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Original article (Orijinal araştırma)

Widespread and high levels of resistance to spinosad and spinetoram in *Frankliniella occidentalis* (Pergande, 1895) (Thysanoptera: Thripidae) populations of Antalya Province (Türkiye)[1]

Frankliniella occidentalis (Pergande, 1895) (Thysanoptera: Thripidae) Antalya ili (Türkiye) popülasyonlarında yaygın ve yüksek düzeyde spinosad ve spinetoram direnci

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Abstract

The western flower thrips, *Frankliniella occidentalis* (Pergande, 1895) (Thysanoptera: Thripidae) is an important agricultural pest worldwide. This invasive thrips has a significant threat to greenhouse vegetable production and export in Antalya. In this study, the prevalence of spinosad and spinetoram resistance in *F. occidentalis* populations from greenhouse locations in Antalya Province (Türkiye) was investigated. Eight *F. occidentalis* populations were taken from vegetable greenhouses in 2018-2019. A leaf dip bioassay was used to determine LC values and resistance levels. Spinosad and spinetoram resistance in the assayed populations were 19-312 and 5-170 times that of the susceptible population, respectively. The findings showed that spinosad and spinetoram resistance has reached significant levels and is now common in Antalya populations. Also, the stability of spinosad and spinetoram resistance was monitored in the most resistant population (Manavgat) for 6 months without insecticides. No significant decline in resistance was not found for both spinosad and spinetoram in this population over this period.

Keywords: *Frankliniella occidentalis*, resistance, spinosyn, stability, Türkiye

Öz

Batı çiçek thripsi, *Frankliniella occidentalis* (Pergande, 1895) (Thysanoptera: Thripidae) dünya çapında önemli bir tarımsal zararlıdır. Bu istilacı thrips, Antalya'da örtü altı sebze üretimi ve ihracatı için önemli bir tehdit oluşturmaktadır. Bu çalışmada Antalya sera üretim alanlarından alınan *F. occidentalis* popülasyonlarında spinosad ve spinetoram direncinin yaygınlık durumu araştırılmıştır. Sebze üretimi yapılan seralardan 2018-2019 yıllarında sekiz *F. occidentalis* popülasyonu toplanmıştır. LC değerlerinin ve direnç seviyelerinin belirlenmesi için yaprak daldırma test yöntemi kullanılmıştır. Test edilen popülasyonlarda spinosad ve spinetoram için direnç oranları duyarlı popülasyona göre sırasıyla 19-312 ve 5-170 kattır. Bulgular, Antalya popülasyonlarında spinosad ve spinetoram direncinin önemli düzeylere ulaştığını ve yaygın duruma geldiğini göstermiştir. Ayrıca, spinosad ve spinetoram direncinin stabiliteleri, en yüksek dirence sahip (Manavgat) popülasyonunda 6 aylık bir süre boyunca insektisit uygulanmaksızın izlenmiştir. Bu popülasyonda hem spinosad hem de spinetoram için bu süre içerisinde direnç düzeylerindeki düşüş önemli bulunmamıştır.

Anahtar sözcükler: *Frankliniella occidentalis*, direnç, spinosyn, kalıcılık, Türkiye

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Introduction

The western flower thrips, *Frankliniella occidentalis* (Pergande, 1895) (Thysanoptera: Thripidae), is a serious agricultural pest worldwide which causes economic losses in many crops both feeding on host plants and as a vector of several serious viruses including tomato spotted wilt virus (TSWV) (EPPO, 1999; Kirk & Terry, 2003; Mouden et al., 2017). *Frankliniella occidentalis*, originated in North America, and has become widespread in many countries in Africa, America, Asia, Australia and Europe (EPPO, 2022a). This species is among the most resistant pests to insecticides worldwide (Gao et al., 2012; Sparks et al., 2012; APRD, 2022).

