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***Original article*** (***Orijinal araştırma***)

# Susceptibility of different plant species to two populations of *Ditylenchus dipsaci* Kühn, 1857 (Tylenchida: Anguinidae) from Turkey[1]

Farklı bitki türlerinin Türkiye'den iki *Ditylenchus dipsaci* Kühn, 1857 (Tylenchida: Anguinidae) popülasyonuna hassasiyetleri

**Elif YAVUZASLANOGLU[2*]** **Gamze AKSAY[3]**

## Abstract

Stem and bulb nematode, *Ditylenchus dipsaci* Kühn, 1857 (Tylenchida: Anguinidae), is one of the most important plant parasitic nematodes worldwide. The host range of local populations needs to be determined for control using crop rotation. Susceptibility of 29 plant species was tested for onion and garlic populations of *D. dipsaci* from Central Anatolian Plateau in Turkey under growth chamber conditions in Karaman in 2019. Based on the reproduction factor of the nematodes, garlic, onion and tomato were excellent hosts for both populations of *D. dipsaci.* Pea and spinach were excellent hosts for the onion population, while good host for the garlic population with cucumber a good host for both populations. Eggplant, pepper and zucchini were identified as poor hosts for both nematode populations. Bean and potato were poor hosts for the onion population, and were non-hosts for the garlic population. Alfalfa, barley, carrot, chickpea, daffodil, hyacinth, kale, leek, lettuce, maize, melon, oat, rye, strawberry, sugar beet, tobacco, tulip and wheat were non-hosts for both populations of *D. dipsaci*. Infection with *D. dipsaci* significantly reduced plant weight of onion and tomato, and plant height of pepper. Rotational crops for use in areas infected with *D. dipsaci* in Central Anatolian Plateau in Turkey were indicated by the current study.

**Keywords:** Host range, plant parasitic nematode, race, rotation, stem and bulb nematode

## Öz

Soğan sak nematodu *Ditylenchus dipsaci* Kühn, 1857 (Tylenchida: Anguinidae) dünyanın her yerine yayılmış önemli bitki paraziti nematodlardan biridir. Nematodun kontrolü için yerel popülasyonların konukçu spektrumunun bilinmesi gerekmektedir. Yirmi dokuz bitki türünün hassasiyet durumları Türkiye'de Orta Anadolu Bölgesi'nden elde edilen *D. dipsaci*'nin soğan ve sarımsak izolatları için Karaman'da 2019 yılında büyütme dolabı koşullarında test edilmiştir. Soğan, sarımsak ve domates, her iki *D. dipsaci* popülasyonu için de mükemmel konukçu olarak belirlenmiştir. Bezelye ve ıspanak, soğan popülasyonu için mükemmel bir konukçu iken, sarımsak popülasyonu için iyi konukçudur. Salatalık her iki popülasyon için de iyi konukçudur. Biber, kabak ve patlıcan her iki nematod popülasyonu için zayıf konukçu olarak tanımlanmıştır. Fasulye ve patates bitkileri soğan popülasyonu için zayıf konukçu iken, sarımsak popülasyonu için konukçu değildir. Arpa, buğday, çavdar, çilek, havuç, kara lahana, kavun, lale, marul, mısır, nergis, nohut, pırasa, sümbül, şeker pancarı tütün, yonca ve yulaf, her iki nematod popülasyonuna da konukçu değildir. *Ditylenchus dipsaci* ile enfeksiyon, soğan ve domatesin bitki ağırlığını ve biberin bitki boyunu önemli ölçüde azaltmıştır. Gerçekleştirilen çalışma ile Türkiye'de Orta Anadolu Bölgesi'nde *D. dipsaci* ile bulaşık alanlarda kullanılabilecek rotasyon bitkileri belirlenmiştir.

**Anahtar sözcükler:** Konukçu spektrumu, bitki paraziti nematod, ırk, ekim nöbeti, soğan sak nematodu

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[2] Karamanoglu Mehmetbey University, Technical Sciences Vocational School, Department of Plant and Animal Production, 70100, Karaman, Turkey
[3] Karamanoglu Mehmetbey University, Institute of Science, 70100, Karaman, Turkey
* Corresponding author (Sorumlu yazar) e-mail: eyavuzaslanoglu@kmu.edu.tr
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## Introduction

Stem and bulb nematode, *Ditylenchus dipsaci* Kühn, 1857 (Tylenchida, Anguinidae), is a migratory endoparasitic nematode damaging more than 500 plant species (Brzeski, 1991). Stem and bulb nematode comprise a species complex which includes individuals with diploid features known as *D. dipsaci* sensu stricto or "normal-sized species" and individuals having polyploid features (Subbotin et al., 2005). The nematodes in *D. dipsaci* sensu stricto are phylogenetically very close to each other and cannot be distinguished as subspecies (Subbotin et al., 2005). The nematodes in this group are described as races according to their reproduction in different plant species. Sturhan & Brzeski (1991) reported more than 30 races for *D. dipsaci*. The races are different for economically and globally important plant species. The race isolated originally from onion is known as the onion race.

