RESEARCH/INVESTIGACIÓN

THE EFFICACY of FOSTHIAZATE, FLUOPYRAM, AND *PAECILOMYCES LILACINUS* AGAINST FIELD POPULATION OF *GLOBODERA ROSTOCHIENSIS*

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ABSTRACT

Saleh, A., A. Altaş, E. Evlice, G. Özer, M. İmren, and A. A. Dababat. 2022. The efficacy of fosthiazate, fluopyram, and *Paecilomyces lilacinus* against field population of *Globodera rostochiensis*. Nematropica 52:8-18.

The potato cyst nematode, *Globodera rostochiensis*, is a major potato pest throughout the world. Despite the environmental concerns associated with the use of chemical nematicides, they remain essential for integrated management programs, especially when resistant varieties are lacking. This study investigated fosthiazate efficacy to control *G. rostochiensis* in potato in comparison to fluopyram and the biological control agent *Paecilomyces lilacinus* strain PL1. Two independent trials were carried out at fields in Ödemiş and Bozdağ Districts, İzmir Province, Turkey. All treatments reduced densities of *G. rostochiensis* in roots and soil compared to the non-treated controls. All pesticides consistently decreased the reproduction factor (Rf = final population density/initial population density) values of *G. rostochiensis* compared to the non-treated controls in Ödemiş and Bozdağ. However, fosthiazate and fluopyram were more effective than the biological agent. Fosthiazate, fluopyram, and *P. lilacinus* strain PL1 applications increased potato yields in Ödemiş and Bozdağ by 21-34% and 20-31%, respectively, compared to the control. In conclusion, the application of fosthiazate and fluopyram provided a higher level of protection against *G. rostochiensis* and should be considered an alternative and integrative option in nematode management programs.

Key words: Fluopyram, fosthiazate, *Globodera rostochiensis*, management, nematicide, *Paecilomyces lilacinus*, potato

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RESUMEN

Saleh, A., A. Altaş, E. Evlice, G. Özer, M. İmren, y A. A. Dababat. 2022. La eficacia del fostiazato, fluopiram, y *Paecilomyces lilacinus* contra una población de *Globodera rostochiensis* de campo. Nematropica 52:8-18.

El nematode del quiste de la papa, *Globodera rostochiensis*, es una de las principales plagas de la papa en todo el mundo. A pesar de las preocupaciones ambientales asociadas con el uso de nematicidas químicos, siguen siendo esenciales para los programas de manejo integrado, especialmente cuando no exiten variedades resistentes. Este estudio investigó la eficacia del fostiazato para controlar *G. rostochiensis* en papa en comparación con fluopiram y el agente controlador biológico *Paecilomyces lilacinus* cepa PL1. Se llevaron a cabo dos ensayos independientes en campos de los distritos de Ödemiş y Bozdağ, provincia de İzmir, Turkey. Todos los tratamientos redujeron las densidades de *G. rostochiensis* en raíces y suelo en comparación con los controles no tratados. Todos los pesticidas redujeron consistentemente los valores del factor de reproducción (FR) de *G. rostochiensis* en comparación con los controles no tratados en Ödemiş y Bozdağ. Sin embargo, fostiazato y fluopiram fueron más efectivos que el agente biológico. Además, el fostiazato aumentó el rendimiento de la papa en Ödemiş, mientras que la cepa PL1 de *P. lilacinus* aumentó menos en Bozdağ con aumentos del 21-34 % y del 19-30 % que el control no tratado, respectivamente. En conclusión, la aplicación de fostiazato y fluopiram proporcionó un mayor nivel de protección contra *G. rostochiensis* y debe considerarse una opción alternativa e integradora en los programas de manejo de nematodos.

