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Activity of Fosthiazate Against Root-Knot Nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood (Nemata: Heteroderidae) on Tomato and Pepper in Greenhouse Conditions

Fosthiazate'in Sera Koşullarında Domates ve Biberde Kök-ur nematodu, *Meloidogyne incognita* (Kofoid & White) Chitwood (Nemata: Heteroderidae)'ya Karşı Etkinliği

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Abstract: Plant-parasitic nematodes (PPNs) are recognized as highly damaging obligate parasites, causing significant reductions in crop yield and quality. Nematicides, which are chemical agents, are employed to enhance crop yield by managing PPNs. Fosthiazate, scientifically known as [O-ethyl S-(methylpropyl) (2-oxo-3-thiazolidinyl)-phosphonothioate], represents a novel organothiophosphate compound proven effective against various nematodes, including potato cyst nematodes (CNs), root-knot nematodes (RKNs), and others. Its mode of action involves targeting the nervous system of the specific nematode pests, inhibiting acetylcholinesterase (AChE), and disrupting normal nerve impulse conduction. In Türkiye, the fosthiazate is registered against RKNs (*Meloidogyne* spp.) in several vegetable crops. This study was conducted to investigate the activity of Tripp 900EC (900 g L^{-1} Fosthiazate) against *Meloidogyne incognita* (Kofoid & White) Chitwood (Nemata: Heteroderidae) on tomato and pepper in greenhouse conditions. The Tripp 900 EC (900 g L^{-1} Fosthiazate) proved to be an effective treatment that inhibited *M. incognita* population by 91.2% and 94.6% on tomato and pepper, respectively. Furthermore, gall formation on the tomato and pepper dropped after Fosthiazate treatment following Fluopyram by 88.5% and 86.2%, respectively. The results indicate that fosthiazate has great potential in controlling *M. incognita* in greenhouse tomato and pepper cultivations.
Keywords: Fosthiazate, management, plant parasitic nematodes, crops

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Öz: Bitki paraziti nematodlar (BPN), tarımsal ürünlerin veriminde ve kalitesinde önemli düşüşlere neden olan oldukça zararlı zorunlu parazitler olarak kabul edilmektedir. Nematisitler, BPN'leri kontrol altına alarak ürün verimini artırmak için kullanılmaktadır. Bilimsel olarak [O-etil S-(metilpropil) (2-okso-3-tiyazolidinil)-fosfonotiyoat] olarak bilinen Fosthiazate, patates kist nematodları (PKN), kök ur nematodları (KUN) ve diğer BPN'ler dahil olmak üzere çeşitli nematodlara karşı etkili olduğu kanıtlanmış yeni bir organik fosfor bileşiğidir. Etki şekli, belirli nematod zararlılarının sinir sistemini hedef almayı, asetilkolinesterazı (AChE) inhibe etmeyi ve normal sinir uyarı iletiminin bozulmasını içerir. Türkiye'de fosthiazate, çeşitli sebze ürünlerinde KUN'larına (*Meloidogyne* spp.) karşı ruhsatlıdır. Bu çalışma, Tripp 900EC'nin (900 g L^{-1} Fosthiazate) sera koşullarında domates ve biberde KUN'a, *Meloidogyne incognita* (Kofoid & White) Chitwood (Nemata: Heteroderidae)'ya karşı etkinliğini araştırmak amacıyla yürütülmüştür. Tripp 900EC (900 g L^{-1} Fosthiazate), *M. incognita* popülasyonunu domates ve biberde sırasıyla %91.2 ve %94.6 oranında inhibe eden etkili bir uygulama olduğunu kanıtlamıştır. Ayrıca domates ve biberde gal oluşumu Fluopyram'ı takiben Fosthiazate uygulamasından sonra sırasıyla %88.5 ve %86.2 oranında azalmıştır. Sonuçlar, fosthiazatın serada domates ve biber yetiştiriciliğinde *M. incognita*'yı kontrol altına almada büyük potansiyele sahip olduğunu göstermektedir.
Anahtar Kelimeler: Fosthiazate, mücadele, bitki paraziti nematodlar, mahsuller