Numerous studies associated with this issue in various countries have shown that many population of this thrips species have gained resistance to not only organic chlorine, organophosphorus, carbamate and pyrethroid classes but also new generation bioinsecticides classes such as avermectin and spinosyn (Immaraju et al., 1992; Brodsgaard, 1994; Jensen, 1998; Kontsedalov et al., 1998; Jensen, 2000; Espinosa et al., 2002; Herron & James, 2005; Bielza et al., 2007; Thalavaisundaram et al., 2008; Zhang et al., 2008; Gao et al., 2012; Sparks et al., 2012; Dong-Gang et al., 2016; Dağlı, 2018; Cubillos-Salamanca et al., 2019; APRD, 2022). *Frankliniella occidentalis* was the first detected in Türkiye in 1993 (Tunç & Göçmen, 1995). Subsequently, it spread rapidly and has already become established in a large number of crop species in most parts of the Türkiye (Tunç & Göçmen, 1995; Bulut & Göçmen, 2000; Atakan, 2003; Kılıç & Yoldaş, 2004; Özsemerci et al., 2006; Sertkaya et al., 2006; Nas et al., 2007; Atakan, 2008a, b; Doğanlar & Aydın, 2009; Tekşam & Tunç, 2009; Hazır et al. 2011; Yıldırım & Başpınar, 2013). Greenhouse cultivation is quite common and extremely valuable from an economic point of view in Antalya. In 2020, 381 kt of fresh vegetables (worth about 307 million USD) were exported from Antalya (Anonymous, 2022a). *Frankliniella occidentalis* is one of the most harmful pest insects in crop plants mainly vegetables grown in greenhouse in Antalya. In addition to the injury caused by feeding directly on the crops, it causes significant economic losses due to its transmission of TSWV, common problem in Türkiye (Şevik, 2011; Şevik & Arlı-Sökmen, 2012; Fidan, 2016; Fidan & Sarı, 2019). In addition, officials of the Antalya Directorate of Agricultural Quarantine report that this thrips sometimes prevents agricultural exports from Antalya, as it is a quarantine pest (EPPO, 2022b). The area where biological and biotechnical control is applied (1.55 kha) is still quite limited when compared to the total greenhouse cultivation area (31.2 kha) in Antalya (Anonymous, 2022a). This situation still leads to the heavily use of pesticides in the management against *F. occidentalis* and other major pests in greenhouse growing. It has been reported that 11 kt of insecticide was used in 2021 against agricultural pests in Türkiye, and about 10% of this amount was applied in Antalya (Anonymous, 2022b). Currently, spinosad and spinetoram are the main active substances used against *F. occidentalis* in Türkiye as well as worldwide (Gao et al., 2012; Bacci et al., 2016). These two insecticides are derivatives of biologically active ingredient produced by *Saccharopolyspora spinosa* Mertz & Yao, 1990, and these spinosyn compounds are considered to have a low environmental risk (Bacci et al., 2016). However, in a previous study, a high level of spinosad resistance (235 times) to *F. occidentalis* was detected in one location (Kumluca) in 2015 (Dağlı, 2018). Due to their considerable safety, use of spinosad, and spinetoram have expanded in agricultural areas in the region recently by obtaining recommendations against important pests in vegetables, industrial plants, vineyards and various fruits (Anonymous, 2022c). More widespread and frequent use of spinosad and spinetoram may lead to increased selection pressure on populations (mainly thrips) which may cause the problem of resistance to these two active ingredients to become more serious. Bioinsecticides such as spinosad and spinetoram should be used within scope of resistance management programs to extend their effective lifespan as much as possible. Periodic screening of populations at different locations and obtaining current resistance levels are necessary to recommend the correct actives and suggestions about pesticide use against pest insects including thrips species.

This study aims to reveal the prevalence of spinosad and spinetoram resistance in *F. occidentalis* populations collected from greenhouses in Antalya Province, especially coastal districts. Additionally, the stability of spinosad and spinetoram resistance in a highly resistant *F. occidentalis* population was investigated. The findings of this study could be contributed to management of *F. occidentalis* by reducing the economic and ecological losses due to insecticide resistance to a certain extent.

Materials and Methods

Collection of thrips populations

A susceptible population of the *F. occidentalis* was collected from a home garden in district Şuhut located at Afyonkarahisar Province (Türkiye) (38°31'40" N, 30°32'45" E) in 2017. Pesticides have generally not been used in that garden. Therefore, this *F. occidentalis* population was found to be quite susceptible to spinosad and spinetoram. One-fiftieth of the recommended dose of spinosad and one percent of the recommended dose of spinetoram cause 90% mortality in this susceptible population.

The greenhouses populations of *F. occidentalis* to be screened for resistance were collected from eight locations in 2018-2019 from greenhouses in districts Aksu, Alanya, Demre, Gazipaşa, Kumluca, Manavgat and Serik in Antalya (Figure 1).