Palabras clave: Fluopiram, fostiazato, *Globodera rostochiensis*, nematicida, manejo, *Paecilomyces lilacinus*, papa

INTRODUCTION

The potato cyst nematodes (PCN), *Globodera pallida* (Stone) Behrens and *Globodera rostochiensis* (Wollenweber) Skarbilovich, have been reported to cause economic damage in global potato production (Subbotin *et al.*, 2010). These nematodes are root parasites that reduce potato yield quality and quantity. The global losses caused by PCN are between 10% and 12% (Urwin *et al.*, 2001; Bates *et al.*, 2002). In Europe, losses of 9% have been reported due to PCN (Turner *et al.*, 2006). In Turkey, the annual loss in potato production due to PCN is estimated at ₺23 million (TurkStat, 2020). The main potato-growing areas in Turkey, including İzmir, Nevşehir, and Niğde Provinces, are commonly infested by both *G. rostochiensis* and *G. pallida* (Kepenekci *et al.*, 2012; Ulutaş *et al.*, 2012). However, the incidence of *G. rostochiensis* is much greater than for *G. pallida* and is reported to have reached 67% in potato fields where PCN was detected (İmren, 2018; Özarslandan *et al.*, 2019; Altaş *et al.*, 2020; Toktay *et al.*, 2020).

As in other countries, the control of PCN in Turkey is commonly acheived by using an integrated pest management strategy, which comprises the application of nematicides, the use of tolerant and/or resistant varieties, and crop rotation (Kepenekci *et al.*, 2012; Ulutaş *et al.*, 2012). The use of chemical nematicides is still necessary in Turkey considering the lack of tolerant and/or resistant varieties to *G. rostochiensis* and the economic constraints associated with the long crop rotations needed to ensure reasonable control of PCN (Kepenekci *et al.*, 2012). In Turkey, concerns about the negative role of agricultural chemicals on human health and the environment and changes in EU legislation may limit the availability and use of many nematicides in the future (Pesticides Database, https://ec.europa.eu/food/plants/pesticides/ eu-pesticides-database_en). Currently, the Pesticide Registration Committee at the Turkish Ministry of Agriculture and Forestry has regulated the use of many nematicides, including terbufos (Counter® 10G), cadusafos (Rugby® 10G), and aldicarb (Temik® 10G) for application on vegetables in Turkey (PPP, 2016). However, nematode control relying on a limited number of alternative compounds carry numerous health, environmental and economic risks due to high mammalian toxicity, risk of developing accelerated degradation, pest resistance due to the reuse of chemicals, and possible low efficacy of some compounds against plant-parasitic nematodes (Pattison *et al.*, 2000). Some of the existing nematicides might be banned for agricultural purposes in the EU by 2023. Thus, there is increasing motivation to expand the range of available alternative products to be used to control PCN.

Fosthiazate directly inhibits acetylcholinesterase (AChE), blocking normal nerve impulse conduction in the nervous system of the target nematodes (Xu, 2007). The root-knot nematodes, *Meloidogyne* spp., are the most targeted nematodes by fosthiazate applications. High efficacy of fosthiazate has been shown to control nematodes in tobacco (*Meloidogyne* *javanica*, *M. arenaria*, and *M. incognita*: Rich *et al.*, 1994), potato (*G. rostochiensis* and *G. pallida*: Tobin *et al.* 2008), tomato (*M. incognita*: Saad *et al.*, 2011), banana (*Meloidogyne* spp., *Radopholus similis*, *Helicotylenchus multicinctus*, and *Hoplolaimus seinhorsti*: Chabrier *et al.*, 2002), tobacco (*Globodera tabacum*: LaMondia, 2002), cereals (*Heterodera avenae*: Cui *et al.* 2017), and peanut (*M. arenaria*: Dickson and DeWaele, 2005). Different formulations of fosthiazate (10% fosthiazate granule, 150 g/l or 900 g/l fosthiazate emulsifiable concentrate) are registered in Turkey as nematicides against plant-parasitic nematodes such as *Meloidogyne* spp. in tomato, potato, pepper, and cucumber, and *Meloidogyne* spp. and *H. multicinctus* in banana production (PPP, 2016). Fosthiazate is also registered in Turkey for *Meloidogyne* spp. management in tomato as a mixture with abamectin (10% fosthiazate + 0.5% abamectin, granule formulation).

Fluopyram (N-{2-[3-chloro-5-(trifluoromethyl)-2-pyridyl]ethyl}-α,α,α-trifluoro-o-toluamide) was developed and registered by Bayer CropScience as a broad-spectrum fungicide to control a variety of Ascomycetes and Deuteromycetes in many high-value crops (Chawla *et al.*, 2018; Kandel *et al.*, 2018a). Fluopyram works by inhibiting succinate dehydrogenase (SDH) in the tricarboxylic acid cycle and blocking the electron transport in mitochondria of fungi (Abad-Feuntes *et al.*, 2015). Fluopyram is not only used for the control of fungal diseases but has also been evaluated for its nematicidal activity (Faske and Hurd, 2015). Jones *et al.* (2017) reported that fluopyram suppresssed *M. incognita* in lima beans. A recent study demonstrated the efficacy of fluopyram applied as seed treatments for reducing the activity of *Heterodera glycines* (Beeman *et al.*, 2019). Another study reported that the soil application of fluopyram was promising in controlling *Belonolaimus longicaudatus* in strawberry in Florida (Watson and Desaeger, 2019).

