and has high economic value as a medicinal and aromatic plant species. Most of the garlic production in the world is undertaken in China, which accounts for 78% of the world's garlic production. Although Türkiye's garlic yield is far below the world average, it is the 10th garlic producer in the world. The average yield of garlic in the world is 1.719 kg/da while Türkiye's average yield remained at 925 kg/da in 2020 (FAO, 2020).

Genetic and environmental influences such as garlic varieties, climate and soil conditions, as well as diseases and pests are the most important factors affecting garlic yield. One of the most important pests of garlic is the stem and bulb nematode, *Ditylenchus dipsaci* (Kühn, 1857) Filipjev, 1936 (Rhabditida: Anguinidae). *Ditylenchus dipsaci* has been detected in garlic-growing areas in 80 different countries in all the continents except Antarctica to date (EPPO, 2022). *Ditylenchus dipsaci* was found in the garlic growing areas of Tekirdağ and Kırklareli provinces in the Marmara Region; Kastamonu, Tokat and Amasya provinces in the Black Sea Region; Kahramanmaraş province in the Mediterranean Region; Balıkesir and Bursa provinces in the Aegean Region; Gaziantep, Hatay and Adıyaman provinces in the Southeastern Anatolia Region; Aksaray province in the Central Anatolia Region in Türkiye (Ates Sonmezoglu et al., 2020; Öcal, 2021).

Ditylenchus dipsaci feeds endo parasitically and degrades the middle lamella between plant cells in the bulbs and leaves of garlic (Duncan & Moens, 2006). As a result of the damage, garlic plants show stunting and chlorosis in the above-ground part, underdevelopment and discoloration and splitting of bulbs, basal plate damage and reduction in roots (Mollov et al., 2012; Testen et al., 2014). Even though the initial population density is low, a fast population increase of *D. dipsaci* can result in significant crop damage. It has been determined that it causes yield losses of up to 64.5% on the garlic plant in Türkiye (Mennan, 2001; Yavuzaslanoğlu et al., 2015).

Three years of rotation with non-host crops is the primary way of controlling *D. dipsaci*, but this method usually unsuccessful due to the morphologically indistinguishable host races with different host preferences (Marek et al., 2005; Dikici et al., 2014). The use of fumigants and nematicides is uneconomical to control *D. dipsaci* in most crops, except in some scenarios in nurseries where the planting material is grown (Duncan & Moens, 2006). However, the presence and use of resistant garlic varieties are an effective, practical, and eco-friendly method of control to keep nematode populations below the economic damage threshold.

So far, some varieties of clover, rye, bean, oat and onion that show resistance to different races of the stem and bulb nematode have been identified (Plowright et al., 2002; Yavuzaslanoğlu, 2019; Yavuzaslanoğlu & Ozsoy, 2020). However, no study has been reported about resistance in garlic to stem and bulb nematode.

Objectives of this study are to investigate: (1) the reactions of 44 garlic genotypes, which include two endemic garlic species, local populations and clones developed by mutation breeding method, to the garlic population of stem and bulb nematode, and (2) the effect of stem and bulb nematode on some growth parameters of the genotypes.

Materials and Methods

Garlic genotypes

In the experiment, two endemic garlic species, *Allium tuncelianum* (Kolman) Özhatay, Matthew, Siranecı, and *Allium macrochaetum* subsp. *macrochaetum* (Alliaceae: Amaryllidaceae), which were collected from nature and cultured, 10 mutant clones, and 32 landraces of garlic (*A. sativum*) (Table 1) were used for investigation of their resistance reactions to *D. dipsaci* and the effect of *D. dipsaci* on some plant growth parameters. Garlic genotypes used in the experiment were obtained the garlic breeding program of Atatürk Horticultural Central Research Institute (Yalova, Türkiye).

Nematode inoculums

KAS-9 population of *D. dipsaci* which was isolated from a garlic field in Kastamonu Province, Taşköprü District, Vakıfbelören Village (N: 41°30'07.37", E: 34°15'01.19", Elevation: 650 m) in Türkiye, and identified by morphological and molecular methods (Ates Sonmezoglu et al., 2020), was used in the study. KAS-9 population was multiplied on sterile carrot discs to obtain nematode inoculums. Nematodes were extracted from two months old carrot cultures by washing them with tap water. Nematode concentration was adjusted to 200 nematodes/10 µl in carboximetilcelilose solution (1% w/v) for inoculation to garlic plants (Kühnhold et al., 2006).