In Turkey, the stem and bulb nematode is found in onion fields in Aksaray, Ankara, Eskişehir, Karaman and Konya Provinces in the Central Anatolia Region, İstanbul and Tekirdağ Provinces in the Marmara Region, Amasya, Çorum, Kastamonu and Tokat Provinces in the Black Sea Region and Adana, Hatay and Mersin Provinces in the Mediterranean Region (Yavuzaslanoglu et al., 2019). Onion yield losses due to the stem and bulb nematode have been reported as 41.5% (Yavuzaslanoglu et al., 2015) to 65% (Mennan & Ecevit, 2002) in Turkey.

Since stem and bulb nematode is a quarantine nematode for onion in Turkey (EPPO, 2020), quarantine measures are made to prevent its spread. In addition, since the host spectrum is quite wide, in order to maintain economic production in the areas where it is infected, it is necessary to apply integrated pest management practices to keep the population level below the economic damage threshold in field. Rotation with non-host plants is a promising control method. It has been found that 3-4 years of rotation with non-host plants significantly reduces *D. dipsaci* populations (Roberts & Grathead, 1986). As host range of the races of *D. dipsaci* can vary in local populations (Viglierchio, 1971), determination of the biological race and the host spectrum of the local nematode population are very important for the implementation of rotation practices. Damage caused by *D. dipsaci* from onion from Amasya Province, Suluova District in Black Sea Region in Turkey was investigated on different plant species (Mennan, 2001). Of the investigated plant species, nematode symptoms were seen on bean, garlic, onion and tomato, and no damage was observed in cucumber, kale, pepper, spinach, wheat and zucchini (Mennan, 2001). However, susceptibility of the plant species to the stem and bulb nematode populations from other locations of onion and garlic production in Turkey have not investigated.

The aim of the study was to investigate the susceptibility of the 29-plant species which could be used in rotation with onion and garlic in field to two populations of *D. dipsaci* from Central Anatolian Plateau in Turkey.

## Materials and Methods

### Plant materials

Totally 29 plant species from 12 families were investigated for their susceptibility against *D. dipsaci*. Taxonomic classification and denomination of plant species are given according to The Plant List (Anonymous, 2020). Standard cultivars of plant species were obtained from commercial seed firms, Agricultural Research Institutes and growers (Table 1).

### Nematode populations

Two populations of *D. dipsaci* were used in the study. Nematode populations were originally isolated from Karaman Province, Central District in Central Anatolian Plateau from onion (37º11'01.7" N, 33º11'23.9" E) and garlic plants (37º10'35.1" N, 33º11'70.0" E).

Nematodes were identified morphologically and with species specific PCR technique using the primers of PF1-PR1, PF2-PR2, DdpS1-rDNA2, DİTNF1-rDNA2, H05-H06, DipU F-DipU R and 18S-26S (Subbotin et al., 2005; Esquibet et al., 2003; Marek et al., 2010). Isolation of DNA and PCR conditions were as same as described by Yavuzaslanoglu et al. (2018). Morphological measurements were made according to literature for this nematode (Öztürk, 1990; Sturhan & Brzeski, 1991; Kepenekçi, 1999; Mennan, 2001; Chizhov et al., 2010).

Table 1. Family, cultivar and source of plant species used in this study from Turkey