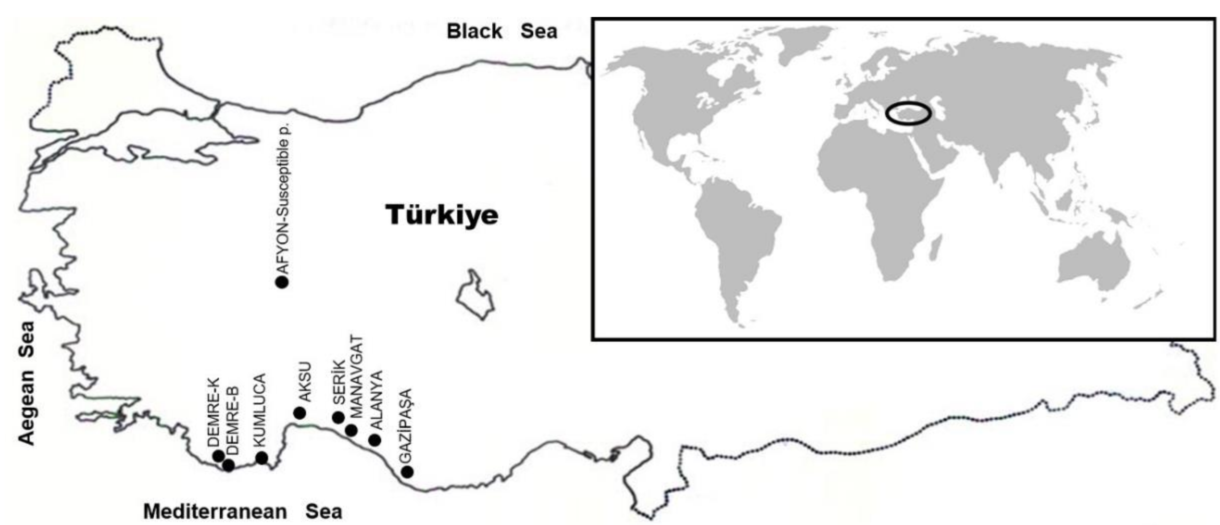

Figure 1. Sampling locations for *Frankliniella occidentalis* populations in Türkiye.

Detailed information about the hosts and locations of the populations collected is given in Table 1. At least 100 adult thrips were collected from the commercial greenhouses to represent each population, and were placed in plastic containers with ventilation openings. The samples were brought to the department laboratory on the day of collection and the thrips collected with a mouth aspirator for transfer to rearing containers with green bean pods. Species identification for the collected populations was undertaken according to Tunç & Göçmen (1995), Doğanlar & Aydın (2009) and Cluever et al. (2015).

Table 1. Locations, host plants, and coordinates of *Frankliniella occidentalis* test populations collected in 2017-2019

Population	Host	Location	Collection date	Coordinates
Aksu	Eggplant	Aksu (Hacıaliler)	08.05.2018	36°55'39" N, 30°50'13" E
Alanya	Eggplant	Alanya (Emişbeleni)	01.05.2018	36°37'25" N, 31°53'08" E
Demre-Beymelek (B)	Pepper	Demre (Beymelek)	03.05.2018	36°14'52" N, 30°01'44" E
Demre-Köşkerler (K)	Pepper	Demre (Köşkerler)	03.05.2018	36°16'14" N, 29°59'40" E
Gazipaşa	Eggplant	Gazipaşa (Macar)	01.05.2018	36°13'27" N, 32°20'31" E
Kumluca	Pepper	Kumluca (Salur)	03.05.2018	36°21'56" N, 30°14'18" E
Manavgat	Eggplant & pepper	Manavgat (Denizyaka)	01.05.2018	36°51'32" N, 31°11'12" E & 36°51'02" N, 31°11'01" E
Serik	Pepper	Serik (Çakış)	02.01.2019	36°55'18" N, 31°11'18" E
Susceptible (home garden)	Pepper	Şuhut, Afyonkarahisar	2017	38°31'40" N, 30°32'44" E

Insecticides

Spinosad and spinetoram were used in this investigation. Details of these active ingredients are given in Table 2.

Table 2. Information about active ingredients spinosad and spinetoram used in experiments

Active ingredient	Commercial name / registration date in Türkiye	Recommended dose for *F. occidentalis*	Active ingredient mg (a.i.)/L	Mode of action (IRAC, 2022)
Spinosad	Laser 480SC Dow Agro Sciences / 1998 (Anonymous, 2022d)	20 ml/decare (Anonymous, 2022d)	96	Nerve action, Nicotinic acetylcholine receptor (nAChR) allosteric modulators, (5).
Spinetoram	Radiant 120SC Dow Agro Sciences / 2014 (Anonymous, 2022e)	50 ml/decare (Anonymous, 2022e)	60	Nerve action, Nicotinic acetylcholine receptor (nAChR) allosteric modulators, (5).

Thrips rearing method

The rearing method of *F. occidentalis* populations was adapted from Steiner & Goodwin (1998), Murai & Loomans (2001) and Espinosa et al. (2002), and was given in detail in the previous study (Dağlı, 2018). Adults were collected from the inside of the vegetable plant flowers with a mouth aspirator and transferred to transparent plastic containers (2 L) covered with filter paper. Green bean fruits were left in the culture cups for feeding and egg laying of thrips. The green beans used here were disinfected with the sodium hypochlorite (6 g/L), then they were dipped in a sugar solution (5 g/L) and left to dry. Green bean fruits in the cultures were replaced every 3-4 days. All *F. occidentalis* populations were continued in a climate room at 23 ± 1°C and a 16:8 h L:D photoperiod.