Experimental setup

All experiments were conducted at Atatürk Horticultural Central Research Institute in 2019-2020. The experiment was performed in a growth chamber at 23±2ºC with a 16:8 hour light: dark cycle. The garlic seeds belonging to 44 garlic genotypes were sown in 760 ml pots (12.5x20x12.5 cm) which were filled with an autoclaved (Smith & Onions, 1994) soil mixture (70% sand, 29% soil, 1% farm manure). One seed of each plant species was planted per pot. Four weeks after germination in all pots, plants which were in the 3-4 leaf stage were inoculated with a 10 µl 1% CMC (carboxymethyl cellulose) solution containing 200 nematodes (Pi) applied directly between the first two leaves (Kühnhold et al., 2006). Plants used as negative control were inoculated with only 10 µl of 1% CMC (carboxymethyl cellulose) solution. Each pot served as a replicate, and the studies used a completely randomized plot design with four replications separately for inoculated and non-inoculated treatments.

Determination of resistance reactions of garlic genotypes to *Ditylenchus dipsaci*

Six weeks after inoculation, nematodes were extracted from all garlic plants for each pot with Oostenbrink dish (Hallman & Viaene, 2013). After 24 h at room temperature, the extracted nematodes were counted under stereo microscope. The nematode reproduction factor (RF) was calculated as nematodes per plant (Pf) divided by initial inoculum density (Pi= 200). Resistance reactions (RR) of genotypes were designated according to their RF values. Genotypes were classified as resistant (R) (RF < 1), moderately susceptible (MS) (1 ≤ RF < 2), susceptible (S) (2 ≤ RF < 4), and highly susceptible (HS) (4 ≤ RF) (Hajihasani et al., 2016). Since there is no resistant and susceptible garlic genotype previously determined to the stem and bulb nematode, relative susceptibility (RS) of the genotypes was calculated according to the Muğla6 genotype, which is the HS to *D. dipsaci* in this study with a 4.1 reproduction factor. The number of nematodes on each genotype divided by the number of nematodes on Muğla6 was given a percentage to express the RS value (Mwaura et al., 2015).

Determination of the effect of *Ditylenchus dipsaci* on plant growth parameters of garlic genotypes

Several plant growth parameters were investigated for the determination of nematode damage on garlic genotypes, including whole plant length (cm), garlic head length (mm), head diameter (mm) and whole plant fresh and dry weight (g). Plant shoots and roots were dried in an oven for 48 hours at 70°C to estimate their dry weights (Mohammad et al., 2007).

Statistical analysis

One-way analysis of variance (ANOVA) was performed to determine differences in *D. dipsaci* RF values among garlic genotypes, using Tukey multiple comparison tests (p < 0.05). Nematode RS values of garlic genotypes were also investigated with Dunnett's test, according to HS genotype, and Muğla6 as the control in the experiment.

In order to determine the effect of *D. dipsaci* on plant growth parameters of garlic genotypes such as plant height (cm), the fresh and dry weights of shoots and roots (g) obtained from treatments with and without nematodes were analyzed by paired *t* test (α=0.05). Reproduction factor (RF) of *D. dipsaci* on garlic genotypes and the data obtained from treatments with and without nematodes for each genotype were analyzed using analysis of variance (ANOVA). When ANOVA showed significant effects, the means were separated by Fisher's LSD test (p<005). All statistical analyses were performed using JMP 13 (SAS Institute Inc., Cary, NC, USA).

Results

Resistance reactions of garlic genotypes to *Ditylenhus dipsaci*

The reproduction factors of *D. dipsaci* on the genotypes in the experiment ranged from 2.6 to 12.7 (Table 1). Resistant genotype against *D. dipsaci* was not detected (RF<1).

Table 1. Names and origins of 44 garlic genotypes used in the study, reproduction factor (RF) of *Ditylenhus dipsaci* on garlic genotypes, relative susceptibility (RS) of garlic genotypes according to Muğla6 genotype in the study and their resistance reaction (RR)

