

Interaction between *Fusarium culmorum* and *Ditylenchus dipsaci* in purple and yellow onion

Fatma G. Göze Özdemir¹, Şerife E. Arıcı¹, Ece B. Kasapoğlu Uludamar² and İbrahim H. Elekcioğlu²

¹Isparta University of Applied Sciences, Faculty of Agriculture, Department of Plant Protection, 32200, Isparta, Türkiye

²Çukurova University, Faculty of Agriculture, Department of Plant Protection, 01330, Adana,

Türkiye

e-mail: ecekasapoglu@gmail.com

Accepted for publication 14 July 2026

Summary. This study examined the interaction between the crown rot fungus *Fusarium culmorum* and the stem nematode *Ditylenchus dipsaci* in onion under controlled conditions. Both *D. dipsaci* and *F. culmorum* reduced plant growth and bulb weight when applied individually. However, simultaneous or sequential co-inoculation did not increase disease severity compared with *F. culmorum* alone, indicating that *D. dipsaci* does not contribute to *F. culmorum*-induced basal rot in onion. In single nematode inoculations, the reproduction factor (RF) was higher in yellow onion (10.7) than in purple onion (9.6). In combined inoculations, RF values ranged from 8.3-9.5 in yellow onion and 5.4-6.4 in purple onion. Notably, *F. culmorum* significantly reduced *D. dipsaci* population density and RF in both cultivars, suggesting an antagonistic interaction. This is the first report demonstrating suppression of *D. dipsaci* by *F. culmorum* in onion, highlighting its potential relevance for integrated nematode management.

Key words: antagonistic interaction, complex disease, onion, stem nematode.

Onion (*Allium cepa* L.) is known to be susceptible to infections caused by pathogenic fungi belonging to *Botrytis* spp., *Fusarium* spp., *Penicillium* spp. and *Pythium* spp. during the early growth phase (Pieta & Kesik, 2008). The primary location in which these pathogens establish a presence is the soil. Several *Fusarium* species have been identified as causative pathogens that result in quantitative and qualitative economic losses in onions. As reported by Schwartz and Mohan (1995), the fungal pathogens *Fusarium culmorum* (Wm.G.Sm.) Sacc. (1892), *F. oxysporum* Schlecht. emend. Snyder & Hansen (1940), *F. solani* (Mart.) Sacc. (1881), *Penicillium verrucosum* var. *cyclopium* (Westling) Samson, Stolk & Hadlok (1976) and *P. verrucosum* var. *verrucosum* Dierckx (1901) have been observed to develop in onion tissues during both the growth period and storage, leading to substantial economic losses. Notably, *Fusarium* basal rot (FBR) poses a major challenge on global onion production. The fungus is also referred to as *Fusarium* rot, *Fusarium* wilt or basal plate rot (Stankovic *et al.*, 2007; Bayraktar *et al.*, 2010). The disease is sometimes referred to as a ‘damping-off’

or ‘die-back’ disease of seedlings (Kintega *et al.*, 2020). The incidence of the disease varies significantly depending on the pathogenicity of the *Fusarium* species, the susceptibility of the cultivars, and the phenological stages of the plant (Köycü & Özer, 1997; Cramer, 2000). *Fusarium oxysporum* and *F. proliferatum* (Matsush.) Nirenberg ex Gerlach & Nirenberg (1982) have been identified as the most common causal agents of FBR in onions (Ghanbarzadeh *et al.*, 2014; Haapalainen *et al.*, 2016; 2023). *Fusarium culmorum* has been proven to have weak virulence in *Allium* species compared to the highly pathogenic *F. oxysporum* and *F. redolens* Wollenw (1913) (Galván *et al.*, 2008). The extent to which *F. culmorum* has a pathogenic effect on onions, or whether it merely uses them as an alternative host, is not yet fully established (Lager, 2011). Although certain *F. culmorum* races are typically the causal organism of *Fusarium* basal rot on garlic, these races are not the primary pathogens of onions (Schwartz & Mohan, 1995).

The following nematodes have been identified as being associated with onion plants: onion stem

nematode (*Ditylenchus dipsaci* (Kühn 1857) Filipjev 1936), root-knot nematodes (*Meloidogyne hapla* Chitwood, 1949; *M. incognita* (Kofoid & White, 1919); *M. javanica* (Treub, 1885) and *M. chitwoodi* Golden, O'Bannon, Santo & Finley, 1980), stubby-root nematode (*Paratrichodorus* sp.) and root lesion nematode (*Pratylenchus penetrans* (Cobb, 1917) Filipjev & Schuurmans Stekhoven, 1941) (Ravichandra, 2014; Becker & Westerdahl, 2018). *Ditylenchus dipsaci* is the best-known endoparasite nematode, causing damage to onion, garlic, tomato and chickpea (Yavuzaslanoglu & Aksay, 2021; Behmand *et al.*, 2022a, b). It has been observed to attack the above-ground plant parts of onions, and has been found to exhibit diverse host races, survival mechanisms and causes losses in storage (Brinkman & Teklu, 2021). In plants infected with *D. dipsaci*, the initial symptoms appear as desiccation of the leaf tips, subsequently accompanied by yellowing, wilting, a reduction in the number and height of stems, and disintegration of the membranes at the base of the stem. This results in cracks, leading to a visible loss of the root system. Its infection has been demonstrated to facilitate the entry of fungi and bacteria into the plant, thereby engendering a dark coloration of the lesions caused by the nematode (Riascos-Ortiz *et al.*, 2023). *Ditylenchus dipsaci* has been shown to cause significant losses in onion plants at a population density of 0.2-10 individuals per 100 g of soil (Subbotin *et al.*, 2005; Riascos-Ortiz *et al.*, 2023). Onion yield losses caused by *D. dipsaci* in Türkiye and worldwide have been reported to reach up to 80% (Sturhan & Brzeski, 1991; Yavuzaslanoglu *et al.*, 2015, 2021; Yavuzaslanoglu & Özsoy, 2020).

