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Analyzing Resistance of Western Flower Thrips (*Frankliniella occidentalis*) to Acrinathrin, Chlorfenapyr, Dinotefuran, Emamectin Benzoate, and Fluxametamide in Greenhouse-Cultivated Tomatoes in Republic of Korea

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Abstract The western flower thrips (*Frankliniella occidentalis*) is a common pest affecting tomatoes and is controlled primarily by chemical insecticides. Since resistance to insecticides has been reported in a variety of pests across many commercial crops, we evaluated the susceptibility of *F. occidentalis* to various insecticides in tomato fields. We studied the resistance of *F. occidentalis* to five insecticides (acrinathrin, chlorfenapyr, dinotefuran, emamectin benzoate, and fluxametamide). The *F. occidentalis* samples were collected from greenhouse-cultivated tomatoes in 12 regions across South Korea, excluding the Yeongnam region. Depending on the region and the insecticide, *F. occidentalis* differed in susceptibility. None of the regional strains of *F. occidentalis* were susceptible to acrinathrin or chlorfenapyr. For fluxametamide, we observed resistance ratios of 1 or less in 10 of the 12 regional populations. For dinotefuran, a low resistance ratio of 1 or less was observed in 3 regional populations, and for emamectin benzoate, we observed a low resistance ratio of 1 or less in only one regional population. It is therefore necessary to establish a region-specific insecticide resistance system to monitor *F. occidentalis* on the basis of confirmed high resistance ratios or high susceptibility.

Key words: Acrinathrin, Dinotefuran, Resistance, Susceptibility, Tomatoes, Western flower thrips

Introduction

In Republic of Korea, tomato production has been on the increase throughout the years; and among the six provinces of Korea, Chungcheong-do, Jeolla-do and Gyeongsang-do are the largest producers of tomato (Korean Statistical Information Center, 2024). Tomato is very sensitive to pests and diseases, and special attention is required during the entire process of tomato production from seedling stage to harvest period (Lange, 1981).

Frankliniella occidentalis, western flower thrips (WFT) is considered a major pest on tomato and other crops of economic importance and is one of most damaging species in the genus *Frankliniella* worldwide (Kirk, 2002). This polyphagous species has a wide host range of more than 500 plant species within 50 plant families (Kim et al., 2023). It has a superior competitive advantage and has become the dominant species in a larger number of recorded cases (He et al., 2020; Wu et al., 2021). It can cause direct damage to leaves, flowers and fruits due to its feeding and oviposition habits, but also causes indirect damage through transmission of viruses, especially, the tomato spotted wilt virus (TSWV), which is known to be the most economically important virus (Mouden et al., 2017; He et al., 2020; Wu et al., 2021). Application of insecticides is the preferred method in the control of *F. occidentalis*, and the recent overuse of insecticides has promoted the development of resistance to several

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insecticide classes (Reitz 2009; Gao et al. 2012; Mouden et al., 2017).

Currently, there are at least 187 documented cases of insecticide resistance in *F. occidentalis* to at least 32 active ingredients across several chemical classes all over the world (Mota-Sanchez & Wise, 2023). It is widely resistant to insecticide groups such as pyrethroids, organophosphates, carbamates, neonicotinoids, avermectins and spinosyns (Cho et al., 2018; Kim et al., 2023). Gao et al. (2012) summarized a significant number of cases of resistance to different insecticides. For instance, resistance ratio (RR at LC_{50}) in acrinathrin (a pyrethroid) was reported to be as higher as 78 times in Australia. Resistance against methomyl (carbamate) was up to 180 in Santa Barbara (California); acephate (organophosphate) resistance ratios were 244, 96 and 100 folds in Kenya, Denmark and Switzerland, respectively; and among spinosyns, spinosad resistance ratio was higher than 13,500 in Spain. There have also been cases of resistance recorded against some avermectins. For instance, resistance ratios of 113 and 45.5 were recorded against abamectin in Santa Barbara (California) and China, respectively.

In Korea, several cases of insecticide resistance in thrips have also been documented. For instance, Cho et al. (2018) evaluated the susceptibility of *F. occidentalis* and *F. intonsa* to 51 commercial insecticides in Gyeonggi Province. It was noted that *F. occidentalis* showed greater resistance to some of the insecticides whilst achieving mortality rates greater than 90% in 15 of the tested insecticides. In Gyeongsangbuk Province (Andong, Bonghwa, and Yeongyang), strains from pepper cultivation were tested against 11 insecticides. High resistance ratios were reported against acrinathrin in all strains. The LC_{50} of the collected strains was more than 300 times higher than the LC_{50} of the susceptible strain, and the LC_{90} was 600 times higher than the recommended concentration (Choi et al., 2023).