Accession number	Genotype Name	Origins	RF	RS	RR
1	2-39/6	Mutant clone	9.2±0.9b-d[1]	224.3*	HS
2	2-78/11	Mutant clone	7.5±0.9b-j	182.9	HS
3	2-01/6	Mutant clone	7.6±0.9b-ı	185.3	HS
4	1-27/6	Mutant clone	7.1±1.3c-k	173.1	HS
5	2-6/12	Mutant clone	5.9±1.5e-m	143.9	HS
6	2-20/4	Mutant clone	10.0±1.2ab	243.9*	HS
7	2-65/5	Mutant clone	9.4±2.4b-d	229.2*	HS
8	3-64/3	Mutant clone	8.0±2.8b-h	195.1	HS
9	2-34/9	Mutant clone	7.0±1.8c-l	170.7	HS
10	2-34/2	Mutant clone	6.7±1.1b-m	163.4	HS
11	Reis10	Landrace	8.5±0.6b-f	207.3	HS
12	Kütahya Beyazı	Landrace	3.2±0.4mn	78.0	S
13	Selection13	Landrace	5.6±0.7g-n	136.5	HS
14	Muğla6	Landrace	4.1±0.5k-n	100.0	HS
15	Muğla3	Landrace	5.8±0.5e-m	141.4	HS
16	Selection10	Landrace	7.1±0.4c-k	173.1	HS
17	Kahramanmaraş	Landrace	4.8±1.2ı-n	117.0	HS
18	Muğla1	Landrace	9.6±0.9bc	234.1*	HS
19	Germencik	Landrace	6.6±1.1d-l	160.9	HS
20	Sabahattin Ufuk	Landrace	5.5±0.4f-n	134.1	HS
21	Kütahya Pembesi	Landrace	3.2±0.9mn	78.0	S
22	Gaziantep/Araban	Landrace	7.7±0.9b-ı	187.8	HS
23	Muğla7	Landrace	4.1±0.8lmn	100.0	HS
24	Selection4	Landrace	5.7±0.4f-m	139.0	HS
25	Burgaz3	Landrace	4.3±0.8k-n	104.8	HS
26	Muğla4	Landrace	5.0±0.7h-n	121.9	HS
27	Adıyaman Beşir	Landrace	5.5±0.7g-n	134.1	HS
28	Selection11	Landrace	5.5±0.7g-n	134.1	HS
29	Selection137	Landrace	5.9±0.8e-m	143.9	HS
30	Selection8	Landrace	5.9±0.4e-m	143.9	HS
31	Selection3	Landrace	6.9±0.8c-l	168.2	HS
32	AdilAtay	Landrace	8.3±0.9b-g	202.4	HS
33	Selection40	Landrace	12.7±1.8a	309.7*	HS
34	Germiyan	Landrace	8.7±1.8b-e	212.1*	HS
35	K-6Taşköprü	Landrace	7.8±0.6b-h	190.2	HS
36	Muğla5	Landrace	4.4±0.4j-n	107.3	HS
37	Afyonkarahisar	Landrace	6.3±0.5d-m	153.6	HS
38	Balıkesir	Landrace	3.6±0.9mn	87.8	S
39	Selection63	Landrace	5.8±0.4e-m	141.4	HS
40	Kula	Landrace	8.9±0.9b-d	217.0*	HS
41	Taşköprü56	Landrace	9.6±0.4bc	234.1*	HS
42	Alata1	Landrace	4.3±0.3k-n	104.8	HS
43	Tunceli garlic (*Allium tuncelianum*)	Endemic genotip	2.6±0.3n	63.4	S
44	Kaya garlic (*Allium macrochaetum*)	Endemic genotip	8.4±1.1b-g	204.8	HS

[1] Different letter in the same column indicate that the means are statistically significantly different among genotypes (p < 0.05, LSD test);
* There is a statistically significant difference in the relative susceptibility (RS) of garlic genotypes based on Muğla6 genotype (p < 0.05, Dunnett’s test).

However, a significant difference was found in the nematode reproduction factors of 44 garlic genotypes (p<0.05). On the other hand, although 36.6% less nematodes were obtained in the Tunceli garlic genotype, which was classified as susceptible with the lowest RF value of 2.6, compared to Muğla6 genotype, no significant difference was detected in terms of both Rf and RS values (p>0.05). The Tunceli garlic was followed by Kütahya Beyazı (RF=3.2), Kütahya Pembesi (RF=3.2), and Balıkesir (RF=3.6) genotypes which were also classified as susceptible (Table 1). The relative susceptibility values of these genotypes compared to Muğla6 were determined as 78, 78 and 87.8, respectively, but no significant difference was determined according to Dunnet's test (p>0.05).

The highest RF value was determined in the Selection40 genotype with 12.7. It had a 309%, a higher reproduction rate which was significantly different than Muğla6 according to Dunnet's test (p<0.05). In Selection40, approximately five times more *D. dipsaci* was obtained compared to Tunceli garlic, which was the lowest reproduction factor detected. Selection40 followed by 2-20/4, Taşköprü56, Muğla1, 2-65/5, 2-39/6, Kula, and Germiyan genotypes which were significantly different from Muğla6 with 10, 9.6, 9.6, 9.4, 9.2, 8.9, and 8.7 RF, respectively (p< 0.05).

