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# FIELD EVALUATION OF NEMATICIDES FOR CONTROL OF THE POTATO CYST NEMATODE, *GLOBODERA ROSTOCHIENSIS*

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## ABSTRACT

Potato cyst nematode (PCN), *Globodera pallida* and *G. rostochiensis* have been reported to cause severe decline potato yield and prolonged soil contamination. The presence of the parasites in potato rhizosphere made the question to control them very quickly. Therefore, the present study was conducted to control the *G. rostochiensis* using three different nematicides, ethoprophos (Mocap 10 G), fosthiazate (Nemathorin 10 G), and fluopyram (Velum Prime SC 400), and a biocontrol agent *Paecilomyces lilacinus* strain PL1 (Bio Nematon SL). Nematicide applications were carried out using label dosages and recommended application methods. The field experiments were conducted in two different naturally infested locations were the site one (Niğde) contained sandy and loam soil, and site (İzmir) contained clay soil conditions. Molecular confirmation was also done to confirm the *G. rostochiensis* species in both locations using PITSr3, PITSp4, and ITS5 primers in multiplex PCR. The results revealed that the initial population densities were found to be statistically similar among the plots, and significant reductions in cyst and egg +J2 population were recorded after harvesting. The highest reduction in Niğde was recorded by using the fluopyram (82%), followed by fosthiazate (74%), ethoprophos (65%), and *P. lilacinus* (58%). In İzmir, overall efficacy of the applied doses was recorded lower were, fluopyram recorded (73%), followed by fosthiazate (56%), ethoprophos (51%), and *P. lilacinus* (41%). The yield results corresponding to applied doses and nematode suppression was recorded as fluopyram increases the yield up to 35% followed by fosthiazate (33%), ethoprophos (30%), and *P. lilacinus* (26%) in Niğde. In İzmir the maximum yield increased was recorded for fluopyram (28%) followed by fosthiazate (26%), ethoprophos (23%), and *P. lilacinus* (22%), respectively. Thus, the results concluded that all applied nematicides are more effective in sandy soil than clay, and the nematicides fluopyram and fosthiazate were recorded as more effective and showed good potential in suppressing the *G. rostochiensis* population and enhancing the potato yield. Additionally, *P. lilacinus* offers a sustainable biological alternative. These results showed the importance of integrating chemical and biological strategies and considering soil characteristics for effective PCN management in potato production systems.

**Keywords:** PCN, management, fluopyram, fosthiazate, *Paecilomyces lilacinus*, potato yield



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## INTRODUCTION

*Globodera rostochiensis* and *G. pallida* have been reported as the destructive pests of potato crop worldwide (Gartner *et al*., 2021). The presence of these destructive pests without specific host plant has been reported up to 30 years in soil in cyst form. The infected plants mostly showed non-specific symptoms and sometimes these symptoms intermingled with other deficiencies such as showing stunted growth, chlorosis, wilting, and premature senescence (Turner and Subbotin, 2013). Onditi and Whitworth (2025) reported that the below ground damage is characterized by reducing and deformed root systems, further smaller tuber development, while at the above-ground level the symptoms frequently appear as irregular patches in the field, which easily confused the abiotic stress such as nutrient deficiencies or drought stresses. Studies indicate that potato cyst nematode (PCN) damage threshold starts as low as 1-2 eggs per g of soil, and yield reductions may escalate to 44% at 40 eggs per g, and up to 87% at 80 eggs per g of soil (Contina *et al.*, 2019). Broader estimates range from 19% up to 80%, depending on cultivar, season, and PCN density (Turner and Evans, 1998). It is estimated that, on an average, PCN contribute to approximately 9% of the total losses in global potato production (Turner and Subbotin, 2013).

Management of PCN include the implementation of long crop rotations, the cultivation of resistant/tolerant cultivars, the utilization of biofumigants and trap crops, sanitation practices, and the application of nematicides (Sukhanova *et al.*, 2022). Although many nematicides have been banned due to environmental and health concerns, chemical control of PCN remains widespread in agriculture. Non-fumigant nematicides are particularly valuable during periods of high PCN pressure when the benefits to yield justify the costs (Clayton *et al*., 2008). Chemical treatments showed positive results in controlling the PCN infestation and enhancing the crop yield have been reported in several studies (Woods and Haydock, 2000; Norshie *et al*., 2016; Saleh *et al*., 2022). The results of the applications of fluopyram, ethoprophos and fosthiazate as non-fumigant soil applied nematicides have proved to be considerable in reducing the initial pest infestation density and protecting crop yield (Hague and Gowen, 1987).