In a study on insecticide resistance of chilli thrips in mango cultivation, high resistance to bifenthrin, dinotefuran, and thiacloprid were confirmed (Kim et al., 2025). In 2023, a study on insecticide resistance of *F. occidentalis* was conducted in tomato cultivation areas in the Yeongnam region (Lee et al., 2023). The current study was conducted to investigate the degree of resistance to five insecticides (acrinathrin, chlorfenapyr, dinotefuran, emamectin benzoate and fluxametamide) in tomato plantations across Korea as a follow-up to the previous study by Lee et al. (2023).

Materials and Methods

Collection and rearing of western flower thrips

The studied populations were collected from tomato crop in greenhouses located in the regions of Cheongyang, Gongju, and Chungju (Chungcheong Province); Cheorwon, Chunchon, and Hoengseong (Gangwon province); Pyeongtaek, Yeoju, and Yongin (Gyeonggii province); and Naju, Iksan, and Muju (Jeolla Province). The collected populations were subsequently examined and identified under a stereo microscope (SM2 1000, Nikon, Tochigi-ken, Japan). Breeding was done on 4-day-old kidney bean cotyledons in the laboratory. The breeding method utilized the method presented in the previous studies (Lee et al., 2023; Kim et al., 2024). Transparent plastic dishes (100 × 40 mm, SPL, Korea) were used as breeding cages. Briefly, the base of insect dish was covered with two units of filter paper (90 mm, ADVANTEC, Japan), humidified with distilled water, and a 5 × 5 cm piece of parafilm was placed in the center. *F. occidentalis* were introduced into the breeding dishes and provided with daily water sustenance and 4-day-old kidney bean cotyledons as food and spawning sources to facilitate population growth across generations. Furthermore, a laboratory strain was bred for comparative analysis under rearing conditions of 25°C ± 1°C, 50–60% humidity, and a 16L:8D photoperiod.

Insecticides

The study evaluated insecticides that are registered for controlling thrips in tomato plantations in the Republic of Korea. Among the seven insecticide classes approved by the Rural Development Administration (RDA, 2023), five insecticides containing a single active ingredient from different chemical classes were selected. These include acrinathrin (pyrethroids), chlorfenapyr (pyrroles), dinotefuran (neonicotinoids), emamectin benzoate (avermectin), and fluxametamide. The characteristics of the selected pesticides were as shown in Table 1.

Basic bioassay experiment on insecticidal activity

The study adhered to protocol No. 10 established by the Insecticide Resistance Action Committee (IRAC, 2024). The specific method of bioassay was performed in the same manner as in the previous study by Lee et al. (2023). Following the recommended concentration (RC), the bioassay was diluted at 2 RC, RC, and 1/2 RC, with three replications and three control groups using distilled water. Five sheets

Table 1. Insecticides used in the experiment

Insecticide	Chemical class	RC[b] (ppm)	IRAC group[c]	Mode of action
Acrinathrin 5.7% SC[a]	Pyrethroids	28.5	3a	Sodium channel modulators
Chlorfenapyr 5% EC	Pyrroles	50	13	Uncouplers of oxidative phosphorylation via disruption of the proton gradient
Dinotefuran 20% SG	Neonicotinoids	100	4a	Nicotinic acetylcholine receptor (Nachr) competitive modulators
Emamectin benzoate 2.15% ME	Avermectin	10.75	6	Glutamate-gated chloride channel (glucl) allosteric modulators
Fluxametamide 9% EC	Isoxazoline	45	30	Gaba-gated chloride channel allosteric modulators