Interactions between *D. dipsaci* and soilborne pathogens have been the objects of study on different plants (Griffin, 1987, 1990; Vrain, 1987; Hillnhütter *et al.*, 2011). As Riedel (1988) reported, *D. dipsaci* functions as an entry or susceptibility agent for a fungal pathogen. The co-infection of *Rhizoctonia solani* Kühn and *D. dipsaci* in sugar beet (*Beta vulgaris* L.) was found to increase the level of damage. McDonald *et al.* (2021) found that plants inoculated simultaneously and sequentially with *D. dipsaci* and *F. oxysporum* initially exhibited greater disease intensity and severity than plants inoculated with both pathogens alone. A review of the extant literature failed to yield any information on the interaction between *F. culmorum* and *D. dipsaci* in onion. The objective of this study was to ascertain the interaction between *D. dipsaci* and *F. culmorum* in the basal rot complex in yellow and purple onion cultivars, and to determine the effects of the organisms on each other's development.

MATERIALS AND METHODS

The research was conducted in the Nematology and Biotechnology Laboratory of the Department of Plant Protection, Faculty of Agriculture, Isparta Applied University, Isparta, Türkiye, between March and June 2024. The experiments were conducted using two onion varieties, *i.e.*, yellow onion (Bratko, Sygenta) and purple onion (Mata Hari, Numhens). These two varieties were selected on the basis that they are susceptible to both *D. dipsaci* and *Fusarium* wilt.

***Ditylenchus dipsaci* culture.** *D. dipsaci* carrots were treated with surface sterilisation by soaking in 1% NaOCl-solution (w/w) for 40 minutes. The carrots were cleaned with sterile demineralised water and then placed on a clean bench (Kühnhold *et al.*, 2006). For the experimental set-up, carrot cultures were maintained at 21°C for a period of 8 weeks (Coyne *et al.*, 2014). Subsequently, extraction was performed using a modified Baermann funnel technique (Rodríguez-Kábana & Pope, 1981). Once sufficient carrot discs had been populated for the experiments, the nematodes were prepared for inoculation.

***Fusarium culmorum* culture.** *Fusarium culmorum* isolate, obtained from bulbs, identified through diagnostic procedures, and confirmed for pathogenicity was stored as spore suspensions in 20% glycerol at -80 °C and later cultured on PDA plates at 24 ± 1 °C for colony growth. A 10-day-old *F. culmorum* culture grown at the same temperature was used as the inoculum. Approximately 10 ml of sterile water was added to each Petri dish, and the spores were gently scraped into the water using a spatula. The resulting spore suspension was filtered through two layers of fine cheesecloth, and the conidia concentration was adjusted to 1.7×10^6 conidia/ml. Finally, one drop of Tween 20 was added to ensure homogeneity of the suspension.

Experimental design. The experiment was set up in yellow and purple onions in a randomised plot design, with five replications per treatment. The inoculation of nematodes was divided into three different applications. The study comprised six treatments involving single, simultaneous, and sequential inoculations (Table 1). In the context of the experiment, each pot was regarded as constituting one replication, with a single bulb being planted in each. The study was conducted separately for yellow and purple onions in 14 cm diam. plastic pots containing 1 kg of sterile soil mixture (comprising 68% sand, 21% silt and 11% clay) under climate chamber conditions (24±1°C, 60±5% RH). Inoculations were administered 7 days after

Table 1. Treatments in the study.

Number	Treatments
1	Only <i>Ditylenchus dipsaci</i> (N)
2	Only <i>Fusarium culmorum</i> (F)
3	Simultaneously <i>Dictylenchus dipsaci</i> and <i>Fusarium culmorum</i> (NF)
4	<i>Fusarium culmorum</i> inoculation 7 days after <i>Ditylenchus dipsaci</i> inoculation (N+7F)
5	<i>Ditylenchus dipsaci</i> inoculation 7 days after <i>Fusarium culmorum</i> inoculation (F+7N)
6	Control that only treated with distilled water (C)

planting the bulbs. The nematode and fungus inoculation method was carried out accurately in each pot, with the four inoculation points being placed precisely 1 cm from the stem. These points were meticulously distributed to guarantee equal distances from each other. For single and sequential inoculations, a volume of 40 ml of spore suspension, containing 1.7×10^6 conidia per ml, was utilised for the purpose of fungal inoculation, which was then distributed to the opened points. The nematode inoculation was administered at a rate of 400 individuals in 40 ml solution per plant, which was then dispersed to the designated locations. For the simultaneous inoculation, 40 ml of conidial suspension applied in the same manner followed immediately by the same amount of nematode suspension (400 individuals) injected into each pot. The control plants were inoculated with 40 ml of sterile distilled water (McDonald *et al.*, 2021). It is important to note that all plants were watered according to the established schedule. The experiments were concluded 45 days after inoculations.

Data analysis. At the end of the experiment, plant growth parameters root length (cm) and fresh weight (g), plant height (cm) and fresh weight (g), and bulb fresh weight (g) were taken. Damage on the onion plate was graded from 0 to 3 (0 = no symptoms (<10% infection); 1 = slight infection (10–20% of the basal plate infected); 2 = moderately infected (20–50%); 3 = highly infected (>50% in both foliar region and bulbs) (Rout *et al.*, 2016). The disease percentage was calculated using the basal rot severity scale values as Abbott's formula (control - treatment)/control $\times 100$ (Abbott, 1925). Nematodes were obtained from sampled plants from each pot and extracted from bulb tissue and 200 g of wet soil using the Oostenbrink method (Hooper *et al.*, 2005). Then, they were counted to determine the final nematode population density (Pf). Nematode reproduction factor (RF= Final population (Pf)/initial population (Pi)) (Oostenbrink 1966; Ayaz *et al.*, 2021) was

calculated for each treatment. The calculation of the nematode reproduction factor was done by multiplying the final number by 400, which is the number used per plant (McDonald *et al.*, 2021).