Insecticide bioassay method

In this study, the leaf dipping method described by Zhang et al. (2008) for the same thrips species was used to calculation LC of the populations. The insecticide test method was presented in detail in the previous study (Dağlı, 2018). Briefly, the bioassay was as follows. First, a 4-6-step dose series was prepared in distilled water including TritonX-100 coving concentrations known to give to 5 and 95% mortality in populations. Bean leaf discs (3 cm) were dipped (5 s) into the insecticide concentrations or in distilled water (as control). After the droplets on the surface dried the discs were placed on the agar in a Petri dish (Figure 2). Adult female thrips were then collected from rearing cups using a small mouth aspirator, anesthetized with CO_2 and poured onto the leaf discs. The Petri dishes were covered with stretch film and were perforated with an insect pin. At least three replicates were used for each tested concentration. Generally, around 20 adults female thrips (mixed-age) were used in each replicate, however, more than 20 individuals were used in some testing populations with large numbers of thrips. Control mortality did not exceed 12%. The mortality of the tested thrips was determined after 3 days. Thrips were considered as dead if they did not any respond when prodded with a brush or pin.

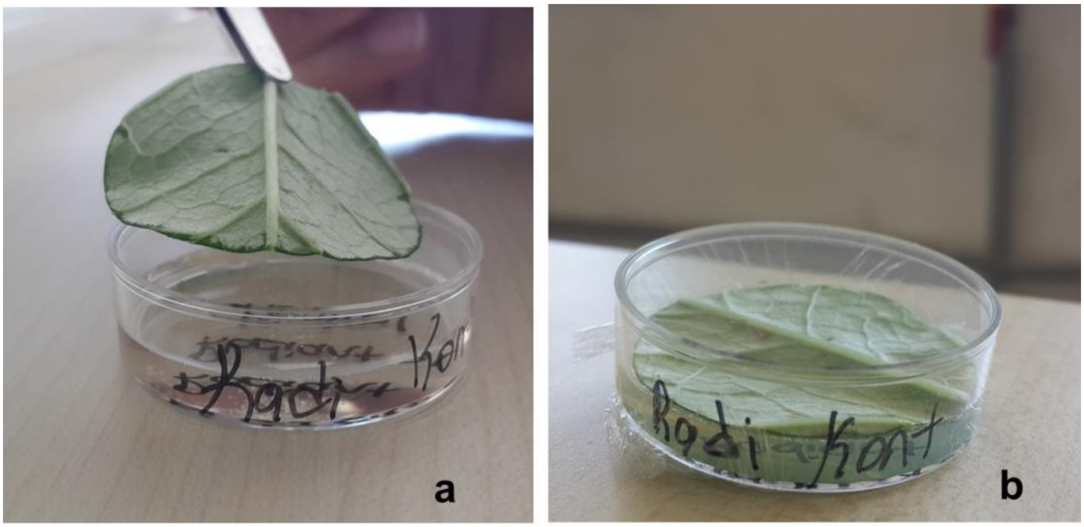

Figure 2. a) Placement of the leaf disc on agar in a petri dish, and b) forming the test cell by covering it with stretch film.

Determining resistance stability

The stability of spinosad and spinetoram resistance was determined in the Manavgat population, which showed high resistance to both insecticides. The Manavgat population, whose LC values and resistance levels were determined against these insecticides, were kept in culture cups in the climate room for about 6 months without use of pesticides, and then the same values were measured again. By comparing the LC values at the beginning and after 6 months, the rate of reversion in resistance was tested at the end of a 6-month period.

Data analysis

The numbers of alive-dead thrips obtained from insecticide bioassays were subjected to probit analysis with PoloPlus, Version 2.0 2002-2022 (LeOra Software, 2022) and LC values and confidence limits (95%) of populations were obtained. Resistance ratios of populations were calculated as LC_{50} values of the greenhouse populations divided by the LC_{50} values of the susceptible population. Confidence limits (95%) of LC values were taken into account in evaluating the significance of the differences in LC values between populations. Any two LC_{50} were considered significantly different if their respective confidence limits (95%) did not overlap.

Results

Spinosad resistance in populations

The LC_{50} values, resistance ratios, and related parameters determined for spinosad in the populations are given in Table 3. LC_{50} values for the spinosad tests for Aksu, Kumluca, Serik, Alanya, Gazipaşa, Demre (Köşkerler), Demre (Beymelek) and Manavgat populations were 7.7, 12.3, 12.7; 14.5, 17.7, 37.6, 42.5 and 125 mg a.i./L, respectively. The highest LC_{50} value was in the Manavgat population at 125 mg a.i./L. The lowest LC_{50} value was in the Aksu population at 7.7 mg a.i./L. Resistance ratios for spinosad in Aksu, Kumluca, Serik, Alanya, Gazipaşa, Demre (Köşkerler), Demre (Beymelek) and Manavgat populations were 19.3, 30.8, 31.8, 36.3, 44.3, 94.0, 106 and 312, respectively. The LC_{90} values of all greenhouse populations were above the spinosad recommended dose of spinosad. Based on these results, spinosad could give well below 90% mortality in these populations at the recommended dose. This result indicates that spinosad applications may be not effective against the thrips in the locations where populations were collected.