[a]SC; Suspension concentrate, EC; Emulsifiable concentrate, SG; Water soluble granule, ME; Micro-emulsion. [b]RC; Recommended concentration, [c]Insecticide Resistance Action Committee group: (https://irac-online.org/mode-of-action/classification-online/)

of filter paper were placed in the insect breeding dish, soaked with distilled water, and covered with a 5 × 5 cm square parafilm. The method of rearing the thrips using soybean cotyledons was standardized and used, but the insecticide response experiment used tomato leaves, the main target crop. Tomato leaves of a diameter of 5 cm were immersed in each insecticide concentration for 30 seconds and then left to dry in a fume hood (Samin Science, Korea) for 30 minutes. The treated leaf was placed onto the parafilm, and 20 adult females were transferred into each dish, and the dish was subsequently sealed to ensure proper containment. The bioassay dishes were stored for 72 hours in a growth chamber (HB-303DH-0, Hanbaek Scientific Co., Korea) under the previously specified conditions. In the assessment, an individual was deemed dead if it did not exhibit any movement when stimulated with a brush. The survival rate was calculated as (survival number/total number) × 100 and the corrected mortality was calculated as ([mean of survival rate in the control group – survival rate in the treatment group]/ mean of the survival rate in the control group) × 100.

Bioassay for resistance assessment

This detailed bioassay was conducted using the chemical's basement findings to determine the mortality of *F. occidentalis*, ranging from 0–20% (stage 1) to 80–100% (stage 5). Consequently, five concentration intervals were scaled for dilution. The bioassay was executed following the same protocol as the baseline bioassay. The tomato leaves were immersed in each dilution for 30 seconds and placed in a fume hood (Samin Science, Korea) for 30 minutes. Twenty adult female *F. occidentalis* were transferred into the dish for each treatment under optimal growth conditions. The number of dead and live *F. occidentalis* was recorded after 72 hours. To ensure the reliability of the results, all assessments were carried out with three replecations, and retests were made in instances where the mortality in the control group exceeded 10%.

Data analysis and resistance comparison

Mortality data from the calibration assay were arcsine transformed and subjected to an analysis of variance (SAS 9.3 user's guide, 2011), with collection region, pesticide, and concentration as main factors and interactions involving the collection region. The evaluation of the arcsine of the corrected mortality rate using the Tukey's test was used to determine the significance of the differences between the treatment means. Probit analysis was used to determine the lethal concentration of each insecticide in the studied populations. The resistance of insecticide by region was expressed in terms of the Resistance ratio (RR) and Control Efficacy Index (CEI). RR_{50} compares the lethal concentration 50 (LC_{50}) of the regional strain to the laboratory strain LC_{50}, and RI compares the lethal concentration 90 (LC_{90}) of the regional strain to the recommended concentration. The LC_{50} values for laboratory populations were derived from the results of previous studies (Lee et al., 2023).

Results

Bioassay of recommended insecticide concentrations

The mortality of the *F. occidentalis* varied depending on the collection region and the type and concentration of insecticide. Interactions between each factor were also confirmed (Table 2).

Mortality of *F. occidentalis* to each insecticide varied significantly by insecticide type. Acrinathrin and dinotefuran showed low mortality rates of less than 30.5% regardless of the region of collection at the recommended concentration. In contrast, emamectin benzoate and fluxametamide each showed

Table 2. Analysis of factors affecting mortality, including region, insecticide, concentration, and all interactions including region

Source	df	Mean square	*F*-value	Pr > *F*
Region (R)	11	5217.8561	80.57	<.0001
Insecticide (I)	4	145658.3723	2249.11	<.0001
Concentration (C)	2	9752.2802	150.58	<.0001
R × I	44	2828.2777	43.67	<.0001
R × C	22	238.1346	3.68	<.0001
R × I × C	96	162.3721	2.51	<.0001

mortality exceeding 50% in all but two regions (Table 3). In general, mortality of the *F. occidentalis* increased in a concentration-dependent manner, but low or high mortality rates were observed regardless of concentration in insecticides with low or high efficacy or in local populations.

The population of *F. occidentalis* from Hoengseong showed 0% mortality regardless of the concentration in the acrinathrin treatment, and the populations from Iksan and

Table 3. Corrected mortality induced by five insecticides in field populations of *Frankliniella occidentalis* collected from tomato cultivation areas in Korea