Fosthiazate is well-known organophosphorus nematicides used to control PCN and other nematode species. Primarily it uses acetylcholinesterase (AChE) nematode inhibiting mode of action through soil spraying and root dipping method, resulting to lethality via contact or systemic absorption methods (Giblin-Davis *et al*., 1993; Xu *et al*., 2024). It is used extensively due to its high activity, lower toxicity, and prolonged action (Xu *et al*., 2024). Fosthiazate is effective against various plant parasitic nematode species (PPNs), especially *Meloidogyne* spp. It is available in various formulations as 500 EC and 900 EC, but the 10% granular formulation is the most commonly utilized in the context of PCN management (Minnis *et al*., 2004; Saleh *et al*., 2022). Ethoprophos is an organophosphorus nematicide which inhibits AChE, effectively targeting PCN and other PPNs (Karpouzas *et al.*, 1999). Its approval was not renewed in the EU in 2019 due to its high toxicity and environmental concerns. Nonetheless, it is still in use in some countries, including the US. Ethoprophos protects potato crops for six to eight weeks at sufficient concentrations (Karpouzas *et al.*, 1999, 2000). More recently, novel active ingredient such as fluopyram, a succinate dehydrogenase (SDH) inhibitor, has been introduced (Desaeger *et al*., 2020). Fluopyram shows strong activity against PPN, reducing juvenile invasion and feeding site establishment, while presenting a more favorable toxicological profile (Schleker *et al.*, 2022). It is registered against various PPNs such as *Meloidogyne*, *Criconemella*, *Pratylenchus*, *Belonolaimus*, *Trichodorus*, and *Paratrichodorus*. The fungal antagonist *Purpureocillium lilacinum* (syn. *Paecilomyces lilacinus*) represents a sustainable addition to integrated pest management (IPM). The fungus adheres to the eggshell, secretes enzymes as chitinases, proteases that degrade it (Khan *et al.*, 2004; Gortari and Hours, 2008). In addition, ammonia release as a result of the decomposition of chitin leads to the mortality of second-stage larvae (Abd-Elgawad and Askary, 2018). Certain strains, such as PL1, are highly effective against PCN, penetrating the cyst wall, colonizing eggs, and reducing hatch rates (Kiewnick and Sikora, 2006).

This study aimed to compare the field efficacy of the nematicides fosthiazate, ethoprophos, and fluopyram with the biocontrol agent *P. lilacinus* strain PL1 against *G. rostochiensis* by population suppression and tuber yield enhancement under different soil conditions.

## MATERIALS AND METHODS

**Sample collection:** Experiments were conducted in the fields of Niğde (Central) (38°17'5.84"N 34°41'32.33"E) and İzmir (Ödemiş) (38°20'32"N 28°03'50"E) provinces in Türkiye, which were naturally infected with *G. rostochiensis*. The selection of fields for the experiments was based on the results of survey studies, considering the history of PCN infestation, population density and the suitability of the areas. Soil samples were taken after harvest to determine the PCN species and their population density. Cysts were extracted from soil using a Fenwick can (EPPO, 2013). Morphologically identified *Globodera* spp. cysts were individually picked using a fine-tipped paintbrush and enumerated under the Leica M165 C stereo microscope. The process of DNA extraction was carried out utilizing the DNAeasy Tissue and Blood (Qiagen, Hilden, Germany, 69506) extraction kit. Molecular identification of DNA samples was performed using PITSr3, PITSp4, and ITS5 multiplex primers (Bulman and Marshall, 1997). The soil analysis classified soil type as sandy loam in Niğde (71.1% sand, 22.3% silt, 6.6% clay, 1.3% organic matter, and pH of 5.2) and as clay in İzmir (40.5 sand, 19% silt, 40.5% clay, 1.4% organic matter, and pH of 5.2).