Paecilomyces lilacinus (Thom) Samson is one of the most widely tested biocontrol agents for controlling plant-parasitic nematodes (Kiewnick and Sikora, 2006; Akhtar and Jitendra Panwar, 2011). The fungus is now a well-recognized biocontrol agent against *Meloidogyne* spp. on various crop plants (Khan *et al.*, 2006; Kiewnick and Sikora, 2006). In laboratory tests, the efficiency of this fungus on the eggs and females of *Meloidogyne* spp. was confirmed within a week (Khan *et al.*, 2006). The production of secondary metabolites by *P. lilacinus*, including leucinotoxins, chitinase, protease, and acetic acid, plays an essential role during the infection process associated with reducing nematode populations (Yang *et al.*, 2011). This fungus had the unique adaptability to grow in wide ranges of soil pH, making it a competitive biocontrol agent in most agricultural soil. Upon introduction, *P. lilacinus* becomes the dominant species in a very short period, which improves plant growth attributes and reduces nematode population densites (Siddiqui and Akhtar, 2009).

In Turkey, fosthiazate, fluopyram, and *P. lilacinus* strain PL1 are registered as nematicides, and in the EU they are widely used against *Meloidogyne* spp. (PPP, 2016). The main objective of this study was to compare the efficacy of fosthiazate (900 g/l), fluopyram (400 g/l), and *P. lilacinus* strain PL1 (108 cob/ml) against *G. rostochiensis* on potato under field conditions.

MATERIALS AND METHODS

Sites

Fields located in Ödemiş (38º20'04 N, 27º82'93 E) District approximately 110 km west of Izmir Province and Bozdağ (38º30'64 N, 28º05'17 E) 30 km north of the Ödemiş site were selected as the experimental sites due to their natural infestation history with *G. rostochiensis* (Altas *et al.*, 2020). The soil type in both locations is sandy (sandy, silicaceous, hyperthermic Arenic Ochraqualf) with 90% sand, 4% silt, 6% clay, and <1% organic matter.

The *Globodera* species was identified by both morphological and molecular tools based on Basic Local Alignment Search (BLAST, http://blast.ncbi.nlm.nih.gov/) analysis of the internal transcribed spacer (ITS) of ribosomal DNA as described by Altas *et al.* (2020). Soil samples were collected prior to the potato harvest, and cyst extraction from the samples was performed using a standard flotation and sieving technique (Southey, 1986). Extracted cysts were categorized to genus level using a V20 model stereo-binocular microscope (Carl Zeiss AG, Oberkochen, Germany). DNA was extracted from a cyst using the Worm Lysis Buffer (WLB) Method (Waeyenberge *et al.*, 2000). The primers F194 and

F195 developed by Ferris *et al.* (1993) were used for sequencing of the ITS, and the resultant sequence was subjected to BLAST analysis (www.ncbi.nlm.nih.gov).

Experimental design and set-up

Each experimental plot measured 28 m^2 (5.6 m wide × 5 m long) and consisted of six rows. Treatments were replicated four times and arranged in a randomized complete block design. Potato 'Agria' (Super Elite class), which is commonly cultivated in the region, was used in this study. A total of 84 tubers were planted with a handheld potato planter at a depth of 15 cm in the combination of 80 cm inter-row spacing and 40 cm intra-row spacing for each plot. The nematicides, fosthiazate 900EC (TRIPP® 900 EC, Doğal Ltd., İstanbul, Turkey), fluopyram 40% SC (Velum Prime® SC 400, Bayer AG, Leverkusen, Germany), and *P. lilacinus* strain PL1 (BIO NEMATON®, Agrobest Group, İzmir, Turkey), were evaluated (Table 1). Chemical treatments were applied prior to planting via drip irrigation through 15,000 l of water/ha. The drip-line had self-compensating drippers with a flow rate of 2 l/hour, connected to a pump to distribute the treatments into the soil at a pressure of 2 atm. The non-treated plots that served as the control were irrigated with the same volume of water as those treated with nematicides.