Insecticide	Region	Correlated mortality (%, mean ± SD)		
		1/2 × RC[a]	RC	2 × RC
Acrinathrin	Cheongyang	10.0±5.0bcd	16.7±2.9abc	30.5±5.1a
	Cheorwon	6.7±5.8bcd	6.7±11.5bcd	3.3±5.8bcd
	Chuncheon	1.7±2.9cd	13.3±2.9bcd	18.3±2.9ab
	Chungju	4.5±7.8bcd	10.2±7.8bcd	16.9±2.9abc
	Gongju	11.7±2.9bcd	6.7±2.9bcd	15.0±5.0bcd
	Hoengseong	0.0±0.0d	0.0±0.0d	0.0±0.0d
	Iksan	0.0±0.0d	0.0±0.0d	1.7±2.9cd
	Muju	0.0±0.0d	1.7±2.9cd	3.3±5.8bcd
	Naju	1.7±2.9cd	3.3±2.9bcd	1.7±2.9cd
	Pyeongtaek	6.4±5.5bcd	8.9±8.4bcd	10.0±10.0bcd
	Yeoju	0.0±2.9d	1.6±2.9cd	6.8±2.9bcd
	Yongin	3.3±2.9bcd	6.7±2.9bcd	8.3±2.9bcd
Chlorfenapyr	Cheongyang	53.3±7.6c-g	73.3±2.9a-d	86.7±7.6ab
	Cheorwon	26.7±5.8g-j	26.7±5.85g-j	26.7±11.g-j
	Chuncheon	50.0±13.2d-g	81.7±5.8abc	90.0±10.0ab
	Chungju	96.7±5.8a	96.7±5.8a	100.0±0.0a
	Gongju	48.3±11.5d-h	71.7±5.8a-e	73.2±5.9a-d
	Hoengseong	23.3±5.8g-j	26.7±15.3g-j	41.1±16.4e-h
	Iksan	40.0±10.0fgh	41.7±2.9e-h	38.3±7.6fgh
	Muju	0.0±0.0j	26.7±2.9g-j	48.3±5.8d-h
	Naju	18.3±5.8hij	26.7±5.8g-j	35.0±5.0f-i
	Pyeongtaek	48.8±11.9d-h	49.3±28.9d-h	61.2±10.2b-f
	Yeoju	22.6±16.7g-j	42.4±7.8d-h	49.2±10.2d-h
	Yongin	1.7±2.9j	6.7±2.9ij	25.0±5.0ghij
Dinotefuran	Cheongyang	4.9±5.0e	9.5±8.3cde	28.3±5.8a-d
	Cheorwon	3.3±5.8e	0.0±0.0e	10.7±11.1cde
	Chuncheon	3.3±5.8e	10.0±5.0cde	13.3±5.8b-e
	Chungju	18.6±5.1b-e	30.5±2.9abc	35.6±10.6ab
	Gongju	3.3±2.9e	6.7±2.9de	10.0±5.0cde
	Hoengseong	6.7±5.8de	20.0±10.0a-e	42.2±29.1a
	Iksan	0.0±0.0e	0.0±0.0e	0.0±0.0e
	Muju	0.0±0.0e	0.0±0.0e	1.7±2.9e
	Naju	3.3±5.8e	0.0±0.0e	1.7±2.9e
	Pyeongtaek	0.0±0.0e	0.0±0.0e	0.0±0.0e
	Yeoju	3.4±0.0e	8.5±5.1cde	18.2±8.5b-e
	Yongin	5.0±5.0e	6.7±2.9de	15.0±5.0b-e

Table 3. Continued

Insecticide	Region	Correlated mortality (%, mean ± SD)		
		1/2 × RC[a]	RC	2 × RC
Emamectin benzoate	Cheongyang	100.0±0.0a	100.0±0.0a	100.0±0.0a
	Cheorwon	46.7±23.1cd	43.7±29.9cd	74.2±5.2abc
	Chuncheon	88.3±10.4ab	100.0±0.0a	98.3±2.9a
	Chungju	81.4±7.8ab	94.9±5.1a	100.0±0.0a
	Gongju	81.7±12.6ab	100.0±0.0a	100.0±0.0a
	Hoengseong	32.5±4.3de	57.8±36.7bcd	85.0±8.7ab
	Iksan	91.7±5.8a	100.0±0.0a	100.0±0.0a
	Muju	100.0±0.0a	100.0±0.0a	100.0±0.0a
	Naju	88.6±3.2ab	98.3±2.9a	100.0±0.0a
	Pyeongtaek	0.0±0.0e	27.4±11.0de	26.7±11.5de
	Yeoju	72.9±7.8abc	88.1±7.8ab	98.3±2.9a
	Yongin	90.0±5.0ab	98.3±2.9a	100.0±0.0a
Fluxametamide	Cheongyang	48.3±5.8fgh	78.3±7.6a-d	86.7±2.9abc
	Cheorwon	23.7±10.9i	20.0±10.0i	36.7±11.5ghi
	Chuncheon	95.0±5.0ab	100.0±0.0a	98.3±2.9ab
	Chungju	93.3±5.8ab	98.3±2.9ab	100.0±0.0a
	Gongju	66.7±2.9c-f	75.0±8.7b-e	88.3±7.6abc
	Hoengseong	56.7±11.5d-g	90.0±10.0abc	96.7±5.8ab
	Iksan	98.3±2.9ab	100.0±0.0a	100.0±0.0a
	Muju	100.0±0.0a	100.0±0.0a	100.0±0.0a
	Naju	81.7±10.4abc	93.3±7.6ab	98.3±2.9ab
	Pyeongtaek	53.3±11.5e-h	75.2±17.7b-e	86.7±5.8abc
	Yeoju	22.0±2.9i	32.2±7.8hi	42.4±7.8ghi
	Yongin	80.0±8.7a-d	91.7±7.6ab	100.0±0.0a