**Trial's set-up and assessment:** The application of nematicides was executed in accordance with the stipulated international label doses and application methods for the management of *Globodera* spp. The nematicides and their respective doses used in the trials are listed in Table 1. Prior to the application, the soil was tilled, the clods were thoroughly broken, and parcels were made. The trials were established according to a randomized complete block design with four replications for each treatment in each experimental field. The plot sizes in the trial had an area of 45 $m^2$ (10 m × 4.5 m) and a single row of safety strip was maintained around the trial area and between the replicates. Prior to the application, soil samples were collected from each plot at a depth of 0-30 cm to ascertain the initial population.

**Table 1. Nematicide treatments' active ingredients, doses and application time used in Niğde (Central) and İzmir (Ödemiş)**

| Product | Active ingredient | Doses | Application time |
|---|---|---|---|
| Bio Nematon SL | % 1.5 ($1\times10^8$ CFU/ml) *Paecilomyces lilacinus* strain PL1 | 15 L/ha | 7.5 L/ha before and 15 days after planting |
| Mocap 10 G | %10 w/w Ethoprophos | 40 kg/ha | Single application before planting |
| Nemathorin 10 G | 10% w/w Fosthiazate | 30 kg/ha | Single application before planting |
| Velum Prime SC 400 | 400 g/l Fluopyram | 625 ml/ha | Single application before planting |

Calibration studies were conducted using sugar fertilizer for ethoprophos and fosthiazete in granular formulations, and a backpack sprayer for *P. lilacinus* strain PL1 and fluopyram in soluble liquid (SL) and suspension concentrate (SC) formulations. The pesticides in the granular formulation were applied by mixing them with sugar fertilizer. After application, the soil surface was mixed to a depth of 0-15 cm, potato planting was carried out, and irrigation was performed using a sprinkler irrigation system. Madeleine variety was planted in Niğde trial, and Granola variety in the İzmir trial. The standard field practices such as fertilization, pesticide applications and irrigation were carried out under farmer conditions from planting to harvest. No additional nematicide applications were made during the trials.

The tubers collected from each plot were weighed after harvesting. Soil samples were taken from 0-30 cm depths to determine the final PCN population of each plot. PCN cysts were obtained from the soil samples of each plot, as described above, and counted under a stereo microscope (Leica M165 C). To determine the number of eggs and second-stage larvae (J2), the cysts collected were pre-soaked in water at 21°C for 24 h. After crushing the cysts in water, the mixture was passed through a sieve to separate the eggs and J2 from the cyst shells. Three 1 ml subsamples were taken from the nematode-water mixture and examined under an inverted microscope (Leica DMI4000B) to determine the number of eggs+J2/100 g soil in each plot.

**Statistical analysis:** The field trials in both Niğde and İzmir were implemented using a randomized complete block design with four replicates per treatment. The percentage effectiveness of each treatment, nematicides and the biocontrol agent, in suppressing the *G. rostochiensis* population was calculated for both cyst and egg+J2 counts using the Henderson–Tilton formula:

$$\text{Effectiveness (\%)} = 100 \times \left(1 - \frac{Ta \times Cb}{Tb \times Ca}\right)$$

Where *Ta* and *Tb* are the final and initial population densities in the treated plots, respectively, and *Ca* and *Cb* are the final and initial population densities in the control plots, respectively.

To assess the effect of treatments on potato yield and pre-treatment and post-harvest cyst and eggs+J2 count, were analyzed separately for Niğde and İzmir using one-way Analysis of Variance (ANOVA). Prior to ANOVA, the data were tested for assumptions of normality. Significant differences among treatment means for yield and nematode populations were separated using Tukey's Honestly Significant Difference (HSD) post-hoc test at a significance level of $\alpha = 0.05$. All statistical analyses were performed using MINITAB 18 software.

# RESULTS

**Potato cyst nematode identification**: Multiplex PCR assays conducted with PITSr3, PITSp4, and ITS5 primers yielded a 434 bp DNA fragment distinct to *G. rostochiensis* in both experimental sites. No amplification product was detected for *G. pallida*.