| Family | Plant species | Cultivar | Source |
|---|---|---|---|
| Amaranthaceae | Spinach (*Spinacia oleracea* L.) | Matador | Arzuman Seed, Konya |
| | Sugar beet (*Beta vulgaris* L.) | Standard | Arzuman Seed, Konya |
| Amaryllidaceae | Daffodil (*Narcissus* spp.) | Carlton | Asya tulip, Konya |
| | Garlic (*Allium sativa* L.) | Standard | Karaman |
| | Leek (*Allium ampeloprasum* L.) | İnegöl | İntfa Seed, Konya |
| | Onion (*Allium cepa* L.) | Banko | İntfa Seed, Konya |
| Apiaceae | Carrot (*Daucus carota* L.) | Nantes | Paşa Seed, Balıkesir |
| Asparagaceae | Hyacinth (*Hyacinthus orientalis* L.) | Fondant | Asya tulip, Konya |
| Brassicaceae | Kale (*Brassica oleracea* L.) | Morris | İntfa Seed, Konya |
| Asteraceae | Lettuce (*Lactuca sativa* L.) | Yedikule 5701 | Arzuman Seed, Konya |
| Cucurbitaceae | Cucumber (*Cucumis sativus* L.) | Beith Alpha | Arzuman Seed, Konya |
| | Melon (*Cucumis melo* L.) | Ananas | Arzuman Seed, Konya |
| | Zucchini (*Cucurbita pepo* L.) | Pelin | Arzuman Seed, Konya |
| Fabaceae | Alfalfa (*Medicago sativa* L.) | Bilensoy 80 | Beyza Seed, Konya |
| | Bean (*Phaseolus vulgaris* L.) | Dermason | Karaman |
| | Chickpea (*Cicer arietinum* L.) | Sarı 98 | Karaman |
| | Pea (*Pisum sativum* L.) | Utrillo | Arzuman Seed, Konya |
| Liliaceae | Tulip (*Tulipa gesneriana* L.) | Negrita | Asya tulip, Konya |
| Poaceae | Barley (*Hordeum vulgare* L.) | Kral 97 | Bahri Dağdaş International Agricultural Research Institute, Konya |
| | Maize (*Zea mays* L.) | Standard | Dekalb, Konya |
| | Oat (*Avena sativa* L.) | Standard | Karaman |
| | Rye (*Secale cereale* L.) | Standard | Karaman |
| | Wheat (*Triticum aestivum* L.) | Çeşit 1252 | Karaman |
| Rosaceae | Strawberry (*Fragaria vesca* L.) | Standard | Karaman |
| Solanaceae | Eggplant (*Solanum melongena* L.) | Balıkesir 76 | EkoherbAsgen Seed, İstanbul |
| | Pepper (*Capsicum annuum* L.) | Çetinel 150 | Arzuman Seed, Konya |
| | Potato (*Solanum tuberosum* L.) | Standard | Karaman |
| | Tobacco (*Nicotiana tabacum* L.) | Basma | Aegean Agricultural Research Institute, İzmir |
| | Tomato (*Solanum lycopersicum* L.) | Kokteyl | Ekoherb Asgen Seed, İstanbul |

**Preparation of inoculum**

Nematodes were cultured on sterile carrot discs (Behmand et al., 2017). Large carrots without any damage or decay were peeled and surface sterilized for 10 min using 95% ethanol and flamed. After a second peeling, sterile carrots were sliced into discs 1 cm thick and placed into 6-cm diameter sterile plastic Petri dishes. Nematode cultures were started from one female and one male nematode. Nematode cultures were incubated at 20ºC in dark. Cultures were subcultured every eight weeks to obtain enough inoculum for the study.

Nematodes applied as inoculum in susceptibility tests were extracted from 2-month-old sterile carrot cultures by washing the surface of the carrot discs with sterile tap water. The nematode suspension was then concentrated to about 200 nematodes per 10 µl for application to plants.

**Experimental design**

Plastic square pots at 7x7x8 cm dimensions were filled with 300 ml sand:field soil:organic matter mixture (70:29:1) sterilized in an autoclave at 121ºC for 120 min. One seed was planted per pot for each plant species with 10 replicate pots. The experiment was laid out in a completely randomized plot design. Experiment included plants inoculated with the two populations of *D. dipsaci* and uninoculated control. Two hundred nematodes including all stages in 10 µl carboxymethyl cellulose solution (1%) from each nematode population was inoculated between first two leaves of plants at the third- to fourth-leaf stage (Kühnhold et al., 2006). The experiment was conducted under growth chamber conditions at 20ºC, 70% RH and 16:8 h L:D photoperiod.

Plants were harvested 6 weeks after inoculation. Plant height, fresh plant weight and symptoms of nematode damage were recorded. Nematodes were extracted from the whole plant and soil in the pots for 24 h using a modified Baermann funnel technique (Hallmann & Subbotin, 2005). The nematode suspensions were then concentrated to 1 ml. The nematode numbers were counted in 50 µl subsample and multiplied by 20 to give the total number of nematodes per sample. The results were expressed as the total number of nematodes for plant and soil per pot. The RF value was calculated by dividing final number of nematodes per pot by the initial nematode number applied (i.e., 200 nematodes/plant). Plant species were categorized as non-host for RF < 1, poor host for 1 < RF < 2, good host for 2 < RF < 4 and excellent host for 4 < RF (Hajihassani et al., 2016).

### Statistical analysis

Data of total number of nematodes per pot was analyzed to determine whether the data comes from the normal distribution using a goodness-of-fit test. According to the test result, the data was transformed to ln(x + 1) values to provide normality. Levene's test was used to test homogeneity of variance of the transformed data.

Analysis of variance (ANOVA) and Tukey HSD test of transformed total numbers of nematodes among plant species were performed for evaluation of the susceptibility of the plant species. Differences between the transformed total numbers and reproduction factors of two nematode populations were examined using t-tests.

Statistically significant difference in plant weight and height of each plant species among nematode treatments was investigated with ANOVA and Tukey HSD test. Statistical analyses were performed using JMP© 5.0 software (JMP, 2020).

## Results and Discussion

### Species identification of nematode populations

Morphological measurements of nematodes from carrot cultures were in agreement with previous records (Öztürk, 1990; Sturhan & Brzeski, 1991; Kepenekçi, 1999; Mennan, 2001; Chizhov et al., 2010) (Table 2).