[a] Three concentrations were tested for each insecticide: half the recommended concentration (1/2 × RC), the recommended concentration (RC), and twice the recommended concentration (2 × RC).

[b] Means associated with the same lowercase letter in each insecticide treatment are not significantly different (Tukey's HSD test, $p < 0.05$).

Pyeongtaek showed 0% mortality in the dinotefuran treatment. In contrast, the populations from Cheongyang and Muju showed 100% mortality regardless of the concentration in the emamectin benzoate treatment from half to double the amount, and the population in the Muju showed 100% mortality in fluxametamide treatment.

Acrinathrin showed a low mortality of less than 20% at the recommended concentration in all 12 regions, and dinotefuran showed a low mortality of less than 20% in all but one region, Chungju. In contrast, emamectin benzoate showed a mortality of over 80% in all regions except Pyeongtaek, Cheorwon, and Hoengseong; and fluxametamide showed a mortality of over 80% in seven regions.

Evaluation of insecticide resistance

The resistance ratio and resistance index of the local population of *F. occidentalis* in the tomato cultivation area for each pesticide were as shown in Table 4.

Acrinathrin exhibited high resistance ratios ranging from 8.6 to 459.3 times across all regional populations. The CEI was highest in the Naju population at 38,070.6, while the Yongin population, which had the lowest CEI, showed a high value of 529.8 times (Table 4).

Chlorfenapyr treatment showed a very high resistance ratio of 47,484.7 in the Cheorwon population, and the resistance level was also significantly higher at 16386.6 compared to other areas. Dinotefuran showed a resistance ratio of 10 or higher only in the Cheorwon, Muju, Chungju, and Naju populations, while the Yeoju, Hoengseong, and Cheongyang populations showed a low resistance ratio of 0.3. On the other hand, the resistance level was highest in the Chungju populations at 31161.7, and the Naju populations also showed a relatively

Table 4. Insecticide resistance metrics (LC_{50}, LC_{90}, RR_{50},and CEI) for field populations of *Frankliniella occidentalis* adults against five insecticides