**Effect of nematicides on PCN populations:** No significant differences were observed in terms of initial nematode population densities (Pi) between plots at the Niğde and İzmir experimental sites (P>0.05). The Pi were recorded as 1.0 cyst/g soil and 154 eggs+J2/g soil in Niğde and 1.6 cysts/g soil and 222 eggs+J2/g soil in İzmir. However, significant differences were observed in terms of final nematode population densities (Pf) for cyst and egg+J2 counts (F=8.82, df=1.38, P<0.05), at both experimental sites. In the control plots, the reproduction factor (Rf) values in Niğde were higher than in İzmir, at 9.3 and 12.0 for cysts and eggs+J2 respectively, compared to 8.1 and 8.6 in İzmir. Significant differences were observed between nematicide applications in both experimental sites (P<0.05) and fluopyram that were statistically allotted the same group with fosthiazate exhibited the most pronounced suppressive effect on the population densities of *G. rostochiensis.* Fluopyram and fosthiazate treatments resulted in $Rf_{cysts}$ of 1.8 and 2.6 in Niğde, and 2.2 and 3.5 in İzmir, respectively, while $Rf_{egg+J2}$ were 2.0 and 2.9 in Niğde, and 2.3 and 3.8 in İzmir. These treatments were followed by ethoprophos and *P. lilacinus* applications, with $Rf_{cyst}$ 3.4 and 4.0, and $Rf_{egg+J2}$ 3.9 and 4.8 in Niğde, $Rf_{cyst}$ 3.9 and 4.6, and $Rf_{egg+J2}$ 4.2 and 4.9 in İzmir, respectively (Table 2).

The efficacy of nematicides against *G. rostochiensis* populations was found to be higher in Niğde than in İzmir. In Niğde, the highest efficacy was achieved with fluopyram, which led to 81% and 83%

reduction in cyst and egg+J2 densities, respectively (Table 2). This was followed by applications of fosthiazate (72% cysts, 75% egg+J2), ethoprophos (63%, 67%), and *P. lilacinus* (57%, 60%). Similarly, in İzmir, fluopyram provided the highest suppression with 73% cysts and 74% egg+J2, followed by fosthiazate (56, 55%), ethoprophos (51%, 51%) and *P. lilacinus* 41%, 41%).

**Table 2. The effect of different nematicide applications on *Globodera rostochiensis* populations and potato yield in İzmir and Niğde trails sites**

| | Cyst / 100 g soil | | | | Eggs+J2 / 100 g soil | | | |
|---|---|---|---|---|---|---|---|---|
| | Pi | Pf | Effect (%) | Rf[1] | Pi | Pf | Effect (%) | Rf |
| Niğde trial site | | | | | | | | |
| *Paecilomyces lilacinus* strain PL1 | 81±14$^{a2}$ | 321±60$^{b}$ | 56.7±1.0$^{c}$ | 4.0±0.4$^{b}$ | 12833±2962$^{a}$ | 61917±17350$^{bc}$ | 59.9±1.6$^{c}$ | 4.8±0.7$^{b}$ |
| Ethoprophos | 113±27$^{a}$ | 376±70$^{b}$ | 63.3±6.8$^{bc}$ | 3.4±0.4$^{bc}$ | 18550±4693$^{a}$ | 72001±15212$^{b}$ | 66.8±5.9$^{bc}$ | 3.9±0.2$^{bc}$ |
| Fosthiazate | 104±23$^{a}$ | 264±45$^{bc}$ | 71.8±5.1$^{ab}$ | 2.6±0.3$^{cd}$ | 16424±2343$^{a}$ | 47836±3974$^{bc}$ | 75.1±4.2$^{ab}$ | 2.9±0.2$^{cd}$ |
| Fluopyram | 90±13$^{a}$ | 158±18$^{c}$ | 80.6±4.6$^{a}$ | 1.8±0.3$^{d}$ | 14347±2714$^{a}$ | 28670±3741$^{c}$ | 82.5±5.4$^{a}$ | 2.0±0.5$^{d}$ |
| Control | 99±10$^{a}$ | 908±60$^{a}$ | | 9.3±0.9$^{a}$ | 15021±2652$^{a}$ | 178416±27714$^{a}$ | | 12.0±1.5$^{a}$ |
| | F=1.82 | F=118.45 | | F=139.92 | F=1.85 | F=51.57 | | F=102.75 |
| | sd:4.19 | sd:4.19 | | sd:4.19 P<0.01 | sd:4.19 | sd:4.19 | | sd:4.19 |
| | P>0.05 | P<0.01 | | | P>0.05 | P<0.01 | | P<0.01 |
| İzmir trial site | | | | | | | | |
| *Paecilomyces lilacinus* strain PL1 | 158±56$^{a}$ | 715±224$^{b}$ | 40.9±16.1$^{b}$ | 4.6±0.7$^{b}$ | 22957±9465$^{a}$ | 110685±40172$^{b}$ | 40.8±159 $^{b}$ | 4.9±0.8$^{b}$ |
| Ethoprophos | 189±7$^{a}$ | 742±50$^{b}$ | 50.7±4.9$^{b}$ | 3.9±0.3$^{b}$ | 26886±2174$^{a}$ | 112702±6714$^{b}$ | 50.5±5.3$^{b}$ | 4.2±0.3$^{b}$ |
| Fosthiazate | 114±6$^{a}$ | 400±17$^{c}$ | 56.1±3.4$^{ab}$ | 3.5±0.2$^{bc}$ | 14703±2598$^{a}$ | 55710±7905$^{c}$ | 55.2±3.4 $^{ab}$ | 3.8±0.2 $^{bc}$ |
| Fluopyram | 183±53$^{a}$ | 380±59$^{c}$ | 73.1±4.4 $^{a}$ | 2.2±0.4$^{c}$ | 24362±8821$^{a}$ | 52539±9634$^{c}$ | 73.7±4.3 $^{a}$ | 2.3±0.5$^{c}$ |
| Control | 158±21$^{a}$ | 1270±200$^{a}$ | | 8.1±1.2$^{a}$ | 22031±2982$^{a}$ | 188510±33267$^{a}$ | | 8.6±1.3$^{a}$ |
| | F=2.67 | F=26.96 | | F=42.85 | F=2.22 | F=20.96 | | F=41.01 |
| | sd:4.19 | sd:4.19 | | sd:4.19 | sd:4.19 | sd:4.19 | | sd:4.19 |
| | P>0.05 | P<0.01 | | P<0.01 | P>0.05 | P<0.01 | | P<0.01 |