Effect of *Ditylenchus dipsaci* on garlic plant growth parameters

Significant differences were determined between genotypes in terms of plant height, head height, head diameter, plant fresh and dry weight values in both nematode inoculated and non-inoculated plants (p<0.01). Although the effect of stem and bulb nematode on plant growth parameters varies according to genotypes, a significant decrease was detected due to nematodes in 97.7%, 70.5%, 77.3%, 75%, and 90.9% of genotypes in terms of plant height, head length, head diameter, fresh weight and dry weight, respectively, (p<0.05) (Tables 2 & 3).

The longest plant length was determined in Alata1 (75.5 cm; 77.8 cm), Kayagarlic (69.6 cm; 77.0 cm), and Gaziantep/Araban (59.4 cm; 66.6 cm) genotypes in both inoculated and non-inoculated plants, respectively. The shortest plant length for inoculated and non-inoculated plants was obtained in Selection 137 (36.7 cm; 44.3 cm), 2-6/1 (36.8 cm; 40.7 cm) and Selection 11 (36.9 cm; 42.2 cm), respectively (Table 2). A significant reduction in plant length was determined with nematode treatment in all genotypes except Alata1 landrace (P<0.05, Table 2). The highest decrease in plant height was determined in the Selection63 landrace with 18.7%, while the least decrease was determined in Alata1 with 3.0%.

The longest head length was determined in Kayagarlic (42.8 cm; 45.4 cm), Kula (41.8 cm; 45.3 cm), and Taşköprü56 (40.3 cm; 44.8 cm) genotypes in nematode inoculated and non-inoculated treatments, respectively. Kütahya Pembesi (22.1 cm; 28.3 cm) and Germiyan (24.0 cm; 28.0 cm) genotypes had the lowest head length in nematode inoculated and non-inoculated treatments. Significant differences were determined in head length in most of the genotypes (Table 2). The highest and lowest head length reduction with nematode treatment was recorded in Kütahya Pembesi (21.9%) and Muğla1 (2.9%) genotypes, respectively (Table 2).

The largest head diameter was found in Alata1 (46.2 cm; 50.0 cm), while the smallest head diameter was of Tunceli garlic (14.5 cm; 16.2 cm). A significant difference was determined between the inoculated and non-inoculated treatments of genotypes except for 10 genotypes (P < 0.05). With nematode treatment, the maximum decrease in head diameter was obtained in Kahramanmaraş (25.7%), and the least decrease was obtained in Muğla7 (5.4%) genotypes (Table 2).

The lowest fresh weight was determined in inoculated genotypes in Kahramanmaraş (7.7 g), Kütahya Pembesi (9.5 g), Selection4 (9.5 g), and in non-inoculated ones in Selection4 (11.4 g), Muğla3 (12.2 g), Selection137 (12.5 g) genotypes. A significant difference was determined between nematode inoculated and non-inoculated all genotypes except 8 genotypes (p < 0.05). With nematode treatment, the highest decrease in fresh weight was obtained in Kahramanmaraş (41.2%), and the least decrease was observed in Kula (10.0%) genotypes (Table 3).

Table 2. Plant length, head length, head diameter, fresh weight and dry weight values of genotypes with *Ditylenchus dipsaci* (N+) and without-*D. dipsaci* (N-) treatments and their % reduction with nematode treatment