Table 2. Morphological and morphometric measurements of *Ditylenchus dipsaci* onion and garlic populations and from the literature

| Characteristics* | Onion population | Garlic population | Öztürk, 1990 | Sturhan & Brzeski, 1991 | Kepenekçi, 1999 | Mennan, 2001 |
|---|---|---|---|---|---|---|
| n | 4 | 5 | 20 | | 12 | 200 |
| L (mm) | 1.11-1.18 | 1.00-1.09 | 0.53-1.10 | 1.00-2.20 | 0.65-0.87 | 1.25-1.71 |
| Stylet length (µm) | 11.70-11.97 | 11.26-12.08 | 6.00-11.80 | 10.00-13.00 | 10.00-13.00 | 12.00-14.00 |
| Tail length (µm) | 66.79-78.19 | 67.81-75.00 | 48.00-66.20 | | 45.00-53.00 | |
| a | 42.49-47.23 | 37.32-42-60 | 34.70-44.20 | 36.00-64.00 | 39.50-52.20 | 39.00-51.00 |
| b | 6.33-7.22 | 5.83-7.02 | 4.80-6.80 | 6.50-12.00 | 5.60-7.20 | 8.41-8.70 |
| c | 14.69-16.99 | 14.13-16.00 | 9.90-12.60 | 11.00-20.00 | 11.20-17.30 | 11.42-21.60 |
| c' | 4.72-6.19 | 4.12-5.45 | 5.60-6.90 | 3.00-6.00 | 4.09-4.81 | |
| V (%) | 78.75-80.48 | 80.03-81.95 | 73.40-81.20 | 76.00-86.00 | 80.20-81.10 | 76.00-73.00 |

* n, number of specimens; L, total body length; a, body length/the largest width part of body; b, body length/distance from esophagus intestine overlapping part to anterior end of body; c, body length/tail length; c', tail length/body width at anus; and V (%), distance from anterior end of body to vulva/body length x 100.

The primers; PF1-PR1, PF2-PR2, DdpS1-rDNA2, DİTNF1-rDNA2, H05-H06, DipU F-DipU R and 18S-26S provided specific bands at 327, 396, 517, 263, 242, 333, 967 bp for both populations, respectively (Figure 1).

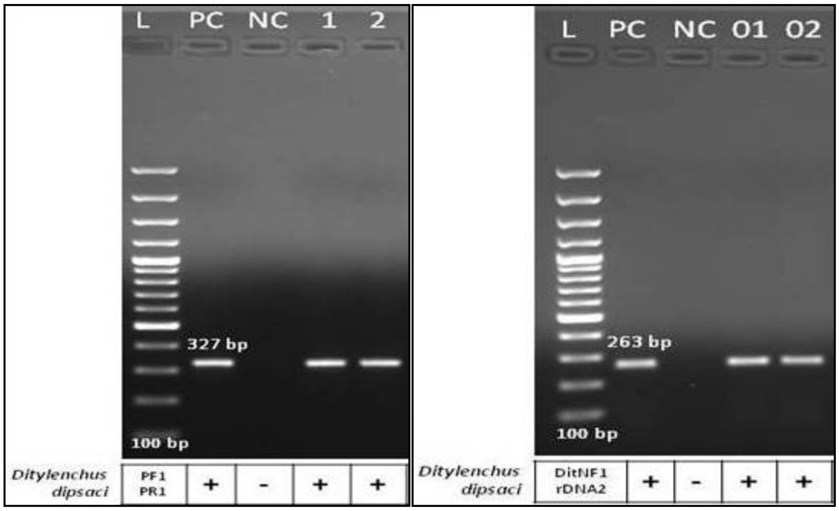


Figure 1. Agarose gels for molecular characterization of onion (1) and garlic (2) populations of *Ditylenchus dipsaci* with PF1-PR1 primer amplified a 327 bp for *D. dipsaci* and DitNF1-rDNA2 primer amplified 263 bp products for *D. dipsaci.* (L, 100 bp ladder; PC, positive control for *D. dipsaci*; and NC,distilled water negative control).

Both nematode populations were identified with all primers used in the study. Additionally, DITNF1-rDNA2, H05-H06, DipU F-DipU R and 18S-26S primers showed both populations were belonging to *D. dipsaci* sensu stricto (Subbotin et al., 2005; Esquibet et al., 2003; Marek et al., 2010). Considering complex nature of *D. dipsaci* species, identification of nematode populations using species specific primers provides useful information. However, host reactions of different plant species potentially grown in the area need to be tested against the local nematode populations for implementation of crop rotation strategies for control of the nematode. Additionally, use of genetically pure nematode cultures for susceptibility tests of plant species is important to eliminate variability in nematode virulence. Therefore, nematode cultures established from one female and male nematode were used in the current study.