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INTRODUCTION

Root-knot nematodes (RKNs) are one of the most damaging plant parasitic nematodes (PPNs) known for causing significant damage to various crops in agriculture, leading to considerable yield losses (Rutter et al., 2022). In Türkiye, the presence of *Meloidogyne incognita* (Kofoid & White) Chitwood (Nemata: Meloidogynidae), a species of RKNs, results in a major threat to tomato (*Solanum lycopersicum* L.) and pepper (*Capsicum annuum* L.), causing considerable damage (Kepenekci et al., 2016). In addressing the challenges posed by nematodes, most farmers employ a range of control methods such as the use of chemicals, plant varieties that possess resistance or tolerance to nematodes, and the practice of crop rotation (Rutter et al., 2022).

However, due to the lack of resistant or sufficiently tolerant varieties against *Meloidogyne incognita* in Türkiye, synthetic nematicides are the most commonly preferred control methods. Economic limitations also play a role, as extended crop rotations are needed for effective nematode control (Kepenekci, 2012; Imren et al., 2017). Apprehensions regarding the potential adverse effects of agricultural chemicals on the environment and human health, combined with alterations in European Union (EU) legislation, could lead to additional limitations on the accessibility and use of specific nematicides in Türkiye.

Fosthiazate is a nematicide that acts by directly inhibiting acetylcholinesterase (AChE), disrupting normal nerve impulse conduction in targeted nematodes, particularly *Meloidogyne* spp. (Rutter et al., 2022). Its effectiveness has been demonstrated in controlling nematodes in various crops such as tobacco, potato, tomato, banana, and peanut (Rich et al., 1994; Chabrier et al., 2002; LaMondia, 2002; Tobin et al., 2008; Cui et al., 2017). Various formulations of fosthiazate are authorized in Türkiye for controlling *Meloidogyne* spp. in crops such as tomato, potato, pepper, cucumber, and banana, according to the Plant Protection Products (PPP) regulations in 2016. Specifically, for tomato cultivation in Türkiye, fosthiazate is officially registered in combination with abamectin, with a formulation consisting of 10% fosthiazate and 0.5% abamectin in granule form. In Türkiye, several nematicides, including fosthiazate, fluopyram, abamectin, and bionematicides like *Purpureocillium lilacinum* strain PL1, are registered against *Meloidogyne* spp.. However, However, their effectiveness still needs to be elucidated in practice. Therefore, the main objective of this study was to assess the effectiveness of fosthiazate (900 g L^{-1}) in controlling *Meloidogyne incognita* on peppers and tomatoes under greenhouse conditions in Türkiye.

MATERIAL AND METHOD

Two large-scale greenhouses situated in the Adanalıoğlu and Homurlu districts of Mersin province were chosen as the experimental locations because of their history of significant natural infestation by *M. incognita* (55 larvae 100 cm^3 of $soil^{-1}$). The experiments were initiated during the autumn of 2020 and the spring of 2021, respectively. The experimental treatments were organized in a randomized block design. The design included four replications to enhance the statistical robustness of the study.

The treatments included: (a) furrow application of fosthiazate 900EC (TRIPP® 900 EC, Doğal Ltd., İstanbul, Türkiye) at a rate of 2.5 L per hectare; (b) furrow application of fosthiazate 900EC at a rate of 2.0 L per hectare; (c) furrow application of fosthiazate 900EC at a rate of 1.5 L per hectare; (d) furrow application of fluopyram 40% SC (Velum Prime® SC 400, Bayer AG, Leverkusen, Germany) at a rate of 1.2 L per hectare; (e) untreated control (Table 1). Each plot consisted of five rows and followed a randomized block design with four replicates. The plot size was 25 m², accommodating approximately 100 tomato plants per plot. To prevent cross-contamination, each plot received a separate 1.3 cm water block irrigation the day before chemical application. This pre-application irrigation aimed to ensure better absorption and effectiveness of the chemicals without inter-plot contamination.