N[1]	Plant length (cm)			Head length (cm)			Head diameter (cm)		
	N+	N-	%	N+	N-	%	N+	N-	%
1	41.9±0.8mn[2]	46.1±0.3 n-s	9.1*	35.9±1.2 b	40.5±1.6b-d	11.3*	34.7±0.6c-e	41.1±1.1cd	15.6*
2	46.7±0.9jk	52.0±1.2lm	10.2*	30.5±1.3 e-j	36.0±1.4d-ı	15.3*	38.9±1.7b	42.2±1.2bc	7.8
3	55.6±0.9e-g	59.4±0.8ef	6.4*	35.3±0.7b	38.7±0.6c-e	8.8*	35.2±0.4cd	41.9±0.7bc	15.9*
4	37.0±0.6q	40.9±0.7t	9.5*	31.7±0.6ef	34.9±0.6e-k	9.2*	30.1±0.7ı-l	34.9±0.7f-k	13.7*
5	36.9±0.6q	40.8±1.0t	9.5*	31.9±0.7d-f	35.6±1.1e-j	10.4*	33.0±0.9ef	36.7±0.9e-g	10.1*
6	51.6±0.9hı	58.9±1.5e-h	12.3*	34.9±0.8b	40.3±0.6c	13.4*	36.1±0.8c	40.7±1.2cd	11.3*
7	46.2±0.8jk	53.4±0.9j-l	13.5*	31.5±1.0e-g	36.8±1.2c-g	14.4*	30.6±0.7g-k	33.8±0.6h-m	9.5*
8	42.5±0.5mn	48.1±0.9n-p	11.6*	32.4±0.7c-e	34.8±0.6e-k	6.9*	33.3±0.6d-f	36.5±1.2e-g	8.7*
9	39.8±0.9op	45.3±0.7q-s	12.1*	34.8±1.5bc	38.0±1.1c-f	8.4	34.8±0.3c-e	38.0±1.5e	8.4
10	41.8±0.9m-o	49.0±0.9m-o	14.7*	34.9±0.9b-d	37.8±1.1c-g	7.7	34.9±0.6c-e	37.7±1.1d-f	7.4
11	55.5±0.8e-g	62.5±1.0cd	11.2*	31.2±0.5e-h	35.7±0.6e-ı	12.6*	32.3±0.4fg	36.1±0.6e-h	10.5*
12	57.6±0.6d	66.0±0.5b	12.7*	25.6±0.5m-o	29.3±0.7no	12.6*	28.8±0.6j-o	31.6±0.4l-o	8.8*
13	46.5±0.9jk	55.1±0.6 ı-k	15.6*	29.1±1.3g-k	32.1±0.9ı-o	9.3	29.2±1.0ı-n	32.8±0.6j-n	10.9*
14	46.0±0.7jk	55.8±1.1 ıj	17.6*	35.2±1.1b	38.4±1.1c-f	8.6	33.3±0.9d-f	36.7±1.1e-g	9.2*
15	56.8±0.3d-f	65.9±0.5 b	13.8*	29.2±0.6g-k	31.3±0.6k-o	6.7*	25.8±0.5p-s	28.2±0.5qr	8.5*
16	47.2±0.8j	54.9±0.7 ı-k	14.0*	29.7±0.5f-k	34.9±0.7e-k	14.9*	29.9±0.6ı-l	32.4±0.8k-n	7.7*
17	46.0±0.5jk	55.1±0.4 ı-k	16.5*	30.2±1.0e-j	32.1±0.6ı-o	5.9	21.1±0.7u	28.4±1.4qr	25.7*
18	55.9±0.5d-f	64.3±0.8 bc	13.0*	37.1±1.0b	38.2±0.8c-f	2.9	33.1±0.4d-f	35.5±0.4e-h	6.7*
19	55.0±0.7fg	61.5±0.9 de	10.6*	31.8±0.5 ef	35.9±0.6d-ı	11.4*	32.2±0.6f-h	35.4±0.8f-ı	9.0*
20	47.4±0.5j	54.8±0.7ı-l	13.5*	29.0±1.2g-k	33.9±0.5f-n	14.5*	28.4±0.8k-o	30.8±0.5m-r	7.8
21	57.3±0.6de	65.7±1.1b	12.7*	22.1±0.6p	28.3±1.2o	21.9*	30.9±0.8g-ı	34.7±0.5f-k	10.9*