**Susceptibility of plant species**

Typical symptoms of *D. dipsaci,* curling of leaves and stunting of pants, were observed on nematode inoculated bean, cucumber, eggplant, garlic, onion, pepper, potato, spinach, tomato and zucchini in the experiment. Mennan (2001) reported that damage symptoms were seen on bean, garlic, onion and tomato, but not on kale and wheat, supporting our results.

The highest nematode reproduction was obtained on garlic (RFs 12.8 and 5.64), tomato (RFs 8.72, and 6.98) and onion (RFs 7.35 and 5.46) for the onion and garlic populations of *D. dipsaci*, respectively. Those plants were determined to be excellent hosts for the two populations of *D. dipsaci*. The transformed total number of nematodes of garlic, tomato and onion was significantly different from alfalfa, daffodil, hyacinth, kale, leek, maize, oat, rye, strawberry and wheat with the onion population, and daffodil, alfalfa, barley, carrot, chickpea, hyacinth, kale, lettuce, maize, melon, oat, rye, sugar beet and tobacco with the garlic population.

The reproduction of the onion population of *D. dipsaci* was generally higher than of the garlic population. However, there was no significant difference between two nematode populations. Pea (RF 4.68) and spinach (RF 5.82) were excellent hosts for the onion population, and they were good hosts for the garlic population with RF 2.81 and 2.60, respectively. Cucumber was good host for both nematode populations (RFs 2.84 and 2.70) (Table 3). Reactions of pepper (RFs 1.87 and 1.33), zucchini (RFs 1.40 and 1.96) and eggplant (RFs 1.42 and 1.46) were poor host with 1 < RF < 2 for both populations (Table 3). Potato (RFs 1.16 and 0.61) and bean (RFs 1.46 and 0.91) were poor host for the onion population but they were non-hosts for the garlic population with RF < 1 (Table 3). Alfalfa, barley, carrot, chickpea, daffodil, hyacinth, kale, leek, lettuce, maize, melon, oat, rye, strawberry, sugar beet, tobacco, tulip and wheat were considered as non-hosts with RF < 1 for both populations (Table 3).

Table 3. Untransformed mean numbers and reproduction factor (RF) values of *Ditylenchus dipsaci* onion and garlic populations per pot

| Plant species | Nematod number (mean ± SED) | | RF | |
|---|---|---|---|---|
| | Onion population | Garlic population | Onion population | Garlic population |
| Alfalfa (*Medicago sativa*) | 47 ± 27 d-g | 114 ± 60 d-g | 0.23 | 0.57 |
| Barley (*Hordeum vulgare*) | 165 ± 132 b-g | 20 ± 20 f-h | 0.83 | 0.10 |
| Bean (*Phaseolus vulgaris*) | 291 ± 142 a-g | 182 ± 64 c-g | 1.46 | 0.91 |
| Carrot (*Daucus carota*) | 53 ± 33 c-g | 20 ± 0 d-h | 0.27 | 0.10 |
| Chickpea (*Cicer arietinum*) | 72 ± 19 c-g | 60 ± 30 d-h | 0.36 | 0.30 |
| Cucumber (*Cucumis sativus*) | 569 ± 217 a-f | 540 ± 460 a-g | 2.84 | 2.70 |
| Daffodil (*Narcissus* spp.) | 111 ± 25 d-g | 160 ± 160 d-h | 0.56 | 0.80 |
| Eggplant (*Solanum melongena*) | 284 ± 112 a-g | 291 ± 129 a-f | 1.42 | 1.46 |
| Garlic (*Allium sativa*) | 2555 ± 1370 a | 1128 ± 260 ab | 12.8 | 5.64 |
| Hyacinth (*Hyacinthus orientalis*) | 33 ± 13 d-g | 28 ± 8 d-h | 0.17 | 0.14 |
| Kale (*Brassica olerac*) | 70 ± 21 e-g | 45 ± 19 d-h | 0.35 | 0.23 |
| Leek (*Allium ampeloprasum*) | 20 ± 0 d-g | 67 ± 29 a-h | 0.10 | 0.33 |
| Lettuce (*Lactuca sativa*) | 53 ± 18 b-g | 40 ± 12 d-h | 0.27 | 0.20 |
| Maize (*Zea mays*) | 54 ± 20 e-g | 10 ± 10 g-h | 0.27 | 0.05 |
| Melon (*Cucumis melo*) | 47 ± 18 b-g | 57 ± 26 d-g | 0.23 | 0.28 |
| Oat (*Avena sativa*) | 33 ± 6.7 e-g | 27 ± 4 e-h | 0.17 | 0.13 |
| Onion (*Allium cepa*) | 1470 ± 668 a-c | 1093 ± 411 a-c | 7.35 | 5.46 |
| Pea (*Pisum sativum*) | 936 ± 48 a-d | 562 ± 210 a-e | 4.68 | 2.81 |
| Pepper (*Capsicum annuum*) | 374 ± 102 a-f | 266 ± 98 a-g | 1.87 | 1.33 |
| Potato (*Solanum tuberosum*) | 231 ± 25 a-f | 122 ± 23 b-g | 1.16 | 0.61 |
| Rye (*Secale cereale*) | 108 ± 73 d-g | 0 ± 0 h | 0.54 | 0.00 |
| Spinach (*Spinacia oleracea*) | 1164 ± 559 a-e | 520 ± 169 a-d | 5.82 | 2.60 |
| Strawberry (*Fragaria vesca*) | 33 ± 10 f-g | 30 ± 10 b-h | 0.17 | 0.15 |
| Sugar beet (*Beta vulgaris*) | 60 ± 31 b-g | 20 ± 0 d-h | 0.30 | 0.10 |
| Tobacco (*Nicotiana tabacum*) | 50 ± 30 a-g | 80 ± 80 d-h | 0.25 | 0.40 |
| Tomato (*Solanum lycopersicum*) | 1745 ± 809 ab | 1396 ± 352 a | 8.72 | 6.98 |
| Tulip (*Tulipa gesneriana*) | 30 ± 10 b-g | 127 ± 107 a-h | 0.15 | 0.63 |
| Wheat (*Triticum aestivum*) | 20 ± 20 g | 30 ± 10 b-h | 0.10 | 0.15 |
| Zucchini (*Cucurbita pepo*) | 280 ± 46 a-f | 392 ± 297 a-g | 1.40 | 1.96 |