The statistical analysis was conducted using SPSS 20 software (IBM Corporation, Armonk, New York, USA). The results obtained are presented as the mean value $\pm$ standard error. The normality of distribution of all data was initially ascertained through the implementation of Kolmogorov-Smirnov and Shapiro-Wilk tests. Thereafter, one-way ANOVA and Tukey multiple comparison tests were performed on data conforming to normal distribution ($P \leq 0.05$).

RESULTS

***Fusarium culmorum* - *Ditylenchus dipsaci* interaction in yellow onion.** The plant and root length, plant and root wet weight parameters of onions indicated that the highest values were observed in the control, and these parameter values were significantly lower than the control in all treatments ($P \leq 0.05$). Statistical analysis revealed no statistically significant differences between the treatments in these parameters ($P \leq 0.05$). In the root length parameter, the statistical difference between the control, (F) and (NF) treatments was insignificant. With regard to onion weight, a significant decrease was observed in the treatments in comparison to the control, with a statistically significant difference noted between the (N) (4.9 g) and (F+7N) (5.8 g) treatments (Table 2).

The highest soil density was found in N treatment (914.0 individuals (200 g soil)⁻¹). Also (NF), (F+7N) and (N+7F) treatments decreased the nematode population in the soil ($P \leq 0.05$) and was found in the same statistical group (b). The lowest bulb density was observed in (F+7N) (316.0 (100 g soil)⁻¹) and (N+7F) (406.0 (100 g soil)⁻¹) treatments. Compared to (N) treatment, total nematode density decreased in inoculations with fungus. Total nematode density was similar in (NF) and (N+7F) treatments but

Table 2. Plant growth parameters in the interaction between *Fusarium culmorum* and *Ditylenchus dipsaci* in yellow onion.

Treatments	Root length (cm) ¹	Plant length (cm)	Root wet weight (g)	Plant wet weight (g)	Bulb wet weight (g)
C	30.0 ± 1.7 a	49.2 ± 2.6 a	3.3 ± 0.1 a	7.0 ± 0.1 a	10.2 ± 0.2 a
F	21.6 ± 2.0 bc	28.8 ± 1.2 b	1.1 ± 0.0 b	1.7 ± 0.2 b	5.2 ± 0.2 bc
N	23.0 ± 0.9 b	29.6 ± 0.8 b	1.3 ± 0.1 b	1.7 ± 0.1 b	4.9 ± 0.1 c
NF	17.4 ± 1.2 bc	26.2 ± 1.2 b	0.9 ± 0.0 b	1.4 ± 0.2 b	5.5 ± 0.1 bc
F+7N	16.6 ± 1.6 c	29.0 ± 1.4 b	1.8 ± 0.7 b	2.4 ± 1.1 b	5.8 ± 0.1 b
N+7F	16.2 ± 1.3 c	28.2 ± 1.6 b	1.3 ± 1.4 b	1.9 ± 1.7 b	5.4 ± 0.2 bc

¹Lower case letters shown in the same column indicate that the statistical difference between the treatments in plant growth parameters is significant ($P \leq 0.05$). Mean ± standard error.

Table 3. Nematode parameters in the interaction between *Fusarium culmorum* and *Ditylenchus dipsaci* in yellow onion.

Treatments	Nematodes/200 g soil ¹	Nematodes/ plant (Bulb density)	Final nematode (PF)	Reproduction factor (RF)
C	-	-	-	-
F	-	-	-	-
N	914.0 ± 35.2 a	528.0 ± 32.0 a	4308.0 ± 333.4 a	10.7 ± 0.8 a
NF	672.0 ± 16.5 b	442.0 ± 21.3 ab	3802.0 ± 88.0 ab	9.5 ± 0.2 ab
F+7N	604.0 ± 18.6 b	316.0 ± 31.4 c	3336.0 ± 113.2 b	8.3 ± 0.2 b
N+7F	678.0 ± 25.7 b	406.0 ± 21.1 bc	3796.0 ± 131.4 ab	9.4 ± 0.3 ab

¹Lower case letters shown in the same column indicate that the statistical difference between the treatments in disease parameters is significant ($P \leq 0.05$). Mean ± standard error.

higher than (F+7N) treatment but also was found in same statistical group. Reproduction factor was lower in (NF), (N+7F) and (F+7N) treatments than in (N) treatment ($P \leq 0.05$). The lowest reproduction factor was found in (F+7N) treatment with 8.3 (Table 3).

Statistical analysis revealed no statistically significant differences in disease severity or percentage between the (F) treatment and the (NF), (N+7F) and (F+7N) treatments. The disease percentage was found to be the lowest in the (N) treatment group (Table 4).

***Fusarium culmorum* - *Ditylenchus dipsaci* interaction on purple onion.** Despite the negative impact of nematode and fungus treatments on plant growth, significant variations were observed among the treatments in terms of plant growth parameters. The lowest recorded values for plant and root length were observed in the (NF) and (N+7F) treatments.

The lowest recorded plant wet weight was found in (NF) (1.3) and (N+7F) (1.0) treatments. The bulb weight was lower in the (F) (5.4), (N) (5.7) and (F+7N) (6.0) treatments than in the control treatment. However, higher amounts of weight loss were determined in the (NF) (3.8) and (N+7F) (3.7) treatments (Table 5).