Insecticide	Region	Slope (±SE)$^{a)}$	LC_{50}(ppm) (95%FL)	LC_{90}(ppm) (95%FL)	$RR_{50}$$^{b)}$	CEI$^{c)}$
Acrinathrin	Cheongyang	0.7 (±0.1)	5285.0 (3134.0–10255.0)	355394.0 (117582.0–1923321.0)	28.1	12470.0
	Cheorwon	3.0 (±0.9)	36489.0 (26415.0–94572.0)	97469.0 (51829.0–866078.0)	193.9	3420.0
	Chuncheon	1.1 (±0.1)	2026.0 (1438.0–2969.0)	33414.0 (18050.0–78991.0)	10.8	1172.4
	Chungju	1.4 (±0.2)	21250.0 (15689.0–33421.0)	169651.0 (85186.0–568471.0)	112.9	5952.7
	Gongju	1.2 (±0.1)	3872.0 (2828.0–5388.0)	46694.0 (27213.0–101597.0)	20.6	1638.4
	Hoengseong	1.2 (±0.2)	3415.0 (2367.0–49.6.0)	37681.0 (20478.0–103109.0)	18.1	1322.1
	Iksan	2.8 (±0.3)	11485.0 (9950.0–13383.0)	32950.0 (26089.0–45714.0)	61.0	1156.1
	Muju	2.2 (±0.4)	27277.0 (35521.0–65865.0)	65865.0 (46892.0–125460.0)	144.9	2311.1
	Naju	1.0 (±0.2)	58767.0 (30197.0–194272.0)	1085011.0 (289580.0–14723504.0)	312.3	38070.6
	Pyeongtaek	2.0 (±0.8)	86438.0 (39755.0–19813078.0)	366066.0 (93229.0–9935885971.0)	459.3	12844.4
	Yeoju	0.9 (±0.1)	2694.0 (1780.0–4208.0)	79629.0 (36587.0–258671.0)	14.3	2794.0
	Yongin	1.3 (±0.1)	1611.0 (1193.0–2205.0)	15099.0 (9369.0–29284.0)	8.6	529.8
Chlorfenapyr	Cheongyang	1.9 (±0.2)	48.0 (40.1–57.6)	228.3 (173.7–325.7)	31.7	4.6
	Cheorwon	1.2 (±0.3)	71984.0 (40778.0–243618.0)	819332.0 (242525.0–14889973.0)	47484.7	16386.6
	Chuncheon	2.2 (±0.2)	23.7 (19.7–28.6)	91.1 (68.7–134.2)	15.6	1.8
	Chungju	1.7 (±0.2)	84.9 (65.9–109.1)	476.5 (336.7–757.3)	56.0	9.5
	Gongju	1.7 (±0.2)	147.8 (120.1–183.9)	807.6 (551.7–1436.0)	97.5	16.2
	Hoengseong	1.0 (±0.1)	24.0 (13.7–37.9)	501.3 (258.0–1454.0)	15.8	10.0
	Iksan	1.3 (±0.1)	32.9 (23.5–45.0)	325.5 (211.2–586.5)	21.7	6.5
	Muju	3.2 (±0.3)	179.5 (157.2–206.9)	447.8 (363.2–600.1)	118.4	9.0
	Naju	0.9 (±0.1)	711.4 (484.4–1046.0)	18116.0 (9811.0–41913.0)	469.3	362.3
	Pyeongtaek	1.1 (±0.1)	2113.0 (1343.0–3616.0)	29405.0 (13522.0–101628.0)	1393.9	588.1
	Yeoju	0.8 (±0.1)	150.8 (95.8–250.1)	7249.0 (2575.0–46400.0)	99.5	145.0
	Yongin	2.6 (±0.2)	287.0 (244.0–337.6)	885.9 (704.8–1203.0)	189.3	17.7

Table 4. Continued

Insecticide	Region	Slope (±SE)[a]	LC$_{50}$(ppm) (95%FL)	LC$_{90}$(ppm) (95%FL)	RR$_{50}$[b]	CEI[c]
Dinotefuran	Cheongyang	1.5 (±0.1)	968.0 (786.2–1199.0)	6575.0 (4635.0–10503.0)	0.3	65.8
	Cheorwon	16.3 (±3.2)	86025.0 (80571.0–92695.0)	103063.0 (95107.0–120199.0)	30.4	1030.6
	Chuncheon	1.4 (±0.1)	6173.0 (4624.0–8484.0)	51152.0 (31279.0–103303.0)	2.2	511.5
	Chungju	0.7 (±0.1)	43506.0 (23792.0–100383.0)	3116174.0 (875609.0–22430366.0)	15.4	31161.7
	Gongju	1.8 (±0.2)	19629.0 (15687.0–25438.0)	98609.0 (66000.0–177142.0)	6.9	986.1
	Hoengseong	0.9 (±0.2)	869.9 (420.6–1674.0)	19725.0 (7378.0–149942.0)	0.3	197.3
	Iksan	1.9 (±0.2)	6050.0 (4870.0–7450.0)	28427.0 (21079.0–42687.0)	2.1	284.3
	Muju	2.6 (±0.4)	85854.0 (71353.0–110511.0)	227181.0 (161426.0–413387.0)	30.4	2271.8
	Naju	0.8 (±0.1)	51036.0 (27490.0–133987.0)	1823337.0 (495416.0–18101308.0)	18.0	18233.4
	Pyeongtaek	1.6 (±0.2)	12231.0 (8795.0–17952.0)	73255.0 (42994.0–168736.0)	4.3	732.6
	Yeoju	1.9 (±0.2)	978.7 (806.9–1219.0)	4503.0 (3122.0–7791.0)	0.3	45.0
	Yongin	1.3 (±0.1)	3595.0 (2676.0–5027.0)	35631.0 (20547.0–80568.0)	1.3	356.3
Emamectin benzoate	Cheongyang	1.8 (±0.2)	0.6 (0.4–0.7)	2.8 (1.9–4.5)	1.0	0.3
	Cheorwon	2.5 (±0.3)	31.9 (26.6–38.7)	106.2 (78.3–171.7)	57.1	9.9
	Chuncheon	2.3 (±0.2)	1.1 (0.9–1.3)	4.0 (3.1–5.8)	2.0	0.4
	Chungju	2.3 (±0.2)	1.4 (1.1–1.6)	5.1 (3.9–7.2)	2.5	0.5
	Gongju	2.1 (±0.2)	1.1 (0.9–1.4)	4.6 (3.4–6.7)	2.1	0.4
	Hoengseong	1.4 (±0.2)	2.3 (1.6–3.2)	19.2 (11.6–41.9)	4.1	1.8
	Iksan	2.9 (±0.3)	0.8 (0.7–1.0)	2.3 (1.9–3.1)	1.5	0.2
	Muju	2.7 (±0.3)	0.9 (0.8–1.1)	2.7 (2.2–3.6)	1.6	0.3
	Naju	2.5 (±0.2)	1.5 (1.3–1.8)	4.8 (3.8–6.7)	2.7	0.5
	Pyeongtaek	2.0 (±0.3)	18.7 (13.6–25.0)	81.1 (55.3–147.8)	33.5	7.5
	Yeoju	1.6 (±0.2)	2.8 (2.2–3.7)	17.7 (12.0–30.4)	5.1	1.6
	Yongin	1.8 (±0.2)	2.1 (1.7–2.7)	11.0 (7.9–17.3)	3.8	1.0