There was no distinct pattern for the botanical families for susceptibility to *D. dipsaci*. Although, some species were excellent and good hosts, other species from the same family were poor host; for example, pea in the Fabaceae is excellent and good host, whereas alfalfa, bean and chickpea in the same family were poor or non-hosts. However, all plant species in the Poaceae were non-hosts.

Seinhorst (1957) developed a host differential set to differentiate 11 races of *D. dipsaci*. This set includes alfalfa, daffodil, pea, potato, red clover, teasel, tulip and white clover. Edwards & Taylor (1963) investigated reaction of this host differential set to an onion population of *D. dipsaci* from Illinois, USA. They reported pea and potatoes as hosts, and alfalfa, clovers (both), daffodil, hyacinth, teasel and tulip as non-hosts. In our study, nematodes reproduced well on pea, but reproduction was lower on potatoes. We also found alfalfa, daffodil, hyacinth and tulip to be non-hosts for both populations of *D. dipsaci*. Hajihassani et al. (2016) investigated the susceptibility of different bean and pea cultivars to *D. dipsaci* garlic population from Canada and the results were in agreement with our results with pea cultivars excellent host, and bean cultivars poor hosts. Consistent with our results, reproduction factor of garlic as control plant was higher than 6 (excellent host) and wheat was less than 1 (non-host). Recently, Poirier et al. (2019) reported barley, carrot, lettuce and maize as non-hosts for a garlic population of *D. dipsaci* from Canada, and therefore useful for rotation in *D. dipsaci*-infested garlic production areas in Canada, these results are similar to our results. They also found the nematode reproduced well on garlic and onion, and less well on potatoes, as we found in our study. In addition, Viglierchio (1971) and Janssen (1994) reported different host reactions for the same race of *D. dipsaci* from different locations. Therefore, it is essential to investigate host reactions of plant species to local *D. dipsaci* populations when planning crop rotations. Results from the current study will contribute to integrated pest management that use crop rotation in the nematode-infested plant production areas. Alfalfa, barley, carrot, chickpea, kale, leek, lettuce, maize, melon, oat, rye, sugar beet and wheat were found to be non-hosts in the current study, could be used as rotational crops with onion and garlic to reduce *D. dipsaci* population densities.

### Fresh weight and height of plant species

A statistically significant decreases were recorded in plant weight of onion and tomato plants with the nematode inoculation with both nematode populations ($P < 0.05$). Fresh weights of onion plants inoculated with both nematode populations were 95% lower than the uninoculated control. Fresh weights of tomato plants were lower 56% and 81% lower in the treatments nematode inoculated with the onion and garlic populations than the uninoculated control, respectively (Table 4). Fresh weight of bean and cucumber were higher with the garlic population than onion nematode population and uninoculated control.

Table 4. Plant fresh weight of plant species in the onion and garlic population of *D. dipsaci* inoculated and uninoculated treatments and statistical differences among nematode treatments according to Tukey HSD test