[1] Reproduction factor (Rf): Final population (Pf) / Initial population (Pi)
[2] Small letters indicate that statistically significant differences were observed between the treatments (P<0.05, Tukey test)

**Effect of nematicides on yield:** Significant differences in the potato yield were recorded from İzmir and Niğde experimental sites (F = 187.26, sd = 1.38, P<0.05) (Fig. 1). The highest average yield was recorded in Izmir which was 48 t/ha, compared to Niğde which was 31 t/ha. In terms of nematicide applications, both experimental sites showed significantly higher (P<0.05) yields in plots treated with nematicides compared to untreated control (Figure 1). The highest yield increase, 28%, was observed with the application of fluopyram, followed by 26%, 23%, and 22% with the fosthiazate, ethoprophos, and *P. lilacinus*, respectively, in Izmir. Similarly, in Niğde, the most significant yield increase, 35%, was observed with fluopyram, followed by 33% with fosthiazate, 30% with ethoprophos, and 26% with *P. lilacinus*. Despite differences in yield increases, fluopyram, fosthiazate, and ethoprophos treatments were statistically grouped similarly in both the experimental sites (Table 3).

**Table 3. The effect of different nematicide applications against *Globodera rostochiensis* on yield of potato in Niğde and İzmir provinces**

| | **Niğde Trial** | | **İzmir Trial** | |
|---|---|---|---|---|
| | Yield (ton/ha) | Yield increase (%) | Yield (ton/ha) | Yield increase (%) |
| *Paecilomyces lilacinus* strain PL1 | 31.2±1.7 a[1] | 25.7±2.3 b | 48.8±1.6 b | 21.5±2.7 b |
| Ethoprophos | 32.2±2.3 a | 29.6±2.8 ab | 49.5±0.6 ab | 23.4±2.8 ab |
| Fosthiazate | 33.1±1.3 a | 33.3±2.5 a | 50.4±0.9 ab | 25.6±4.1 ab |
| Fluopyram | 33.6±1.5 a | 35.3±3.3 a | 51.5±1.0 a | 28.4±1.8 a |
| Control | 24.9±1.3 b | - | 40.1±0.7 c | - |
| | F=18.39 | F=9.43 | F=78.88 | F=3.98 |
| | sd:4.19 P<0.01 | sd:4.19 P<0.05 | sd:4.19 P<0.01 | sd:4.19 P<0.05 |

[1] Small letters indicate that statistically significant differences were observed between the treatments (P<0.05, Tukey test)