The highest soil and bulb nematode density was observed in the (N) treatment. It was determined that nematode density decreased significantly in NF (6.4), F+7N (5.4) and N+7F (5.6) treatments where fungi and nematodes were applied together compared to N (9.6) treatment ($P \leq 0.05$). No statistically significant difference was found between the total nematode density and reproduction factors of NF, F+7N and N+7F treatments (Table 6).

There was no statistically significant difference in disease severity and disease percentage between (F) treatment and (NF), (N+7F) and (F+7N) treatments.

Table 4. Disease severity in the interaction between *Fusarium culmorum* and *Ditylenchus dipsaci* in yellow onion.

Treatment	Disease severity (0-3 index) ¹	Disease rate (%)
C	-	-
F	2.8 ± 0.2 a	70.0 ± 5.0 a
N	0.8 ± 0.3 b	20.0 ± 9.2 b
NF	3.0 ± 0.0 a	75.0 ± 0.0 a
F+7N	3.0 ± 0.0 a	75.0 ± 0.0 a
N+7F	2.6 ± 0.2 a	65.0 ± 6.1 a

¹ Lower case letters shown in the same column indicate that the statistical difference between the treatments in disease parameters is significant ($P \leq 0.05$). Mean ± standard error.

Table 5. Plant growth parameters in *Fusarium culmorum*-*Ditylenchus dipsaci* interaction in purple onion.

Treatment	Root length (cm) ¹	Plant length (cm)	Root wet weight (g)	Plant wet weight (g)	Bulb wet weight (g)
C	29.6 ± 1.7 a*	53.2 ± 1.6 a	3.1 ± 0.1 a	7.3 ± 0.3 a	10.5 ± 0.5 a
F	25.4 ± 1.2 abc	36.8 ± 1.9 bc	1.5 ± 0.0 b	2.2 ± 0.2 b	5.4 ± 0.2 b
N	25.2 ± 1.9 abc	33.4 ± 1.2 bcd	1.8 ± 0.1 b	2.4 ± 0.1 b	5.7 ± 0.1 b
NF	19.0 ± 1.8 c	27.4 ± 1.1 d	1.0 ± 0.1 b	1.3 ± 0.1 c	3.8 ± 0.1 c
F+7N	26.6 ± 1.8 ab	39.6 ± 1.9 b	1.5 ± 0.0 b	2.8 ± 0.1 b	6.0 ± 0.2 b
N+7F	20.8 ± 1.1 bc	32.2 ± 1.5 cd	2.5 ± 1.6 ab	1.0 ± 0.0 c	3.7 ± 0.0 c

¹ Lower case letters shown in the same column indicate that the statistical difference between the treatments in plant growth parameters is significant ($P \leq 0.05$). Mean ± standard error.

Table 6. Nematode parameters in *Fusarium culmorum*-*Ditylenchus dipsaci* interaction in purple onion.

Treatment	Soil density (200 g) ⁻¹	Bulb density plant ⁻¹	Final nematode (PF)	Reproduction factor (RF)
C	-	-	-	-
F	-	-	-	-
N	706.0 ± 34.2 a	318.0 ± 27.8 a	3842.0 ± 191.1 a	9.6 ± 0.4 a
NF	478.0 ± 24.9 b	193.0 ± 12.8 b	2583.0 ± 120.3 b	6.4 ± 0.3 b
F+7N	404.0 ± 31.8 b	180.0 ± 3.5 b	2200.0 ± 159.1 b	5.4 ± 0.3 b
N+7F	412.0 ± 24.1 b	188.0 ± 10.6 b	2248.0 ± 122.3 b	5.6 ± 0.3 b

¹ Lower case letters shown in the same column indicate that the statistical difference between treatments in nematode parameters is significant ($P \leq 0.05$). Mean ± standard error.

Disease severity and disease percentage of N treatment were significantly lower than the other treatments (Table 7).

DISCUSSION

In this study, the interaction of *D. dipsaci* and *F.*

culmorum on onion was investigated by means of sequential, simultaneous and single inoculation. In comparison with the control, the presence of nematodes and fungi had a detrimental effect on the growth of plants and bulbs in both yellow and purple onions. In the case of the purple onion variety, the lowest plant and bulb growth parameters were found

Table 7. Disease parameters in *Fusarium culmorum*-*Ditylenchus dipsaci* interaction in purple onion.

Treatment	Disease severity (0-3 index) ¹	Disease rate (%)
C	-	-
F	2.8 ± 0.2 a	70.0 ± 5.0 a
N	0.8 ± 0.3 b	20.0 ± 9.2 b
NF	3.0 ± 0.0 a	75.0 ± 0.0 a
F+7N	2.4 ± 0.2 a	60.0 ± 6.1 a
N+7F	2.8 ± 0.2 a	70.0 ± 5.0 a

¹Lower case letters shown in the same column indicate that the statistical difference between treatments in disease parameters is significant ($P \leq 0.05$). Mean ± standard error.

in the simultaneous (NF) treatment and fungus (N+7F) treatment 7 days after nematode inoculation. The present study demonstrated that the (F+7N) treatment resulted in superior plant growth in comparison to the other two treatments. In yellow and purple onion varieties, the *F. culmorum* (F) and *D. dipsaci* (N) treatments alone caused similar damage to plant and onion development. No statistical difference was found in the disease severity and percentage results in NF, F+7N and N+7F inoculations of *D. dipsaci* and *F. culmorum*. In particular, no positive or negative effect of consecutive inoculations on the development of *F. culmorum* was determined in both varieties. This occurrence may be attributed to the root secretions of the *Allium cepa* plant. This phenomenon requires further investigation. A study on gerbera (*Gerbera jamesonii* Hook) demonstrated that *M. incognita* infection increased the susceptibility of plants to *F. oxysporum* f. sp. *gerbera*, resulting in increased severity and progression of wilt (Meena *et al.*, 2015). Castillo *et al.* (1998) studied the interaction between *Pratylenchus thornei* Sher & Allen, 1953 and *F. oxysporum* f. sp. *ciceris* on *Fusarium* wilt in chickpea (*Cicer arietinum* L.). They found that *Fusarium* wilt was more severe when *P. thornei* inoculation occurred 10 days before fungus inoculation than when plants were inoculated simultaneously or with either pathogen alone. In addition, studies conducted with different pathogens on different plants reported that fungi developed better and disease severity increased in the presence of nematodes (Hoseini *et al.*, 2010; Mallaiah *et al.*, 2014). These results are not consistent with the present study we conducted. In this study, it was determined that *D. dipsaci* infection had no effect on the development and infection of *F. culmorum* in onion cultivars in simultaneous and sequential inoculations with *F. culmorum* alone. It has also been shown that *F. culmorum* infects purple and yellow onions, but there is no difference between