The experiments were planted on 5 May 2018 and 25 April 2019 at the Bozdağ and Ödemiş sites, respectively. Experiments were irrigated throughout the growing season and as needed. Two fertilizer applications were supplied at the time of planting and 45 days after planting at a rate of 2.5 kg/100 m^2 of 20-20-20 (N-P-K) and 5 kg/100 m^2 of 13.18.15+2 (MgO)+10(SO_3), respectively.

Assessments

The initial nematode population density (Pi) of *G. rostochiensis* was determined prior to applying nematicides and planting tubers, while the final population density (Pf) was determined just after harvest. For both Pi and Pf, soil samples were taken at a depth of 15 cm using a soil core with a diameter of 20 mm. Samples were collected by taking 10 cores from each plot in a W pattern. Collected samples were mixed thoroughly and dried at 25ºC prior to nematode extraction. A 200 g subsample was washed on 18- and 100-mesh sieves to extract cysts based on the Fenwick can technique (Fenwick, 1940). The number of eggs and juveniles was estimated from a sample of 50 cysts by crushing them to liberate the eggs in 50 ml water (Shepherd, 1986). The number of eggs and juveniles were counted in a 1 ml aliquot using a Fenwick slide and expressed as the number of eggs and juveniles/g soil (Southey, 1986). The multiplication rates (Rf) of *G. rostochiensis* were calculated by dividing the Pf/Pi. Progeny tubers were harvested after the plants had senesced naturally and involved mechanical lifting, followed by hand forking of the plots to collect all potatoes. The yield was expressed in tons per hectare (t/ha). Plant growth parameters (root weight and shoot weight) were determined at 6 wk after planting by uprooting two plants from the middle rows. The roots and stems were dried at 65°C for 3 days and then weighed.

Statistical analysis

Data sets were subjected to arcsine transformations of the square root of proportions to

Table 1. Nematicide application treatments and rates used in trials in Ödemiş and Bozdağ Districts, İzmir Province, Turkey.

Product	Active ingredient	Active ingredient rate[z]	Doses (l/ha)	Active ingredient/ha
TRIPP® 900 EC	Fosthiazate	900 g/l	2.5	2250
BIO NEMATON®	*Paecilomyces lilacinus* Strain PL1 (%1.5)	10^{11} cfu/l	5	5.10^{11}
Velum Prime® SC	Fluopyram	400 g/l	1.2	480
Non-treated				

[z] cfu = colony forming unit

normalize data to minimize variance differences between measures being compared and then analyzed using analysis of variance (ANOVA). Significant differences between treatments were detected using Fisher's least significant difference (LSD) at $P < 0.01$ using SPSS for Windows, Version 16.0. (SPSS Inc., Chicago, IL, USA).

RESULTS

Globodera rostochiensis *population identity and initial densities*

The identification of nematode populations obtained from the experimental fields was confirmed to species level using the BLASTn analysis based on ITS sequences, which showed 100% homology with those of *G. rostochiensis* sequences (Accession Nos. GQ294521, FJ212167, etc.) deposited in GenBank. Experimental fields were sampled extensively to ensure that the selected sites were evenly infested with *G. rostochiensis*. The fields in Ödemiş and Bozdağ were naturally infested with *G. rostochiensis* with Pi of 34 and 13 eggs and juveniles/g soil, respectively.

Efficiency of nematicides

Population densities of *G. rostochiensis* significantly declined in the treated plots compared with the non-treated control ($P \leq 0.01$). The highest Rf values of *G. rostochiensis*, 10.80 and 8.66, were recorded from the non-treated plots in Bozdağ and Ödemiş, respectively (Fig. 1). The Rf values of non-treated plots at both locations were approximately 7, 6, and 2 times those of fosthiazate, fluopyram, and *P. lilacinus* strain PL1 treatments, respectively. The effects of fosthiazate and fluopyram were statistically similar and were different from those of *P. lilacinus* strain PL1 ($P < 0.01$).