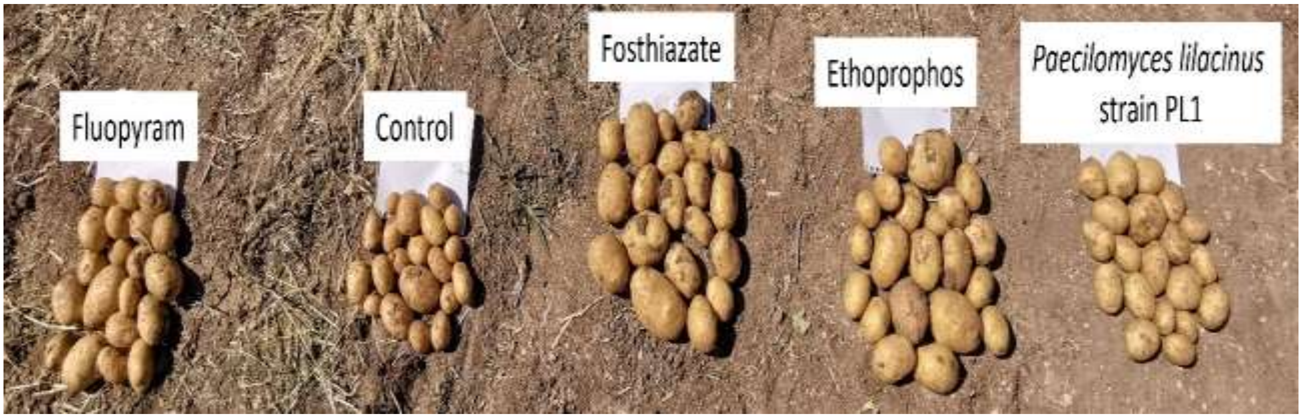


**Figure 1. Twenty tubers were randomly selected from each treatment in Niğde nematicide trial against *Globodera rostochiensis***

## DISCUSSION

The potato cyst nematodes, *G. rostochiensis* and *G. pallida*, are globally recognized quarantine pests that inflict significant damage on potato crops, resulting in yield losses of up to 80% (Brodie *et al.*, 1993; Singh *et al*., 2013). Although interest in non-chemical alternatives has increased, chemical control remains the most widely used control method by farmers (Niere and Karuri, 2018; Arshad *et al*., 2021). Given the inability to attain total efficacy in PCN management via resistant varieties, nematicides remain a crucial control measure in many countries facing PCN problem (EFSA, 2012). However, due to regulatory constraints, the utilization of numerous prevalent fumigants and non-fumigant nematicides, including 1,3-dichloropropene, aldicarb, carbofuran, cadusafos, and ethoprophos, has been prohibited in numerous countries. In some countries, the use of certain fumigant nematicides in PCN contaminated areas is specifically permitted; however, in many countries such as Germany and Scotland, pre-planting applications of fosthiazate continues to be the sole chemical option (Pickup and Hockland, 2002; EFSA, 2012; Augustin, 2021).

All treatments in this study were effective in suppressing *G. rostochiensis* population densities and improving yield performance, although significant differences in efficacy were observed among the nematicide treatments. Increase in yield was attributed to nematicide applications ranging from 22% to 28% in İzmir and from 26% to 35% in Niğde. Similarly, Saleh *et al*. (2022) reported a 20-34% increase in potato yield after nematicide application. However, in this study, the highest yield increase was determined in fosthiazate and fluopyram treatments, while in our study, higher yield was obtained in fluopyram compared to fosthiazate. Feist *et al.* (2020), reported that the application of 1 μM fluopyram inhibited egg hatching in *G. pallida* by 82%, while ≥5 μM application completely inhibited hatching. Fluopyram, a novel class of nematicide with a more environmentally acceptable toxicological profile, has been demonstrated to be effective against numerous other PPNs, particularly root-knot nematodes, in addition to PCN (Oka, 2020). Additionally, fosthiazate, demonstrated to be effective against numerous PPN species across a broad spectrum of crops, has proved to be effective against PCN in previous studies (Qin *et al.*, 2004). Norshie *et al.* (2016) reported that fosthiazate treatment resulted in an 80% reduction in *G. pallida* root infection in potatoes. However, the yield was relatively stable in one of the treatment plots, while it demonstrated approximately twofold increase in the second plot. Another study reported that fosthiazate reduced PCN population by 59–90% compared to the control in two separate fields with mixed populations of *G. rostochiensis* and *G. pallida*, while consistently increasing yield, whereas *Pochonia chlamydosporia* treatment demonstrated no effect on yield (Tobin *et al.*, 2008). The present study revealed that ethoprophos showed less efficacy compared to fluopyram and fosthiazate regarding its effect on *G. rostochiensis* population and yield. Greco *et al.* (2000) determined that ethoprophos application reduced the *G. rostochiensis* population and increased yield by 20–43%. However, a subsequent study revealed that the application of ethoprophos exhibited more than 30% impact on cyst density, yet exerted minimal effect on yield (Hajji-Hedfi *et al.*, 2017). The lowest increase in yield was found in the *P. lilacinus* application, with an increase ranging from 22% to 26%, which is consistent with the results reported by Saleh *et al*. (2022). Jatala *et al.* (1985) reported that *P. lilacinus* produces enzymatic and exopathic toxic compounds, causing up to 30% damage to *G. pallida* eggs without direct penetration, and promoting premature hatching. In a another study, it was documented that the application of *P. lilacinus* to soil resulted in a 80-85% reduction in PCN density, accompanied by a 26-30% increase in yield (Nagachandrabose, 2020). Hajji *et al*.