22	59.5±0.9c	66.7±0.9ab	10.7*	28.7±0.7ı-k	30.9±0.7l-o	7.1*	29.2±0.5ı-n	32.1±0.7l-n	9.0*
23	42.9±0.7m	47.6±0.8n-q	9.9*	30.7±0.6e-ı	33.8±1.0g-l	9.2*	27.5±0.6n-p	29.1±0.7o-r	5.4
24	41.9±0.7mn	45.9±0.8o-r	8.7*	27.5±0.9k-m	30.2±0.8l-o	8.9	28.8±0.8j-o	30.9±0.5n-p	6.7
25	50.6±0.8ı	59.3±1.2e-g	14.7*	25.1±0.7no	28.7±0.7o	12.5*	30.7±0.8g-j	35.1±0.7f-j	12.5*
26	52.9±0.5h	59.5±1.2e	11.1*	31.2±1.2e-h	35.5±1.1e-j	12.1*	26.9±0.7o-r	29.4±0.7o-q	8.5*
27	47.6±0.5j	54.5±0.4ı-l	12.6*	29.0±1.5g-k	31.8±1.5j-o	8.8	24.7±1.1st	28.7±0.9p-r	13.9*
28	36.9±0.6q	44.3±0.8rs	16.7*	25.9±1.2l-o	29.8±1.3no	13.1	25.2±1.0q-t	28.4±1.2qr	11.3
29	36.8±0.5q	44.4±0.5rs	17.1*	29.2±0.6g-k	33.7±0.6g-m	13.3*	28.9±1.1ı-o	33.0±1.1ı-n	12.4*
30	40.9±0.6n-p	46.6±0.4n-r	12.3*	28.9±0.8h-k	32.8±0.8h-n	11.9*	29.5±0.7ı-m	34.1±0.7h-l	13.5*
31	39.0±0.5p	45.4±0.6q-s	14.1*	30.9±0.6e-ı	35.6±0.5e-j	13.2*	30.7±0.7g-j	35.3±0.7f-j	13.0*
32	39.3±1.1p	45.5±1.2p-s	13.6*	25.7±0.7l-o	29.6±0.4m-o	13.2*	27.4±0.4m-q	30.8±0.4n-q	11.0*
33	39.8±0.5op	43.3±1.0st	8.08*	28.0±0.5j-m	32.7±1.5ı-n	14.8*	28.9±0.7ı-o	33.8±0.7h-m	14.5*
34	42.4±0.9mn	49.1±0.4n	13.6*	24.1±0.7op	21.6±6.4p	-11.5	24.9±0.6r-t	27.9±0.9r	10.7*
35	45.1±0.7kl	52.7±2.5kl	14.4*	30.0±1.4e-j	36.6±1.4c-h	18.0*	30.8±0.7g-j	35.2±0.9f-j	12.5*
36	46.4±0.9jk	56.8±0.7g-ı	18.3*	32.3±0.8de	35.7±1.3e-ı	9.5	28.5±0.9l-o	32.8±0.9j-n	13.1*
37	53.6±0.9gh	60.9±0.8de	12.0*	29.6±0.4f-k	33.3±0.7g-n	11.1*	30.0±0.5h-l	34.1±0.4g-l	12.0*
38	50.9±0.6ı	56.9±0.6f-ı	10.5*	24.4±0.7op	30.1±0.6l-o	18.9*	23.3±0.9 t	28.8±0.5p-r	19.1*
39	46.1±0.6jk	56.7±0.5hı	18.7*	29.8±0.4f-k	33.7±0.9g-l	11.6*	29.4±0.6 ı-n	32.8±1.4j-n	10.0
40	46.9±0.4jk	55.9±1.5ıj	16.1*	41.9±0.8a	45.3±0.7a	7.5*	38.5±0.9b	42.5±1.0bc	9.4*
41	47.0±0.3j	56.8±0.7g-ı	17.3*	40.4±0.8a	44.8±0.5ab	9.8*	39.9±0.9b	44.4±0.9b	10.1*
42	75.5±0.5a	77.8±1.1a	3.0	34.9±0.7b	39.7±0.8cd	12.1*	46.2±0.4a	50.1±1.1a	7.8*
43	43.4±0.8lm	48.4±1.1no	10.3*	28.2±1.4jkl	30.8±1.9l-o	8.4	14.5±0.8v	16.2±1.4s	10.5
44	69.7±0.5b	77.1±0.6a	9.6*	42.9±1.4a	45.4±1.0a	5.5	39.5±0.8b	42.2±1.0bc	6.4