varieties.

The study determined that *D. dipsaci* population density in both yellow and purple onions was significantly suppressed in all applications with *F. culmorum* in the soil, plant and onion. It was found that this negative effect did not change irrespective of simultaneous or sequential inoculations, and nematode population densities were similar. When only the N application was evaluated, it was determined that *D. dipsaci* developed better in yellow onions. The nematode reproduction factor values of the applications were found to be lower in purple onions than in yellow onions. In the present study, a negative effect of *F. culmorum* on *D. dipsaci* reproduction was identified. This assertion was made by McDonald *et al.* (2021), it was hypothesised that the formation of physical barriers, such as the basal layer of mycelium mat, could be induced by defence responses to *F. oxysporum*'s primary infection. Such responses, which may include the thickening of cell walls or competition for nutrients, could potentially enhance the reproductive capacity of *D. dipsaci*. As posited by Mokbel *et al.* (2007), the presence of fungal colonies at a level sufficient to impede nematode penetration, or the location of fungal colonies that have been colonised by nematodes for feeding purposes, may result in a decline in nematode population density. In their study, Hillnhütter *et al.* (2011) investigated the interaction between *D. dipsaci* and *R. solani* in sugar beets. As previously mentioned, the findings indicated that these parasites have the capacity to interact with other harmful organisms, thereby exerting a deleterious synergistic effect on the yield of sugar beets. In the event of the simultaneous infection of a plant by a pathogen and a nematode, the level of damage caused to the plant is significantly higher than that caused by the application of *R. solani* alone. In addition, the number of *D. dipsaci* in plant is lower when the plants are infected with pathogens or nematodes, as

compared to those infected with *D. dipsaci* alone. In the study conducted by Isadeha *et al.* (2025), the co-inoculation of *D. gigas* Vovlas *et al.*, 2011 and *Botrytis fabae* Sardiña, 1929 was undertaken within the confines of a plant bioculture. In the context of the *D. gigas* population in the fabae, an antagonistic interaction has been observed. It has been hypothesised that the number of nematodes obtained from the application of *D. gigas* in isolation is greater than the number obtained from the application of two organisms in combination. Regmi *et al.* (2022) reported that the reproduction factor of stem nematodes decreased in the presence of *F. oxysporum* f. sp. *lycopersici*, but the damage was higher in tomato plants with both pathogens. McDonald *et al.* (2021) found the highest nematode reproduction factor in garlic plants inoculated only with *D. dipsaci*, while the nematode reproduction factor decreased when *F. oxysporum* f. sp. *cepae* was inoculated before *D. dipsaci*. In a study conducted on wheat with twelve *F. culmorum* isolates, it was determined that only three isolates formed a synergistic relationship with *P. thornei* in simultaneous and sequential inoculations, while no interaction was detected in the other isolates (Göze Özdemir *et al.*, 2023). When *F. culmorum* first infected wheat, a decrease in the densities of *P. thornei* SK11 and SK24 populations was observed, while no negative effect was detected in the YLVC24 population (Göze Özdemir *et al.*, 2022). The lowest nematode density was found in *Pratylenchus loosi* Loof, 1960 treatment 2 weeks after *F. proliferatum* (Matsush.) inoculation in tea plants (Hoseini *et al.*, 2010). Saadabi & Yassin (2007) conducted a study with *Pratylenchus sudanensis* Loof & Yassin, 1971 and *F. oxysporum* f.sp. *vasinfectum* on cotton plants and found that the total nematode density in the soil and root was highest in the *P. sudanensis* treatment. The nematode density decreased in the other concurrent treatment and in the nematode treatment 7 days before the fungus, while the highest decrease was observed in the fungus treatment 7 days before nematode infection. *Fusarium oxysporum* f. sp. *medicaginis* has been observed to have an impact on the growth of alfalfa, yet no effect on the reproduction of *D. dipsaci* (Griffin, 1990). Moreover, certain secondary metabolites of *Fusarium* species have been documented as effective against plant-parasitic nematodes in studies conducted with stem nematodes (Kundu *et al.*, 2016; Bogner *et al.*, 2017; Ali *et al.*, 2023).

This study constitutes the first investigation into the interaction of *D. dipsaci* and *F. culmorum* on onion plants under controlled conditions. The present study sets out to compare the effects of sequential,

simultaneous and single inoculation with *F. culmorum* and *D. dipsaci*. The infection of the plant by both pathogens resulted in a negative impact on its growth. The present study found that *D. dipsaci* did not contribute to the disease severity caused by *F. culmorum* in onion. However, inoculation of *F. culmorum* in onion reduced the reproduction factor of *D. dipsaci*. This is the first study to demonstrate that *F. culmorum* has the capacity to mitigate the damage caused by *D. dipsaci* to onions. Further studies are needed to understand the physiological and ecological mechanisms underlying this antagonistic interaction.