Table 3. Lethal concentration (LC) values and resistance ratio (at LC_{50}) to spinosad in the *Frankliniella occidentalis* greenhouse populations collected from districts of Antalya (Türkiye) in 2017-2019

Populations	n*	Slope ± S.E	LC_{50} mg (a.i.)/l (95% CL)	Resistance Ratio**	LC_{90} mg (a.i.)/l (95% CL)	χ^2	df
Aksu	375	1.0 ± 0.1	7.7 3.8-15.4	19.3	133 57.1-474	25.4	13
Alanya	567	1.0 ± 0.1	14.5 8.1-25.2	36.3	265 130-741	22.7	13
Demre-B	493	1.1 ± 0.1	42.5 29.0-62.8	106	587 328-1340	12.8	13
Demre-K	255	0.9 ± 0.1	37.6 18.0-71.8	94.0	1100 484-3680	11.1	13
Gazipaşa	417	1.1 ± 0.1	17.7 8.9-33.1	44.3	259 124-754	22.9	13
Kumluca	400	1.0 ± 0.1	12.3 6.1-22.0	30.8	241 118-696	16.5	13
Manavgat	260	0.9 ± 0.1	125 45.0-399	312	3620 868-16,600	17.4	9
Serik	307	1.1 ± 0.1	12.7 4.0-29.9	31.8	195 77.7-895	20.2	10
Susceptible	314	1.8 ± 0.2	0.4 0.2-0.8	–	1.9 0.9-7.4	23.7	10

*n: number of adult female thrips used in bioassay;
**Resistance ratio: LC_{50} of the greenhouse populations / LC_{50} of the susceptible population.

Table 4. LC value and the resistance ratio (at LC_{50}) to spinetoram in the *Frankliniella occidentalis* greenhouse populations collected from districts of Antalya (Türkiye) in 2017-2019

Populations	n*	Slope ± S.E	LC_{50} mg (a.i.)/l (95% CL)	Resistance Ratio**	LC_{90} mg (a.i.)/l (95% CL)	χ^2	df
Aksu	507	1.9 ± 0.2	3.2 1.9-5.1	16.0	15.4 9.0-36.5	27.5	13
Alanya	389	0.8 ± 0.1	2.8 1.6-4.8	14.0	91.3 41.8-268	10.1	13
Demre-B	438	1.0 ± 0.1	10.6 5.6-21.2	53.0	206 85.7-762	25.0	13
Demre-K	299	1.3 ± 0.2	0.9 0.4-1.5	4.5	7.9 4.2-25.9	10.0	10
Gazipaşa	328	0.9 ± 0.1	7.8 3.7-14.5	39.0	185 83.5-642	11.5	11
Kumluca	363	1.0 ± 0.1	10.0 4.1-22.7	50.0	203 73.2-1,350	24.8	10
Manavgat	454	1.2 ± 0.1	34.0 20.0-56.2	170.0	389 203-1,060	19.3	13
Serik	369	1.1 ± 0.1	1.5 0.4-4.6	7.5	18.3 5.5-267	76.6	13
Susceptible	653	2.1 ± 0.2	0.2 0.1-0.2	–	0.6 0.4-1.0	5.4	10

*n: number of adult female thrips used in bioassay;
**Resistance ratio: LC_{50} of the greenhouse populations / LC_{50} of the susceptible population.

Spinetoram resistance in populations

The LC_{50} and resistance ratios determined for spinetoram in populations are given in Table 4. The LC_{50} values of Demre (Köşkerler), Serik, Alanya, Aksu, Gazipaşa, Kumluca, Demre (Beymelek) and Manavgat populations were 0.9, 1.5, 2.8, 3.2, 7.8, 10.0, 10.6 and 34.0 mg a.i./L, respectively. The resistance ratios of Demre (Köşkerler), Serik, Alanya, Aksu, Gazipaşa, Kumluca, Demre (Beymelek) and Manavgat populations against spinetoram were 4.5, 7.5, 14.0, 16.0, 39.0, 50.0, 53.0 and 170, respectively. LC_{90} values in five of the eight greenhouse populations tested in this study were above the recommended dose of the spinetoram. According to these findings, spinetoram application at the recommended dose will give less than 90% mortality in thrips collection locations of Alanya, Gazipaşa, Kumluca, Demre (Beymelek) and Manavgat populations.

Resistance stability to spinosad and spinetoram

The stabilities of spinosad and spinetoram resistances were monitored over a 6-month period in the Manavgat population, which had the highest resistance to these insecticides (Tables 5 & 6).