| Plant species | Plant fresh weight (g ± SEM) and Tukey HSD group | | |
|---|---|---|---|
| | Onion population | Garlic population | Non-inoculated |
| Alfalfa (*Medicago sativa*) | 0.32 ± 0.12 a | 0.30 ± 0.08 a | 0.35 ± 0.18 a |
| Barley (*Hordeum vulgare*) | 1.41 ± 0.22 a | 1.43 ± 0.49 a | 1.77 ± 0.27 a |
| Bean (*Phaseolus vulgaris*) | 3.62 ± 0.45 b | 6.46 ± 0.84 a | 3.01 ± 0.67 b |
| Carrot (*Daucus carota*) | 0.10 ± 0.03 a | 0.19 ± 0.07 a | 0.13 ± 0.06 a |
| Chickpea (*Cicer arietinum*) | 3.44 ± 0.50 a | 4.50 ± 0.82 a | 4.31 ± 0.29 a |
| Cucumber (*Cucumis sativus*) | 1.43 ± 0.19 b | 2.86 ± 0.15 a | 1.36 ± 0.37 b |
| Daffodil (*Narcissus* spp.) | 37.5 ± 1.44 a | 43.1 ± 1.72 a | 38.4 ± 3.39 a |
| Eggplant (*Solanum melongena*) | 0.12 ± 0.01 a | 0.14 ± 0.02 a | 0.17 ± 0.01 a |
| Garlic (*Allium sativa*) | 4.16 ± 0.77 a | 2.69 ± 0.71 a | 3.13 ± 1.24 a |
| Hyacinth (*Hyacinthus orientalis*) | 66.8 ± 7.70 a | 70.7 ± 4.67 a | 70.6 ± 1.43 a |
| Kale (*Brassica oleracea*) | 3.01 ± 0.39 a | 2.84 ± 0.53 a | 3.42 ± 0.45 a |
| Leek (*Allium ampeloprasum*) | 0.04 ± 0.03 a | 0.38 ± 0.37 a | 0.04 ± 0.01 a |
| Lettuce (*Lactuca sativa*) | 1.19 ± 0.12 a | 1.84 ± 0.39 a | 1.88 ± 0.64 a |
| Melon (*Cucumis melo*) | 2.04 ± 0.17 a | 1.72 ± 0.29 a | 1.07 ± 0.23 a |
| Maize (*Zea mays*) | 4.37 ± 0.59 a | 3.74 ± 0.10 a | 4.27 ± 0.32 a |
| Oat (*Avena sativa*) | 0.89 ± 0.31 a | 1.11 ± 0.28 a | 1.77 ± 0.63 a |
| Onion (*Allium cepa*) | 0.01 ± 0.00 b | 0.01 ± 0.00 b | 0.19 ± 0.06 a |
| Pea (*Pisum sativum*) | 4.85 ± 0.45 a | 4.27 ± 0.55 a | 4.20 ± 0.63 a |
| Pepper (*Capsicum annuum*) | 0.14 ± 0.02 a | 0.22 ± 0.05 a | 0.28 ± 0.07 a |
| Potato (*Solanum tuberosum*) | 20.8 ± 2.66 a | 27.0 ± 1.82 a | 17.2 ± 1.83 a |
| Rye (*Secale cereale*) | 0.86 ± 0.14 a | 0.67 ± 0.28 a | 0.83 ± 0.06 a |
| Spinach (*Spinacia oleracea*) | 2.62 ± 0.18 a | 2.16 ± 0.30 a | 3.30 ± 0.89 a |
| Sugar Beet (*Beta vulgaris*) | 1.84 ± 0.30 a | 0.76 ± 0.50 a | 1.53 ± 0.54 a |
| Strawberry (*Fragaria vesca*) | 5.37 ± 0.84 a | 2.21 ± 0.61 a | 4.74 ± 0.95 a |
| Tobacco (*Nicotiana tabacum*) | 0.98 ± 0.12 a | 1.45 ± 0.31 a | 1.77 ± 0.74 a |
| Tomato (*Solanum lycopersicum*) | 0.86 ± 0.23 b | 0.35 ± 0.11 b | 1.94 ± 0.55 a |
| Tulip (*Tulipa gesneriana*) | 31.3 ± 1.07 a | 22.3 ± 5.58 a | 26.5 ± 2.85 a |
| Wheat (*Triticum aestivum*) | 2.18 ± 0.01 a | 1.29 ± 0.43 a | 1.43 ± 0.35 a |
| Zucchini (*Cucurbita pepo*) | 2.83 ± 0.72 a | 3.39 ± 1.34 a | 4.74 ± 1.56 a |

The height of pepper was significantly lower by 29% and 30% with the onion and garlic populations than the uninoculated plants, respectively ($P < 0.05$). The height of maize was higher in both nematode population than uninoculated control. The height of daffodil with the garlic population was higher than with then onion population and uninoculated control (Table 5).