[1] N: Accession number; [2] Different letters in the same column indicate that the means are statistically significantly different among genotypes (p< 0.05, LSD test); * There is a statistically significant difference between nematode treatments of the genotype in the investigated plant growth parameter (p< 0.05, t test)

Table 3. Fresh weight and dry weight values of genotypes with *Ditylenchus dipsaci* (N+) and without-*D. dipsaci* (N-) treatments and their % reduction with nematode treatment

N[1]	Fresh weight (g)			Dry weight (g)		
	N+	N-	%	N+	N-	%
1	20.8±0.8c[2]	29.7±0.5cd	29.9*	7.8±0.3g-ı	11.5±0.4c-g	32.1*
2	19.6±0.4c-e	22.6±1.0fg	13.2*	7.9±0.6f-ı	10.8±0.7e-g	26.8*
3	20.3±0.3c	24.7±0.3f	17.8*	8.6±0.5e-h	11.9±0.4c-e	27.7*
4	16.5±0.7g	21.9±1.1 fg	24.6	7.9±0.7f-ı	11.8±0.6c-f	33.0*
5	16.1±0.7g	20.4±0.9gh	21.1*	7.9±0.7g-ı	11.6±0.8d-f	31.8*
6	19.5±1.1cd	24.7±1.6f	21.1*	9.1±0.2d-f	12.3±0.6c-e	26.0*
7	17.5±1.2d-g	24.9±3.6ef	29.7	8.4±0.7e-h	11.7±0.8c-f	28.2*
8	16.7±1.0fg	21.6±1.0g	22.6*	8.9±0.5d-g	11.7±0.7c-f	23.9*
9	19.0±0.9c-e	27.9±1.2de	31.8*	7.6±0.4hı	11.7±1.0c-f	35.0*
10	17.0±0.3d-g	22.8±0.5fg	25.4*	7.9±0.2f-ı	10.0±0.0f-h	21*
11	12.9±0.7hı	17.5±0.5h-k	26.3*	6.9±0.6ıj	9.0±0.5hı	23.3*
12	10.5±0.8k-p	13.8±0.7l-p	23.9*	5.7±0.5kl	7.8±0.7ı-m	26.9*
13	12.5±0.9h-k	14.4±0.8l-p	13.1	5.5±0.5lm	7.1±0.3k-r	22.5*
14	12.2±1.2h-m	14.0±0.8l-p	12.8	5.3±0.6l-o	7.1±0.7k-r	25.3
15	10.9±0.6ı-p	12.2±0.3op	10.6	5.1±0.3l-o	7.3±0.3j-q	30.1*
16	11.5±0.8ı-p	14.8±0.7j-o	22.3*	5.2±0.2l-o	7.3±0.2j-r	28.7*
17	7.7±0.5q	13.1±0.6m-p	41.2*	4.2±0.3n-p	6.5±0.6k-s	35.4*
18	16.4±1.1g	18.6±1.1hı	11.8	7.5±0.5hı	9.9±0.7gh	24.2*
19	17.3±0.7e-g	21.9±0.9fg	21.0*	7.6±0.5hı	9.7±0.5gh	21.6*
20	10.6±0.4 j-p	13.2±1.2l-p	19.7	4.9±0.3l-p	6.2±0.7l-s	20.9
21	9.5±0.5 pq	14.7±0.5j-o	35.3*	4.1±0.5n-p	5.9±0.3q-s	30.5*
22	11.9±0.7 h-o	14.4±1.0l-p	17.3	4.8±0.3l-p	6.6±0.3k-s	27.3*
23	10.1±0.5 m-p	13.1±0.9m-p	22.9*	4.7±0.5l-p	6.3±0.6o-s	25.4
24	9.6±0.9 pq	11.5±0.9p	16.5	3.7±0.4p	5.1±0.4s	27.5*
25	11.6±0.5 ı-p	14.9±0.4j-o	22.1*	4.7±0.2l-p	6.3±0.2m-s	25.4*
26	11.5±0.8 ı-p	13.3±0.6l-p	13.5	5.7±0.3j-l	7.8±0.7ı-n	26.9*
27	9.9±0.4 op	13.9±0.9l-p	28.7*	4.2±0.2n-p	5.8±0.3rs	27.5*
28	10.2±0.5 l-p	12.9±0.7m-p	20.9*	4.2±0.2n-p	5.4±0.2s	22.2*
29	9.9±0.5 n-p	12.6±0.5n-p	21.4*	4.5±0.3l-p	6.3±0.4n-s	28.5*
30	10.2±0.5 m-p	14.9±0.5j-o	31.5*	4.4±0.4m-p	5.8±0.4rs	24.1*
31	10.9±0.6 ı-p	15.0±0.6j-o	27.3*	5.3±0.6l-n	7.9±0.8ı-l	32.9*
32	10.8±0.3 ı-p	14.3±0.7k-p	24.5*	5.3±0.5l-o	7.6±0.5ı-p	30.2*
33	18.8±0.5 c-f	23.3±0.7fg	19.3*	9.9±0.5b-d	13.0±0.9b-d	23.8*
34	12.8±0.7 h-j	16.1±0.6ı-m	20.4*	6.8±0.7ı-k	8.7±0.5h-j	21.8
35	25.4±0.9 b	34.8±1.8b	27.0*	9.5±0.3c-e	11.7±0.6c-f	18.8*
36	10.1±0.6 m-p	13.1±0.8m-p	22.9*	4.9±0.3l-p	6.6±0.3l-s	25.7*
37	12.5±0.9 h-l	16.1±0.7ı-m	22.3*	5.0±0.0m-o	6.6±0.2k-s	24.2*
38	9.9±0.9 op	13.9±0.9l-p	28.7*	4.1±0.3op	6.1±0.4p-s	32.8*
39	12.0±0.9 h-n	15.5±1.2j-n	22.5*	5.2±0.3l-o	8.1±0.2ı-k	35.8*
40	25.1±0.8 b	27.9±0.6d	10.0*	10.6±0.3bc	14.5±0.4b	26.8*
41	24.9±0.9 b	33.1±2.2bc	24.8*	10.7±0.7b	13.1±0.7bc	18.3*
42	37.2±0.9 a	47.0±0.9a	20.8*	15.9±0.6a	18.8±0.7a	15.4*
43	10.9±1.0 ı-p	12.6±0.9n-p	13.5	5.1±0.1l-o	7.6±0.3ı-p	32.9*
44	13.9±0.7 h	17.6±0.5h-j	21.0*	10.6±0.2 bc	17.7±0.6a	40.1*