Table 5. Stability of spinosad resistance in spinosad-resistant Manavgat population of *Frankliniella occidentalis*

Assessment	n*	Slope ± S.E	LC_{50} mg (a.i.)/l (95% CL)	LC_{90} mg (a.i.)/l (95% CL)	χ^2	df
Initial (12.10.2018)	260	0.9 ± 0.1	125 45.0-400	3,620 868-16,600	17.4	9
After 6 months (11.04.2019)	285	1.3 ± 0.2	108 32.1-332	1,120 356-45,900	30.6	10

*n: number of adult female thrips used in bioassay.

Table 6. Stability of spinetoram resistance in spinetoram-resistant Manavgat population of *Frankliniella occidentalis*

Assessment	n*	Slope ± S.E	LC_{50} mg (a.i.)/l (95% CL)	LC_{90} mg (a.i.)/l (95% CL)	χ^2	df
Initial (07.11.2018)	454	1.2 ± 0.1	34.0 20.0-56.3	389 203-1,060	19.3	13
After 6 months (08.05.2019)	497	1.6 ± 0.2	25.6 10.1-44.6	159 88.1-483	24.2	13

*n: number of adult female thrips used in bioassay.

The Manavgat population of which initial LC values were determined for spinosad and spinetoram was maintained for about 6 months without pesticide pressure. Afterwards, LC values for these two active substances were redetermined. When the Manavgat population, which was 312 times more resistant to spinosad, was maintained without pesticides for 6 months, the LC_{50} value decreased 0.9 times the initial value, from 125 to 108 mg a.i./L (Table 5). However, this reversion was not significant because the confidence limits the initial and final assessments overlap. Similarly, in the Manavgat population, which was 170 times more resistant to spinetoram and was maintained without pesticide for 6 months, the LC_{50} value for spinetoram decreased 0.8 times compared to the initial LC_{50} value, from 34.0 to 25.6 mg a.i./L. Likewise, this reversion was not significant (Table 6). Even though LC_{90} values deceased by a greater proportion compared to the initial LC_{90} values for both insecticides, they were still well above the recommended doses of spinosad and spinetoram (Tables 5 & 6).

Discussion

In this study, resistance to spinosad and spinetoram was found to be high in eight *F. occidentalis* populations collected from greenhouses in Aksu, Alanya, Demre, Gazipaşa, Kumluca, Manavgat and Serik Districts of Antalya Province. Also, the stability of spinosad and spinetoram resistance over 6 months was monitored in the Manavgat population, which showed the highest resistance among the populations.

Greenhouse populations ranged from 19 (Aksu) to 312 (Manavgat) times more resistant to spinosad. The confidence intervals (95%) of these populations did not overlap with those of the susceptible population. Therefore, resistance to spinosad was found to be significantly elevated in all populations. The LC_{90} dose range detected for spinosad in populations (133 to 3620 mg a.i./L) was above the recommended label dose of spinosad (96 mg a.i./L). These findings showed that widespread and high levels of resistance to spinosad has developed in Antalya greenhouse populations of thrips. Therefore, spinosad may not be sufficiently effective in the locations where greenhouse populations were collected. Spinosad resistance in *F. occidentalis* population has also been reported in previous studies in Türkiye and around the world. *Frankliniella occidentalis* populations were taken from Antalya and its districts in 2007-2009, and 141 times resistance to spinosad was determined only in Kumluca from these populations (unpublished data). Spinosad resistance was found to be 235 times in the *F. occidentalis* population taken from a greenhouse in Kumluca in 2015 where pesticides were used heavily (Dağlı, 2018). While spinosad resistance was seen only in Kumluca populations in previous studies, the findings of this study showed that spinosad resistance became widespread and reached high levels in all greenhouse populations from locations Gazipaşa to Demre. Spinosad has been used against *F. occidentalis* and some other important pests for more than 20 years in Antalya (Anonymous, 2022d). It is not unexpected that resistance to this active substance was widespread and high in greenhouse populations where spinosad has been used for years without applying resistance management programs. In contrast, the susceptible population used for this study obtained in 2017 from vegetables in a home garden where almost no pesticides has been applied, approximately 300 km from the area where the greenhouse populations were collected. This indicates that susceptible populations may still exist in the areas not sprayed by insecticides. In other words, it also shows how closely the development of resistance is related to the frequency of insecticide application. All greenhouse populations tested in the study show significant levels of resistance to spinosad. However, significant differences were detected among populations in terms of resistance levels. The reason for the differences in terms of the resistance levels of the populations to spinosad may be due to frequency of spinosad applications among the location. Previous studies published and related to resistance to this thrips in other countries also indicate that spinosad resistance in *F. occidentalis* has become a serious problem worldwide. Significant levels of spinosad resistance have been reported in some *F. occidentalis* populations in USA (Loughner et al., 2005), Spain (Bielza et al., 2007), Japan (Zhang et al., 2008), Australia (Herron & James, 2005; Herron & Langfield, 2011; Herron et al., 2014), China (Dong-Gang et al., 2016; Wang et al., 2016; Zhang et al., 2022) and Mexico (Cubillos-Salamanca et al., 2019). More than 3,680 times resistance to spinosad was detected in the *F. occidentalis* Spain populations where spinosad was applied more than 10 times annually in 2004 (Bielza et al., 2007). Spinosad resistance was determined as 1,400 fold in a *F. occidentalis* population taken from ornamental plant Chrysanthemum sp. in Australia in the 2010-2011 season, and it was emphasized that this result indicates an increase in spinosad resistance in populations (Herron & Langfield, 2011). In two populations of *F. occidentalis* taken from the Shouguang and Liaocheng, China in 2014-2015, 17 and 89 times resistance was found, respectively (Dong-Gang et al., 2016). Resistance in spinosad was found in the range of 2 to 248 times in populations collected from commercial blackberries in Mexico (Cubillos-Salamanca et al., 2019). In addition to *F. occidentalis*, resistance to spinosad and spinetoram has been reported for important pest insect’s species belong to order Lepidoptera, Diptera and Hymenoptera (Sparks et al., 2012).