Tuber yield

The tuber yield increased significantly after the application of fosthiazate, fluopyram, and *P. lilacinus* strain PL1 compared to the non-treated control in both experiments ($P \leq 0.01$). The application of fosthiazate resulted in the highest tuber yield (58.80 t/ha for Ödemiş and 54.38 t/ha for Bozdağ) followed by the applications of fluopyram and *P. lilacinus* strain PL1 (55.02 t/ha and 56.21 t/ha) and (48.11 t/ha and 48.78 t/ha) for Ödemiş and Bozdağ, respectively (Table 2). Fosthiazate resulted in a yield increase of 34% in Ödemiş and 31% in Bozdağ, which was not significantly different to yields obtained from plots treated with fluopyram (32% in Ödemiş and 29% in Bozdağ). *P. lilacinus* strain PL1 increased potato yield by 21% in both Ödemiş and Bozdağ trials.

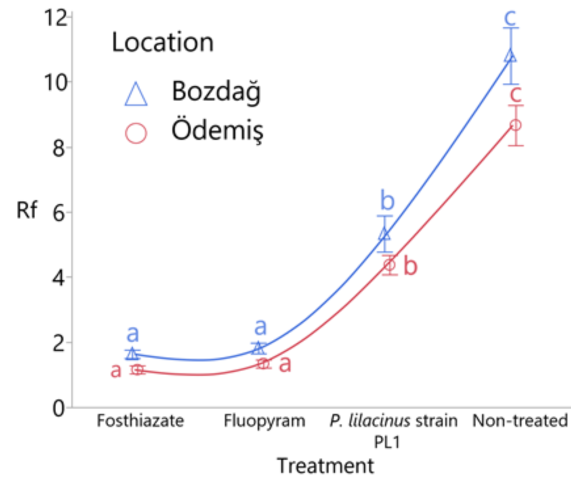

Figure 1. Effect of nematicides treatments on *Globodera rostochiensis* population densities (cyst/g soil) at Ödemiş and Bozdağ, Turkey. Error bars represent one standard deviation of the mean. Bars with the same letter represent means that did not differ significantly ($P < 0.01$) according to Fisher's least significant difference. Rf: Reproduction factor (Rf).

Plant biomass

The plant growth parameters, including root and shoot dry weights, were positively affected by the application of fosthiazate, fluopyram, and *P. lilacinus* strain PL1 compared to the non-treated in both experiments ($P \leq 0.01$). The application of fosthiazate resulted in the highest root weight (35.6 g) per plant in the Ödemiş experiment, followed by fluopyram (33.8 g) and *P. lilacinus* strain PL1 (27.9 g). Similarly, the application of fosthiazate resulted in the highest root weight (33.2 g) per plant in the Bozdağ experiment, followed by fluopyram (30.4 g) and *P. lilacinus* strain PL1 (24.9 g). The shoot weights varied among nematicide treated and non-treated plots (Fig. 2). The heaviest shoot weights were in fosthiazate-treated plots, followed by fluopyram and *P. lilacinus* for both experiments.

Table 2. Effect of nematicides on the yield of potato in soil infested with *Globodera rostochiensis* at Ödemiş and Bozdağ Districts, İzmir Province, Turkey.

Location	Nematicide	Treated (t/ha)	Non-treated[y]	Yield increase (%)
Ödemiş	Fosthiazate	58.8 ± 4.7 a[z]	38.6 ± 4.2 a	34.3 ± 3.0 a
		(50.4 - 63.9)	(32.7 - 43.4)	(31.2 - 37.1)
	P. lilacinus strain PL1	48.1 ± 5.9 b	37.9 ± 3.1 a	21.3 ± 2.3 c
		(39.3 - 54.1)	(31.4 - 41.8)	(18.7 - 25.4)
	Fluopyram	55.0 ± 3.9 ab	37.6 ± 3.2 a	31.5 ± 2.6 ab
		(50.4 - 60.4)	(29.1 - 41.2)	(27.5 - 34.5)
Bozdağ	Fosthiazate	54.4 ± 2.3 ab	38.6 ± 4.6 a	31.0 ± 3.0 a
		(49.3 - 57.8)	(30.1 - 43.2)	(26.2 - 34.2)
	P. lilacinus strain PL1	48.8 ± 3.1 b	39.2 ± 4.6 a	19.7 ± 1.7 b
		(42.6 - 52.7)	(33.2 - 44.5)	(16.3 - 22.6)
	Fluopyram	56.8 ± 4.2 a	39.2 ± 3.8 a	29.0 ± 3.2 a
		(50.6 - 61.6)	(34.5 - 43.6)	(24.1 – 33.5)

[y]Experiments conducted in Bozdağ and Ödemiş had separate non-treated plots.
[z]Means within a column followed by the same letter are not significantly different ($P < 0.01$) according to Fisher's least significant difference (LSD) for each experiment. ± standard error of the mean.