Table 1. Nematicides used in greenhouse trials.
Çizelge 1. Sera denemelerinde kullanılan nematisitler.

Product	Active ingredient	Active ingredient rate* ($g L^{-1}$)	Dose ($L ha^{-1}$)	Active ingredient ($g ha^{-1}$)
TRIPP® 900 EC	Fosthiazate	900	2.5	2250
TRIPP® 900 EC	Fosthiazate	900	2.0	1800
TRIPP® 900 EC	Fosthiazate	900	1.5	1350
Velum Prime® SC	Fluopyram	400	0.6	240

The application rates of chemicals were determined based on both prior research findings and the guidelines provided on the product labels. Consequently, fosthiazate was applied 3-6 days before the planting, while fluopyram was applied one day before planting. Following the chemical application, six-week-old 'Torry F1' tomato seedlings were transplanted onto the beds. These beds were spaced 1.5 meters apart, with each bed accommodating 20 tomato plants arranged at a spacing of 0.5 meters on the row. Conventional flood irrigation practices were used, taking into account the precise water needs of the crops. Furthermore, herbicides, insecticides, and fungicides were administered weekly, commencing three weeks after the treatment, following the recommended guidelines of that period.

Plant vigor ratings were assessed 45 days after treatment (DAT) using a scale ranging from 0 to 100%, where 0% indicated plant death and 100% represented optimum growth. The measurement of plant heights was conducted on ten randomly selected plants at the same time. Simultaneously, the infection of RKN was evaluated by carefully extracting roots and assigning a rating for galls of nematode on a scale of 0–10. This scale ranged from 0 (indicating no galls) to 10 (representing 90–100% of roots being galled). Following the gall rating analysis, the fresh weight of the roots was recorded. Furthermore, nematode populations were assessed 45 DAT by gathering soil samples from the rhizosphere of ten tomato plants per plot through the use of a soil probe (2.5 cm wide by 20 cm deep). Nematodes were then extracted, identified based on genera, and quantified from 100 cm^3 of soil using standard centrifugation and sieving procedures. The root galling index caused by *M. incognita* was determined at 45 DAT by inspecting the roots of six plants per plot and evaluating the extent of damage to the roots.

Statistical analysis

Before analysis, data were tested for normal distribution and arcsine-transformed. ANOVA Fisher's LSD test ($P<0.01$) was used to determine the differences among treatments. The statistical analysis was conducted using SPSS for Windows, Version 16.0 (SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

Fosthiazate and fluopyram significantly reduced the gall formation on the roots of tomatoes and peppers compared to control treatments (Table 2). All application rates of fosthiazate significantly decreased the root galling index on both tomatoes and peppers (Table 2). Plots treated with fluopyram and fosthiazate at a rate of 2.5 L ha^{-1} had the maximum plant height, reaching 39.2 cm.

Saad et al. (2011) documented that the use of fosthiazate and abamectin led to an increase in plant fresh weight and height in tomatoes. Additionally, Saad et al. (2012) observed that the use of fosthiazate, crustacean, and cadusafos significantly increased the root length in tomato plants infested with *M. incognita.*

Table 2. Effects of nematicides on *M. incognita* root gal formation in the greenhouse trials.
Çizelge 2. Sera denemelerinde nematisitlerin M. incognita'nın köklerde gal oluşumu üzerine etkileri.

Product	Active ingredient	Doses (L ha^{-1})	Root galling indeks*	
			Tomato	Pepper
TRIPP® 900 EC	Fosthiazate (900 g L^{-1})	2.5	1.1 a	1.4 a
TRIPP® 900 EC	Fosthiazate (900 g L^{-1})	2.0	4.9 b	5.4 b
TRIPP® 900 EC	Fosthiazate (900 g L^{-1})	1.5	5.8 c	6.5 c
Velum Prime® SC	Fluopyram (400 g L^{-1})	0.6	1.2 a	1.5 a
Non-treated (Control)	-	-	7.6 d	8.1 d

*The nematode root galling index, assessed 45 days after treatment (DAT), was measured on a scale of 0 to 10. In this scale, 0 indicates no galls, while 10 represents 100% of roots exhibiting galling.