Resistance ratios for spinetoram ranged from 4.5 (Demre-Köşkerler) to 170 times (Manavgat) in greenhouse populations. The confidence limits of these populations did not overlap with those of the susceptible population. Therefore, the resistance ratios for spinetoram in populations were found to be significant, as with spinosad resistance. LC_{90} values (91.3 to 389 mg a.i./L) for spinetoram in five of the eight greenhouse populations (Alanya, Demre-Beymelek, Gazipaşa, Kumluca and Manavgat) were above the recommended dose for spinetoram (60 mg a.i./L). Therefore, spinetoram may not be sufficiently effective in these sampling locations. The LC_{90} dose values of the other three populations (Demre-Köşkerler, Serik, Aksu) were in the range of 7.9-18.3 mg a.i./L. The recommended dose of spinetoram (60 mg a.i./L) was expected to cause over 90% mortality in these locations. However, it should be taken into account that there were resistant individuals in these three populations, albeit at a lower frequency, and frequent use of spinetoram in these locations should be avoided in order to prolong its efficacy. Results of current study shows that most of greenhouse populations of the *F. occidentalis* has developed widespread and high levels of resistance to spinetoram. As with spinosad resistance, the problem of resistance to spinetoram has become common worldwide. Spinetoram resistance was reported in China (Wang et al., 2016; Zhang et al., 2022), Australia (Langfield et al., 2018; Langfield et al., 2019; Chen et al., 2021). Resistance to spinetoram and spinosad has been found to be 17 and 15 times in *F. occidentalis* populations collected from the eggplant fields in the Shouguang and Shandong, China in 2014. Additionally, 14 times resistance to cyantraniliprole and 128 times resistance to insect growth regulator, pyriproxyfen were detected in these populations (Wang et al., 2016). The resistance ratio to spinetoram in Changping population was nearly 17,000 times (Zhang et al., 2022). In Western Australia, 17 (at LC_{50}) and -77 times (at $LC_{99.9}$) resistance to spinetoram was detected in *F. occidentalis* populations taken from stone fruits in 2017, and it was emphasized that there were failures of control at the field recommended dose (Langfield et al., 2018). Resistance to spinetoram between 6 and 56 times has been reported in *F. occidentalis* populations collected from Victoria and Queensland, Australia (Langfield et al., 2019). In addition, with PCR diagnostic test based on the G275E mutation for spinetoram resistance in Australian *F. occidentalis* populations, it was reported that spinetoram-resistant *F. occidentalis* populations collected from cotton in 2018-2019 carried the G275E mutation and resistant individuals were common (Chen et al., 2021).

Based on 12 studies on several insect species, it was reported that the most common mechanism leading to spinosad resistance in insects is target site resistance, and metabolic and other types of resistance mechanisms are more limited (Sparks et al., 2012). This general situation is also similar to resistance mechanisms in *F. occidentalis*. In most studies, spinosad resistance in *F. occidentalis* was found to be related to target site resistance (Bielza et al., 2007; Zhang et al., 2008; Gao et al., 2012). In our previous study associated with synergist and enzyme tests on a spinosad-resistant *F. occidentalis* population, it was determined that the metabolic resistance mechanism does not contribute to resistance (unpublished data). However, Herron et al. (2014) reported that metabolic resistance exists in spinosad-resistant *F. occidentalis* populations, based on the synergist PBO and esterase-based research results. Jensen (2000) investigated the resistance mechanisms in *F. occidentalis* with enzyme and synergist tests and concluded that different mechanisms may cause resistance in different *F. occidentalis* populations or those different resistance mechanisms may occur simultaneously in the same populations. Accordingly, multiple mechanisms such as target site mutation and metabolic resistance are likely to occur in resistant populations. Spinosad and spinetoram are in the same insecticide group and both are compounds that act on the nicotinic acetylcholine receptor in the insect nervous system (IRAC, 2022). The mechanism or mechanisms leading to spinosad resistance may also be expected to contribute to spinetoram resistance. Thus, several insect species such as spinosad-resistant *Drosophila melanogaster* Meigen, 1830 (Diptera: Drosophilidae), *Plutella xylostella* (Linnaeus, 1758) (Lepidoptera: Plutellidae), and *Chloridea virescens* (Fabricius, 1777) (Lepidoptera: Noctuidae) also show equal levels of cross-resistance to spinetoram as has been reported (Sparks et al., 2012).