DISCUSSION

Globodera rostochiensis is a major threat to the production of potato in many countries, including Turkey (Hafez *et al.*, 2007; Kepenekci *et al.*, 2012; Toktay *et al.*, 2020). Cysts of *G. rostochiensis* are tolerant to unfavourable environmental conditions and can persist in soil for more than 10 yr, which makes their management very difficult (Williamson and Hussey, 1996). Since there are few genetic resistance sources in commercially available potato cultivars (Jones *et al.*, 2013), chemical nematicides are considered the most effective nematode management strategy and should not be removed from an IPM strategy (Sasanelli *et al.*, 2015). The results of the current study confirmed that fosthiazate, fluopyram, and *P. lilacinus* strain PL1 suppressed *G. rostochiensis*. Plots treated with fosthiazate and fluopyram resulted in a substantial yield increase. However, the fosthiazate resulted in the highest yield compared with fluopyram or *P. lilacinus* strain PL1.

Fosthiazate is an organophosphate pesticide that provides good and stable control of cyst nematodes (Tobin *et al.*, 2008), root-knot nematodes (Rich *et al.*, 1994), root-lesion nematodes (Kimpinski *et al.*, 1997; Zasada *et al.*, 2010), and free-living nematodes in a wide range of crops such as potatoes, bananas, tomatoes, and other vegetables. Similar to our results, several previous studies reported that fosthiazate suppressed nematode populations and increased yields. For example, Kimpinski *et al.* (1997) reported that potato tuber yields were higher in fosthiazate-treated plots (30%) when compared to non-treated plots. Norshie *et al.* (2016) reported that soil applications of fluensulfone, oxamyl, and fosthiazate at planting reduced infection of potato roots by *G. pallida* and suppressed nematode population development, increased shoot weight, and improved the growth and yield of potato when compared to the non-treated plots. Fosthiazate has been reported to reduce and suppress the hatch of *G. rostochiensis* and *G. pallida* (Tobin *et al.*, 2008) by paralyzing nematodes in the soil as they migrate towards the root after emerging from the cyst (Kimpinski *et al.*, 1997). The relationship between the population density of PCN and yield parameters has been documented in several studies (Tobin *et al.*, 2008; Saad *et al.*, 2012; Norshie *et al.*, 2016), indicating that these plant-parasitic nematodes are primarily responsible for yield losses. Similarly, Woods *et al.* (1999) reported that fosthiazate is an acetylcholinesterase inhibiting compound that adversely affected hatch and movement of *G. pallida* in soil, subsequently reducing root invasion. Saad *et al.* (2012) reported that the application of fosthiazate in a mixture with abamectin suppressed population densities of *M.*