ACKNOWLEDGEMENTS

Thanks to Prof. Dr Yusuf Yanar for the *Fusarium culmorum* isolate and confirmatory diagnosis.

REFERENCES

- ABBOTT, W.S. 1925. A method for computing the effectiveness of insecticides. *Journal of Economic Entomology* 18: 265-267. DOI: 10.1093/jee/18.2.265a
- ALI, A., ÖLMEZ, F., TATAR, M., TABBASUM, I., AZEEM, H., SARWAR, R. & ALI, F. 2023. Mycotoxin production by *Fusarium* species and a recent deep insight into management through biocontrol approaches. *Journal of Global Innovations in Agricultural Sciences* 11: 455-480. DOI: 10.22194/JGIAS/23.1234
- AYAZ, İ., KASAPOĞLU ULUDAMAR, E.B., BEHMAND, T. & ELEKCIOĞLU, H.I. 2021. Investigation of the development of root lesion nematodes, *Pratylenchus* spp. (Tylenchida: Pratylenchidae) in three chickpea cultivars. *Turkish Journal of Entomology* 45: 23-31. DOI: 10.16970/entoted.753614
- BAYRAKTAR, H., TÜRKKAN, M. & DOLAR, F.S. 2010. Characterization of *Fusarium oxysporum* f. sp. *cepae* from onion in Turkey based on vegetative compatibility and rDNA RFLP analysis. *Journal of Phytopathology* 158: 691-697. DOI: 10.1111/j.1439-0434.2010.01685.x
- BECKER, J.O. & WESTERDAHL, B.B. 2018. *Onion and Garlic Nematodes*. UC IPM Pest Management Guidelines. UC ANR Publication 3453.
- BEHMAND, T., KASAPOĞLU ULUDAMAR, E.B. & ELEKCIOĞLU, I.H. 2022A. Development of an *in vivo* bioassay to identify Turkish chickpea genotypes resistance to *Ditylenchus dipsaci* (Kühn, 1857) (Tylenchida: Anguinidae). *Turkish Journal of Entomology* 46: 89-98. DOI: 10.16970/entoted.1022988
- BEHMAND, T., KASAPOĞLU ULUDAMAR, E.B. & ELEKCIOĞLU, I. 2022B. Vertical distribution of root lesion nematodes (*Pratylenchus thornei* (Sher et Allen)