Research findings showed that there were differences in resistance levels to spinosad and spinetoram in Antalya greenhouse populations. Resistance ratios against spinosad (19.3-312 times) were generally higher than those of spinetoram (4.5-170 times) in populations. The fact that the populations were exposed to selection pressure for a longer period to spinosad than to spinetoram may be the main reason for this situation. Spinosad has been used in Antalya more than 20 years (Anonymous, 2022d). However, spinetoram came into use in 2014 (Anonymous, 2022e). Nevertheless, a significant level of resistance to spinetoram has been detected in the majority of thrips populations, although it has been used for a short period, nearly 4 years. It is most likely that populations of *F. occidentalis* highly resistant to spinosad show lower levels of cross-resistance to spinetoram. This is also supported by the results of previous research on the *F. occidentalis* population in 2015 (Dağlı, 2018). In the study conducted on the Kumluca-2015, *F. occidentalis* population was highly resistant to spinosad (235 times) but that it was never exposed to spinetoram. Spinosad and spinetoram with recommended doses were able to kill the entire susceptible thrips population in laboratory bioassays. However, mortality rates at the recommended doses of spinosad and spinetoram in the Kumluca-2015 population were 38 and 88%, respectively (Dağlı, 2018). Spinosad-resistant populations show cross-resistance to spinetoram, albeit at lower levels. Therefore, it should be taken into account that use of insecticides with different mode of actions instead of spinosad and spinetoram at the same locations would be suitable for resistance management.

The findings in the stability tests showed that there was no significant reversion in spinosad and spinetoram resistance in the high-resistant Manavgat population, which was maintained for 6 months without pesticide exposures, and the resistance to both active substances was mostly stable. In the Manavgat population, which was continued pesticide-free for 6 months, the LC_{50} value for spinosad decreased from 125 to 108 mg a.i./L, only 0.9 times the initial value. In the same population, the LC_{50} for spinetoram decreased from 34.0 to 25.6 mg a.i./L, only 0.8 times lower than the initial LC_{50}, LC_{90} dose values after 6 months (1120 and 159 mg a.i./L) for spinosad and spinetoram in the Manavgat population, respectively were still well above the recommended doses (96 and 60 mg a.i./L) of these active substances. A similar result was obtained from a previous investigation on the stability of spinosad resistance in *F. occidentalis*. Although the highly resistant Kumluca-2015 population for spinosad was maintained without pesticide for 12 months, it was determined that there was no significant reversion in the resistance level (Dağlı, 2018). Spinosad resistance has also been reported to remain stable for 8 months in *F. occidentalis* Spanish populations (Bielza et al., 2008). Stability tests show that after high levels of resistance to spinosad and spinetoram developed in *F. occidentalis* populations, the resistance problem may not disappear in the short term, even if these insecticides are not used. For resistance management tactics to perform successfully, they must be applied before insecticides develop resistance in populations. Avoidance of frequent use of spinosad and spinetoram in locations where there are still susceptible populations of pests and alternating use of active substances with other modes of action may prolong the useful life of these insecticides.

Direct feeding damage, transmission of TSWV and being a very important quarantine pest necessitate almost a zero tolerance level for *F. occidentalis*. In recent years resistance breaking by some TSWV isolates in resistant cultivars has further increased the importance of the control of *F. occidentalis* (Fidan & Sarı, 2019). Briefly, to successfully manage this pest, it must be kept away from plant-growing areas. The use of spinosad and spinetoram in the control of *F. occidentalis* in Antalya greenhouse locations should be limited and other active substances with different modes of action should be included. However, it is not easy to come across highly effective active substances that can be recommended as alternatives in practice. The fact that carbamate and organic phosphorus active substances other than formetanate were removed from the recommendation lists in greenhouse vegetable production and the detection of high levels of resistance to the pyrethroid acrinathrin in *F. occidentalis* populations from the same locations (Toure & Dağlı, 2021) limited the number of alternative active substances that can be recommended. For this reason, instead of using only insecticides in management, strategies should be sought to achieve the level of success required by quarantine conditions against pests by using insect nets, and an integration biological and biotechnical control methods.

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