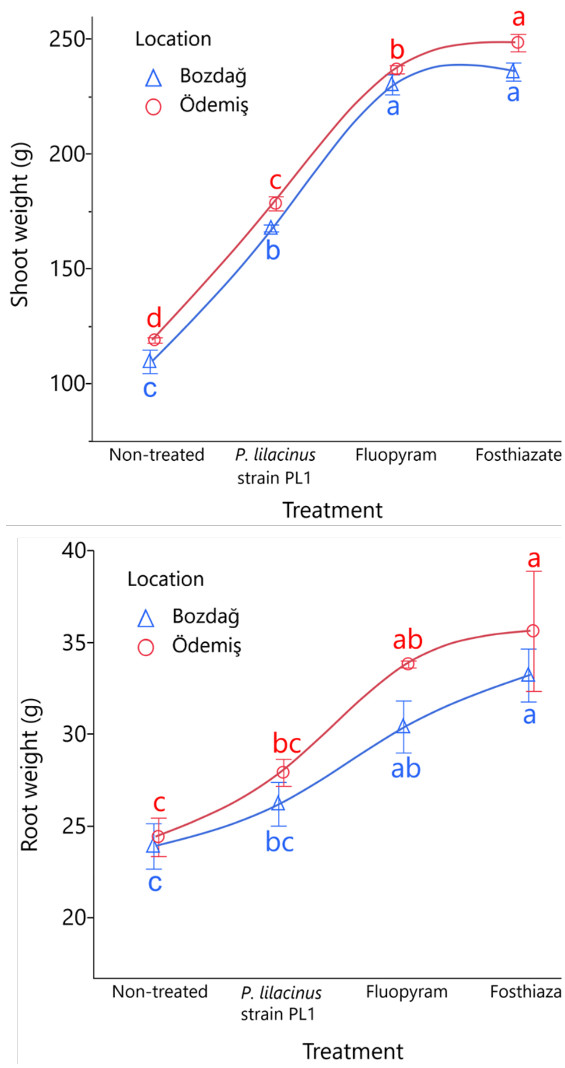

Figure 2. Effect of different nematicide treatments on potato dry root and shoot parameters in soil infested with *Globodera rostochiensis*. Error bars represent one standard deviation of the mean. Bars with the same letter represent means that did not differ significantly ($P < 0.01$) according to Fisher's least significant difference.

incognita by 82.1%.

Fluopyram, a phenylamide fungicide, has been used widely to control soilborne fungi (Kandel *et al.*, 2018b). Information on the efficacy of fluopyram against *G. rostochiensis* and *Meloidogyne chitwoodi* was limited in Turkey (Kepenekci *et al.*, 2012). In our field trials, the application of fluopyram significantly enhanced potato yield compared to the non-treated control, which agrees with the results of a previous study by Hungenberg *et al.* (2013), who reported fluopyram controlled *M. incognita* and increased tomato yield. Yield increase associated with the application of fluopyram may have been associated with nematode control (Hungenberg *et al.*, 2016), or perhaps the management of fungal pathogens, especially soilborne root pathogens such as *Fusarium* spp. (Amiri *et al.*, 2018; Bauske *et al.*, 2018).

The fungus *P. lilacinus*, a nematode egg parasite, is currently used as a biological control agent against various plant-parasitic nematodes, particularly the *P. lilacinus* strain 251 for which a commercial formulation is available (Kiewnick *et al.*, 2002). The application of *P. lilacinus* L1 significantly reduced population densities of *G. rostochiensis* and enhanced potato yield compared to the non-treated control in our field trials. The fungus is generally specialized in parasitizing stationary stages of nematodes, particularly eggs. Commercial formulations of the fungal agent successfully suppressed *M. incognita* on potato (Jatala *et al.*, 1980) and on tomato (Lara Martez *et al.*, 1996) in field conditions, and on banana in greenhouse conditions (Jonathan and Rajendran, 2000). Additionally, *P. lilacinus* controlled *R. similis* on banana (Davide and Zorilla, 1985) and on betel vine when introduced into the soil prior to nematode inoculation (Sosamma *et al.*, 1994). A reduction in infection by *Heterodera* spp. particularly *H. schachtii* (Nigh *et al.*, 1980) and *H. glycines* (Chen and Dickson, 1996) by *P. lilacinus* has been demonstrated under laboratory conditions.

The current study showed that there was a significant positive effect of the evaluated nematicides on plant parameters. The nematicides used in this study increased root weight, shoot weight, and tuber yield compared to non-treated control. Saad *et al.* (2010) recorded that abamectin and fosthiazate increased plant height and fresh weight in tomato. Saad *et al.* (2012) reported that fosthiazate, cadusafos, and crustacean increased root length in *M. incognita*-infested tomato plants. Several reports have confirmed that PCN are destructive pests in the potato production areas in Turkey (Ulutaş *et al.*, 2012; İmren, 2018; Özarslandan *et al.*, 2019; Altaş *et al.*, 2020; Toktay *et al.*, 2020), but the impact of PCN on potato yield in Turkey is relatively unknown (Kepenekci *et al.*, 2012).

In conclusion, this study demonstrated that fosthiazate, fluopyram, and *P. lilacinus* strain PL1 were able to reduce population densities of *G.*

rostochiensis and can be part of any IPM strategy against this nematode. These compounds could be further tested in combination with other nematicides, tolerant and/or partially resistant cultivars, trap cropping, crop rotation, and possibly other antagonistic organisms under an IPM strategy manage PCN.

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