Table 5. Height of plant species in the onion and garlic population of *D. dipsaci* inoculation and uninoculated treatments and statistical differences among nematode treatments according to Tukey HSD test

| Plant species | Plant height (cm ± SEM) and Tukey HSD group | | |
|---|---|---|---|
| | Onion population | Garlic population | Non-inoculated |
| Alfalfa (*Medicago sativa*) | 13.7 ± 3.8 a | 8.9 ± 2.0 a | 9.7 ± 1.7 a |
| Barley (*Hordeum vulgare*) | 39.3 ± 3.1 a | 42.5 ± 0.5 a | 37.3 ± 3.2 a |
| Bean (*Phaseolus vulgaris*) | 34.3 ± 6.4 a | 41.6 ± 6.4 a | 19.7 ± 0.3 a |
| Carrot (*Daucus carota*) | 3.5 ± 0.8 a | 5.7 ± 09 a | 6.0 ± 1.5 a |
| Chickpea (*Cicer arietinum*) | 24.0 ± 2.7 a | 32.0 ± 2.4 a | 28.7 ± 1.3 a |
| Cucumber (*Cucumis sativus*) | 6.4 ± 0.4 a | 7.8 ± 0.3 a | 5.8 ± 1.4 a |
| Daffodil (*Narcissus* spp.) | 19.0 ± 1.2 b | 36.5 ± 0.5 a | 19.0 ± 3.8 b |
| Eggplant (*Solanum melongena*) | 3.1 ± 0.2 a | 3.2 ± 0.2 a | 4.0 ± 0.0 a |
| Garlic (*Allium sativa*) | 30.4 ± 3.4 a | 33.0 ± 2.2 a | 32.8 ± 2.4 a |
| Hyacinth (*Hyacinthus orientalis*) | 11.3 ± 0.7 a | 17.0 ± 2.0 a | 19.3± 2.9 a |
| Kale (*Brassica oleracea*) | 10.3 ± 0.7 a | 12.3 ± 0.5 a | 11.2 ± 0.9 a |
| Leek (*Allium ampeloprasum*) | 6.0 ± 5.0 a | 6.0 ± 3.5 a | 11.3 ± 0.8 a |
| Lettuce (*Lactuca sativa*) | 4.8 ± 0.4 a | 5.6 ± 0.5 a | 5.0 ± 0.6 a |
| Maize (*Zea mays*) | 37.0 ± 1.9 a | 44.5 ± 0.5 a | 28.3 ± 0.9 b |
| Melon (*Cucumis melo*) | 14.0 ± 0.6 a | 12.5 ± 1.0 a | 9.0 ± 2.1 a |
| Oat (*Avena sativa*) | 40.0 ± 5.9 a | 44.3 ± 5.5 a | 42.3 ± 2.9 a |
| Onion (*Allium cepa*) | 6.4 ± 1.3 a | 9.9 ± 1.4 a | 11.2 ± 0.4 a |
| Pea (*Pisum sativum*) | 29.3 ± 1.6 a | 26.4 ± 1.8 a | 27.0 ± 4.2 a |
| Pepper (*Capsicum annuum*) | 4.1 ± 0.3 b | 4.1 ± 0.3 b | 5.8 ± 0.4 a |
| Potato (*Solanum tuberosum*) | 12.7 ± 1.2 a | 22.1 ± 3.7 a | 17.0 ± 6.0 a |
| Rye (*Secale cereale*) | 30.6 ± 4.3 a | 35.5 ± 4.5 a | 35.3 ± 4.9 a |
| Spinach (*Spinacia oleracea*) | 9.4 ± 0.9 a | 12.2 ± 2.5 a | 16.0 ± 6.1 a |
| Strawberry (*Fragaria vesca*) | 8.6 ± 0.9 a | 5.5 ± 1.5 a | 9.0 ± 1.2 a |
| Sugar beet (*Beta vulgaris*) | 11.0 ± 1.0 a | 8.8 ± 2.3 a | 8.5 ± 1.5 a |
| Tobacco (*Nicotiana tabacum*) | 9.0 ± 1.0 a | 9.3 ± 1.3 a | 9.2 ± 2.9 a |
| Tomato (*Solanum lycopersicum*) | 10.9 ± 1.7 a | 12.7 ± 4.9 a | 15.3 ± 3.2 a |
| Tulip (*Tulipa gesneriana*) | 25.0 ± 5.0 a | 9.7 ± 3.3 a | 13.0 ± 3.5 a |
| Wheat (*Triticum aestivum*) | 40.0 ± 0.0 a | 35.0 ± 2.0 a | 35.7 ± 1.8 a |
| Zucchini (*Cucurbita pepo*) | 10.6 ± 1.1 a | 9.8 ± 1.5 a | 12.0 ± 1.5 a |

Wright & Perry (2006) reported stunting and lose of weight duo to the tissue decay with *D. dipsaci* infection of plants. Plant weight and height was used successfully for interpretation of susceptibility of onion, pepper and tomato to *D. dipsaci* in the current study in consistent with those results. Significantly higher height of daffodil and maize and weight of bean and cucumber were recorded with nematode inoculated treatments were probably related to plant genetic and physiological properties and environmental conditions.

In conclusion, results of this study can be applied by growing of the poor and non-host plant species, such as alfalfa, barley, bean, carrot, chickpea, kale, leek, maize, oat, potato, rye, sugar beet and wheat in rotation with main hosts, onion and garlic, in areas in Central Anatolian Plateau that are infested with stem and bulb nematode. Future research should development of integrated control strategies including host rotation for areas in Central Anatolian Plateau in Turkey with *D. dipsaci* infestations.

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