- Pratylenchus neglectus* (Rensch) Filipjev & Schuurmans Stekhoven (Tylenchida: Pratylenchidae) and stem and bulb nematode *Ditylenchus dipsaci* (Kühn, 1857) (Tylenchida: Anguinidae) on chickpea growing areas in Turkey. *KSU Journal of Agriculture and Natural* 25: 282-291. DOI: 10.18016/ksutarimdoga.vi.887744
- BOGNER, C.W., KAMDEM, R.S., SICHTERMANN, G., MATTHÄUS, C., HÖLSCHER, D., POPP, J. & SCHOUTEN, A. 2017. Bioactive secondary metabolites with multiple activities from a fungal endophyte. *Microbial Biotechnology* 10: 175-188. DOI: 10.1111/1751-7915.12467
- BRINKMAN, P. & TEKLU, M.G. 2021. Integrated nematode management of *Ditylenchus dipsaci* in onion: a nematode in a world all on its own. In: *Integrated nematode management: state-of-the-art and visions for the future* (R.A. Sikora, J. Desaegeer & L. Molendijk. Eds.). pp. 297-303. Wallingford, UK. CAB International. DOI: 10.1079/9781789247541.0041
- CASTILLO, P., MORA-RODRÍGUEZ, M.P., NAVAS-CORTÉS, J.A. & JIMÉNEZ-DÍAZ, R.M. 1998. Interactions of *Pratylenchus thornei* and *Fusarium oxysporum* f. sp. *ciceris* on chickpea. *Phytopathology* 88: 828-836.
- CRAMER, C.S. 2000. Breeding and genetics of *Fusarium* basal rot resistance in onion. *Euphytica* 115: 159-166. DOI: 10.1023/A:1004071907642
- GALVÁN, G.A., KONING-BOUCOIRAN, C.F., KOOPMAN, W.J., BURGER-MEIJER, K., GONZÁLEZ, P.H., WAALWIJK, C. & SCHOLTEN, O.E. 2008. Genetic variation among *Fusarium* isolates from onion, and resistance to *Fusarium* basal rot in related *Allium* species. *European Journal of Plant Pathology* 121: 499-512. DOI: 10.1007/s10658-008-9270-9
- GHANBARZADEH, B., GOLTAPPEH, E.M. & SAFAIE, N. 2014. Identification of *Fusarium* species causing basal rot of onion in East Azarbaijan province, Iran and evaluation of their virulence on onion bulbs and seedlings. *Archives of Phytopathology and Plant Protection* 47: 1050-1062. DOI: 10.1080/03235408.2013.829628
- GÖZE ÖZDEMİR, F.G., ARICI, Ş.E. & ELEKCIOĞLU, İ.H. 2022. Interaction of three populations of *Pratylenchus thornei* with *Fusarium culmorum* in wheat plant. *KSU Journal of Agriculture and Nature* 25:1042-1050. DOI: 10.18016/ksutarimdoga.vi.947535
- GÖZE ÖZDEMİR, F.G., ARICI, Ş.E. & ELEKCIOĞLU, İ.H. 2023. Interaction of different *Fusarium culmorum* isolates and *Pratylenchus thornei* on wheat. *Journal of Tekirdağ Agricultural Faculty* 20: 1-11. DOI: 10.33462/jotaf.1017523
- GRIFFIN, G.D. 1987. Interaction of *Ditylenchus dipsaci* and *Meloidogyne hapla* on resistant and susceptible plant species. *Journal of Nematology* 19: 441.
- GRIFFIN, G.D. 1990. Pathological relationship of *Ditylenchus dipsaci* and *Fusarium oxysporum* f. sp. *medicaginis* on alfalfa. *Journal of Nematology* 22: 333.
- HAAPALAINEN, M., LATVALA, S., KUIVAINEN, E., QIU, Y., SEGERSTEDT, M. & HANNUKALA, A.O. 2016. *Fusarium oxysporum*, *F. proliferatum* and *F. redolens* associated with basal rot of onion in Finland. *Plant Pathology* 65: 1310-1320. DOI: 10.1111/ppa.12521
- HAAPALAINEN, M., KUIVAINEN, E., LIVONEN, S., NIEMI, M. & LATVALA, S. 2023. Pathogenicity of *Fusarium oxysporum* and *Fusarium proliferatum* isolates from symptomless onions (*Allium cepa*) and onions with *Fusarium* basal rot. *Plant Pathology* 72: 1122-1135. DOI: 10.1111/ppa.13718
- HILLNHÜTTER, C., ALBERSMEIER, A., BERDUGO, C.A. & SIKORA, R.A. 2011. Synergistic damage by interactions between *Ditylenchus dipsaci* and *Rhizoctonia solani* (AG 2-2IIIB) on sugar beet. *Journal of Plant Diseases and Protection* 118: 127-133. DOI: 10.1007/BF03356392
- HOOVER, D.J., HALLMANN, J. & SUBBOTIN, S.A. 2005. Methods for extraction, processing and detection of plant and soil nematodes. In: *Plant Parasitic Nematodes in Subtropical and Tropical Agriculture* (M. Luc, R.A. Sikora & J. Bridge. Eds.). pp. 53-86. Wallingford, UK. CAB International.
- HOSEINI, S.M.N., POURJAM, E. & GOLTAPPEH, E.M. 2010. Synergistic studies on interaction of nematode-fungal system of tea plant in Iran. *Journal of Agricultural Science and Technology* 6: 487-496.
- ISADEHA, A., SHAW, M.W. & PEMBROKE, B. 2025. Spatial spread of *Ditylenchus gigas* and its interaction with *Botrytis fabae* on *Vicia faba*. *Annals of Applied Biology* 186: 125-131. DOI: 10.1111/aab.12945
- KINTEGA, K.R., ZIDA, P.E., TARPAGA, V.W., SANKARA, P. & SEREME, P. 2020. Identification of *Fusarium* species associated with onion (*Allium cepa* L.) plants in field in Burkina Faso. *Advances in Bioscience and Biotechnology* 11: 94-110. DOI: 10.4236/abb.2020.113008
- KÖYCÜ, N.D. & ÖZER, N. 1997. Determination of seedborne fungi in onion and their transmission to onion sets. *Phytoparasitica* 25: 25-31. DOI: 10.1007/BF02981476
- KUNDU, A., SAHA, S., WALIA, S. & DUTTA, T.K. 2016. Anti-nemic secondary metabolites produced by *Fusarium oxysporum* f. sp. *ciceris*. *Journal of Asia-Pacific Entomology* 19: 631-636. DOI: 10.1016/j.aspen.2016.06.003
- KÜHNHOLD, V., KIEWNICK, S. & SIKORA, R. 2006. Development of an *in vitro* bioassay to identify sugar beet resistance to the stem nematode *Ditylenchus dipsaci*. *Nematology* 8: 641-645. DOI: 10.1163/156854106778877875
- LAGER, S. 2011. Survey of *Fusarium* species on yellow onion (*Allium cepa*) on Öland. Swedish (SLU), Swedish University of Agricultural Science, Uppsala.