[1] N: Accession number; [2] Different letters in the same column indicate that the means are statistically significantly different among genotypes ($p < 0.05$, LSD test); * There is a statistical difference between nematode treatments of the genotype in the investigated plant growth parameter ($p < 0.05$, t test)

The highest dry weight was found in Alata 1 (15.9; 18.8 g), Taşköprü56 (10.7; 13.1 g), Kula genotypes (10.6; 14.5 g) and the lowest was in Selection4 genotype (3.7; 5.1 g) in inoculated and non-inoculated treatments, respectively. A significant difference was determined between nematode treatments in all genotypes except four genotypes ($p < 0.05$). With nematode treatment, the highest decrease in dry weight was obtained in Selection63 (35.8%), and the least decrease was in Alata1 (15.4%) (Table 3).

Discussion

In the study, resistance reactions of total 44 garlic genotypes, including garlic breeding material, landraces and wild relatives, to stem and bulb nematode were revealed. Although a fully resistant genotype was not detected, a much lower nematode multiplication rate was detected in Tunceli garlic, Kütahya Beyazı, Kütahya Pembesi and Balıkesir genotypes compared to other genotypes. Similar to our results, a study conducted in Türkiye to determine the resistance of commercial and local onion cultivars to stem and onion nematodes reported no fully resistant onion cultivars, but low nematode growth (Yavuzaslanoğlu, 2019; Yavuzaslanoğlu & Özsoy, 2020). Being important genetic resources, the garlic genotypes which show lower nematode multiplication and tolerance can be directly recommended for cultivation in areas where the stem and bulb nematode is infested.

To evaluate onion yield, Pang et al. (2009) used plant dry weight and Ibrahim (2010) used plant length, number of leaves and tuber weight. Islam et al. (2007) reported that there was a positive correlation between tuber yield and plant growth parameters such as plant length, plant weight, number of leaves, and stated that all parameters could be used to determine the tolerance in greenhouse conditions. Parameters of plant length, head diameter, plant fresh and dry weight were used to determine the tolerance of garlic genotypes to *D. dipsaci* and a significant decrease was detected in most of the genotypes. When plant growth parameters like plant length, head length, head diameter, plant fresh and dry weight values are evaluated; Alata1, Muğla1, Muğla7 and Kula landraces had the lowest decrease due to the nematode in terms of at least one plant growth parameter. Although these genotypes do not decrease nematode reproduction, they show good growth in presence of *D. dipsaci*. Therefore, these genotypes can be recommended for cultivation in nematode-infested areas. Similar results were revealed in a study by Yavuzaslanoğlu (2019), where significant differences were detected in some genotypes for plant length and plant diameter, but no significant differences were found in plant weight.

Some varieties of oat, rye, bean, clover and onion have been reported to be resistant to races of stem and bulb nematode (Plowright et al., 2002; Yavuzaslanoğlu, 2019; Yavuzaslanoğlu & Ozsoy, 2020). However, to our knowledge**,** there are no studies conducted to determine the resistance of garlic plant varieties to stem and bulb nematode. This is the first study that broadens our knowledge about resistance to stem and bulb nematode in garlic genotypes. Based on the results, we conclude that genotypes which displayless nematode reproduction and also showed tolerance against *D. dipsaci* damage can be used in infested areas and also used as genetic resources for garlic breeding against *D. dipsaci*. It is also necessary to observe the reaction of these garlic genotypes against *D. dipsaci* under field conditions.

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