The results confirm the potent nematicidal activity of fosthiazate observed in greenhouse tests. Treatments from both fosthiazate and fluopyram proved effective in reducing population levels of *M. incognita* (Table 3). Untreated plots with tomatoes exhibited the highest nematode count and root galling index. By contrast, fosthiazate at a dose of 2.5 L ha^{-1} emerged as the most efficient treatment in mitigating nematode counts and root galling caused by RKNs early in the season (Table 3).

Table 3. Effect of fosthiazate and fluopyram on *Meloidogyne incognita* in greenhouse trials.
Çizelge 3. Fosthiazate ve fluopyram'ın sera denemelerinde Meloidogyne incognita üzerine etkisi.

Product	Active ingredient	Doses (L ha^{-1})	Nematodes* (100 cm^3 soil)	
			Tomato	Pepper
TRIPP® 900 EC	Fosthiazate (900 g L^{-1})	2.5	11 a	14 a
TRIPP® 900 EC	Fosthiazate (900 g L^{-1})	2.0	41 b	46 b
TRIPP® 900 EC	Fosthiazate (900 g L^{-1})	1.5	58 c	55 c
Velum Prime® SC	Fluopyram (400 g L^{-1})	0.6	13 a	12 a
Non-treated	-	-	74 d	69 d

* Nematodes (*Meloidogyne incognita*) present in 100 cubic centimetres of soil were counted 45 days after treatment (DAT) using a conventional method involving sieving and centrifugation in both cultivation periods.

Meloidogyne spp., RKNs, are detrimental soil-borne pathogens and responsible for significant global economic losses amounting to $157 billion (Abad et al., 2008). Controlling poses challenges due to their ability to live in the roots of plants (Radwan et al., 2012). Various chemical nematicides are employed for RKN control. Previous reports have demonstrated the efficacy of fosthiazate in managing RKNs in cucumber, leading to reduced root gall indices and increased crop yield in comparison to untreated control groups (Toth et al., 2019). Furthermore, studies indicate that when used in combination with other nematicides, fosthiazate reduces the root galling activity of *M. incognita*, consequently enhancing the yield of tomato (Landi et al., 2018).

Numerous reports have highlighted the commendable nematicidal properties and a distinct mode of action of fosthiazate compared to presently existing nematicides. The efficacy of fosthiazate in reducing populations of RKNs, as observed in this study, aligns with previous findings indicating its effectiveness against *Meloidogyne* spp. in various crops such as tobacco (Pullen and Fortnum, 1999; Rich et al., 1994) and peanuts (Minton et al., 1993).

The current study's results are in agreement with earlier studies reporting inhibition of *G. rostochiensis* in potatoes and pepper after fosthiazate, *P. lilacinus* strain PL1, and fluopyram treatments. Fosthiazate, classified as an organophosphate pesticide, exhibits high nematicidal activity and provides robust and consistent control against RKNs (Rich et al., 1994), CNs (Tobin et al., 2008), and root-lesion nematodes (Kimpinski et al., 1997) in a diverse range of crops, including bananas, tomatoes, potatoes, and various vegetables. These compounds warrant further exploration for combining fosthiazate with other nematicides and control methods such as trap cropping, crop rotation, partially resistant and/or tolerant cultivars, and potentially antagonistic organisms within the Integrated Pest Management (IPM) strategy to optimize their efficacy against PPNs.

CONCLUSION

The obtained results highlight the high nematicidal activity of fosthiazate against *M. incognita*, demonstrating its capacity to enhance marketable tomato and pepper yields and establishing it as a promising nematicide. Nevertheless, further investigations are necessary to explore its prolonged effectiveness, elucidate promotion mechanisms, assess dissimilar dosages, and determine the optimal planting time after application in crops.

CONFLICT OF INTEREST

The authors have no competing interests to declare that are relevant to the content of this article.

DECLARATION OF AUTHOR CONTRIBUTION

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Mustafa İmren and Ebubekir Yüksel. The first draft of the manuscript was written by Mustafa İmren and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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