- MALLAIAH, B., MUTHAMILAN, M., PRABHU, S. & ANANTHAN, R. 2014. Studies on interaction of nematode, *Pratylenchus delattrei* and fungal pathogen, *Fusarium incarnatum* associated with crossandra wilt in Tamil Nadu, India. *Current Biotica* 8: 157-164.
- MCDONALD, M.R., IVES, L., ADUSEI-FOSU, K. & JORDAN, K.S. 2021. *Ditylenchus dipsaci* and *Fusarium oxysporum* on garlic: One plus one does not equal two. *Canadian Journal of Plant Pathology* 43: 749-759. DOI: 10.1080/07060661.2021.1910345
- MEENA, K.S., RAMYABHARATHI, S.A., RAGUCHANDER, T. & JONATHAN, E.I. 2015. *Meloidogyne incognita* and *Fusarium oxysporum* interaction in Gerbera. *African Journal of Microbiology Research* 9: 1281-1285. DOI: 10.5897/AJMR2015.7450
- MOKBEL, A.A., IBRAHIM, I.K.A., SHEHATA, M.R.A. & EL-SAEEDY, M.A.M. 2007. Interaction between certain root-rot fungi and the root-knot nematode, *Meloidogyne incognita* on sunflower plants. *Egyptian Journal of Phytopathology* 35: 1-11.
- OOSTENBRINK, M. 1966. *Major Characteristics of the Relation Between Nematodes and Plants*. Mededelingen Landbouwhogeschool. Wageningen 66-4: 1-46.
- PIETA, D. & KESIK, T. 2008. The influence of after-crop plant mulch and onion cultivation on microorganism composition in soil. *Acta Scientiarum Polonorum Hortorum Cultus* 7: 65-75.
- RAVICHANDRA, N.G. 2014. Nematode Diseases of Horticultural Crops. In: *Horticultural Nematology* (N.G. Ravichandra. Ed.). pp. 127-205. New Delhi, India, Springer. DOI: 10.1007/978-81-322-1841-8_8
- REGMI, H., VALLAD, G.E., HUTTON, S.F. & DESAEGER, J. 2022. Interaction studies between *Meloidogyne javanica* and *Fusarium oxysporum* f. sp. *lycopersici* (Fol) Race 3 on different isolines of tomato cv. Tasti Lee. *Journal of Nematology* 54: 20220018. DOI: 10.2478/jofnem-2022-0018
- RIASCOS-ORTIZ, D., CAICEDO-CASTRO, J., ARBOLEDA-RIASCOS, C., SÁNCHEZ, F., MOSQUERA-ESPINOSA, A.T. & DE AGUDELO, F.V. 2023. Morpho-molecular characterization of *Ditylenchus dipsaci* and alternatives for its management in green onion *Allium fistulosum* Crops from Colombia. *Agricultural Sciences* 14: 1516-1534.
- RIEDEL, R.M. 1988. Interactions of plant-parasitic nematodes with soil-borne plant pathogens. *Agriculture, Ecosystems & Environment* 24: 281-292.
- ROUT, E., TRIPATHY, P., NANDA, S., NAYAK, S. & JOSHI, R.K. 2016. Evaluation of cultivated and wild *Allium* accessions for resistance to *Fusarium oxysporum* f. sp. *cepae*. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences* 86: 643-649. DOI: 10.1007/s40011-015-0506-0
- RODRIGUEZ-KABANA, R. & POPE, M. H. 1981. A simple incubation method for the extraction of nematodes from soil. *Nematropica* 11: 175-185.
- SAADABI, A.M.A. & YASSIN, A.M. 2007. Role of *Pratylenchus sudanensis*, a root-lesion nematode in the syndrome of cotton wilt in Gezira area of Sudan. *Agricultural Journal* 2: 415-418.
- SCHWARTZ, H.F. & MOHAN, S.K. 1995. *Compendium of Onion and Garlic Diseases*. The American Phytopathological Society, Minnesota. 54 pp.
- STANKOVIC, S., LEVIC, J., PETROVIC, T., LOGRIECO, A. & MORETTI, A. 2007. Pathogenicity and mycotoxin production by *Fusarium proliferatum* isolated from onion and garlic in Serbia. *European Journal of Plant Pathology* 118: 165-172. DOI: 10.1007/s10658-007-9126-8
- STURHAN, D. & BRZESKI, M.W. 1991. Stem and bulb nematodes, *Ditylenchus* spp. In: *Manual of Agricultural Nematology* (W.R. Nickle. Ed.). pp. 423-464. New York, USA. Marcel Dekker, Inc.
- SUBBOTIN, S.A., MADANI, M., KRALL, E., STURHAN, D. & MOENS, M. 2005. Molecular diagnostics, taxonomy and phylogeny of the stem nematode *Ditylenchus dipsaci* species complex based on the sequences of the ITS-rDNA. *Phytopathology* 95: 1308-1315. DOI: 10.1094/PHYTO-95-1308
- VRAIN, T.C. 1987. Effect of *Ditylenchus dipsaci* and *Pratylenchus penetrans* on *Verticillium* wilt of alfalfa. *Journal of Nematology* 19: 379.
- YAVUZASLANOĞLU, E., DIKICI, A. & ELEKCIOĞLU, İ.H. 2015. Effect of *Ditylenchus dipsaci* Kühn, 1857 (Tylenchida: Anguinidae) on onion yield in Karaman Province, Turkey. *Turkish Journal of Agriculture and Forestry* 39: 227-233.
- YAVUZASLANOĞLU, E. & ÖZSOY, V.S. 2020. Resistance reactions of onion landraces collected from Turkey to the stem and bulb nematode *Ditylenchus dipsaci*. *Mediterranean Agricultural Sciences* 33: 195-199. DOI: 10.29136/mediterranean.691432
- YAVUZASLANOĞLU, E. & AKSAY, G., 2021. Susceptibility of different plant species to two populations of *Ditylenchus dipsaci* Kühn, 1857 (Tylenchida: Anguinidae) from Turkey. *Turkish Journal of Entomology* 45: 77-86. DOI: 10.16970/entoted.795993
- YAVUZASLANOĞLU, E., AKSAY, G. & ÇETINKAYA, A. 2021. *In vitro* effectiveness of some plant species as green manure for the control of stem and bulb nematode (*Ditylenchus dipsaci*). *Anatolian Journal of Botany* 5: 32-36. DOI: 10.30616/ajb.866427

F. G. Göze Özdemir, Ş. E. Arıcı, E. B. Kasapoğlu Uludamar and İ. H. Elekcioglu. Взаимодействие между *Fusarium culmorum* и *Ditylenchus dipsaci* при заражении фиолетового и жёлтого лука.

Резюме. В данном исследовании изучали взаимодействие гриба *Fusarium culmorum*, вызывающего корневую гниль, и стеблевой нематоды *Ditylenchus dipsaci* на луке в контролируемых условиях. Как *D. dipsaci*, так и *F. culmorum* при отдельном внесении снижали рост растений и массу луковиц. Однако одновременная или последовательная совместная инокуляция не приводила к увеличению степени поражения по сравнению с инокуляцией только *F. culmorum*, что указывает на то, что *D. dipsaci* не способствует развитию базальной гнили лука, вызываемой *F. culmorum*. При инокуляции только нематодой коэффициент размножения (RF) был выше у желтого лука (10,7), чем у фиолетового (9,6). При совместной инокуляции значения RF составляли 8,3-9,5 у желтого лука и 5,4-6,4 у фиолетового лука. Примечательно, что *F. culmorum* значительно снижал плотность популяции *D. dipsaci* и коэффициент её размножения у обоих сортов, что свидетельствует об антагонистическом взаимодействии. Это первое сообщение, демонстрирующее подавление *D. dipsaci* грибом *F. culmorum* на луке, что подчеркивает потенциальную значимость данного взаимодействия для интегрированной системы управления численностью нематод.