(2017) reported that the application of *P. lilacinum* resulted in a 63% reduction in *G. pallida* populations and a 36-37% increase in tuber weight.

The comparatively lower yield observed in İzmir may be associated with the higher initial nematode population at this site or the influence of soil structure. These results are consistent with previous reports highlighting the impact of soil type on nematicide efficacy. The clay soil of the İzmir site likely limited nematicide performance relative to the sandy loam soils of Niğde, where nematicides showed more effective. The mobility of compounds in soil is significantly influenced by the content of organic matter. The decrease in mobility is primarily attributable to adsorption onto organic matter and clay (Morris *et al.*, 2018; Norshie *et al.*, 2018). It was demonstrated that while certain nematicides were found to be effective in sandy or loamy soils, their efficacy was reduced when used on soils with high levels of clay or peat (Moss *et al.*, 1975). Ethoprophos applied at 11.2 kg/ha provided partial control of *G. pallida* in alluvial clay soils but was ineffective in peaty clay soils, whereas 5 kg/ha ethoprophos was effective against *G. rostochiensis* in sandy clay soils (Whitehead *et al.*, 1985). Furthermore, fosthiazate, while effective in sandy clay soils, proved to be less effective than aldicarb and oxamyl in clay soils; a difference attributed to soil texture (Woods and Haydock, 2000; Minnis *et al.*, 2002).

Two types of nematicides, fumigants and non-fumigants, are used in the management of potato cyst nematodes (Brodie *et al.*, 1993). The utilization of these nematicides is chiefly directed toward attaining acceptable levels of yield (Augustin, 2021). Nematicides decrease the initial population and thus reducing damage in the early stages, thereby increasing yields in most cases. However, if PKN-susceptible hosts are present, the population will continue to multiply in the subsequent stages. This highlights the greater effectiveness of nematicides when applied in fields with low pre-planting nematode densities (Evans and Haydock, 2000; Trudgill *et al.*, 2003). However, when the initial population is high, nematicides can be ineffective in preventing yield losses or in suppressing population growth (Trudgill *et al.*, 2003). Minnis *et al.* (2004) found that the use of granular fosthiazate increased yield from 22 t/ha to 35 t/ha. Nevertheless, Trudgill *et al*. (2014) reported that nematicide treatment did not generally increase yield potential and that their benefits are largely cultivar and site dependent. Moreover, depending on their mode of action and half-life, PCN population densities returning to or even exceeding initial levels post-application after nematicide application (Niere and Karuri, 2018). Furthermore, the efficacy achieved through chemical control against *G. pallida* is lower compared to *G. rostochiensis* (Whitehead *et al.*, 1994).

**Conclusion:** Field trials conducted in two regions demonstrated that the applications of fluopyram, fosthiazate, ethoprophos, and *P. lilacinus* strain PL1 exerted a substantial impact on enhancing potato yield while concomitantly reducing the population level of *G. rostochiensis*. Given that ethoprophos is banned in the European Union and Türkiye, the results indicated that the application of fluopyram, fosthiazate, and *P. lilacinus* provided substantial protection against *G. rostochiensis*, which means these could act as alternate nematicides to ethoprophos.

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