Table 4. Continued

Insecticide	Region	Slope (±SE)[a]	LC_{50}(ppm) (95%FL)	LC_{90}(ppm) (95%FL)	RR_{50}[b]	CEI[c]
Fluxametamide	Cheongyang	1.2 (±0.1)	4.8 (3.4–6.7)	61.3 (37.1–122.1)	0.3	1.4
	Cheorwon	2.7 (±0.3)	612.0 (507.6–741.9)	1846.0 (1399.0–2795.0)	32.0	41.0
	Chuncheon	2.3 (±0.2)	3.4 (2.8–4.1)	12.2 (9.4–17.3)	0.2	0.3
	Chungju	2.7 (±0.2)	4.3 (3.7–5.1)	13.0 (10.5–17.5)	0.2	0.3
	Gongju	1.9 (±0.2)	6.7 (5.3–8.3)	30.9 (22.7–46.6)	0.3	0.7
	Hoengseong	2.1 (±0.3)	8.7 (6.7–11.2)	34.7 (24.3–59.9)	0.5	0.8
	Iksan	3.0 (±0.3)	4.0 (3.5–4.7)	10.8 (8.8–14.2)	0.2	0.2
	Muju	2.8 (±0.3)	4.0 (3.4–4.6)	11.3 (9.2–15.1)	0.2	0.3
	Naju	2.1 (±0.2)	8.1 (6.7–9.9)	33.0 (24.7–48.6)	0.4	0.7
	Pyeongtaek	1.1 (±0.1)	11.3 (6.9–18.4)	184.6 (93.8–487.5)	0.6	4.1
	Yeoju	1.3 (±0.2)	97.9 (74.2–128.6)	875.8 (551.8–1744.0)	5.1	19.5
	Yongin	1.9 (±0.2)	5.9 (4.7–7.2)	27.4 (20.3–41.4)	0.3	0.6

[a] Standard error.
[b] Resistance ratio, RR=LC_{50} value of field strain / LC_{50} value of laboratory strain.
[c] Control efficacy index, CEI=LC_{90} value of field strain / Recommended concentration.

high index value of 18233.4 compared to other areas.

Emamectin benzoate showed high resistance ratios (57.1 and 33.5, respectively) only in Cheorwon and Pyeongtaek, populations while most regions showed low resistance ratios (<5). Control efficacy index also showed low values (<1) in most regions, except Cheorwon and Pyeongtaek populations.

Fluxametamide also showed low resistance ratios (<1) except in Cheorwon (32.0) and Yeoju populations (5.1). Control efficacy indexs also showed low values (<1) in all regions except Cheorwon, Yeoju, Pyeongtaek, and Cheongyang.

Discussion

In the current study, the resistance of *F. occidentalis* was assessed against acrinathrin, chlorfenapyr, dinotefuran, emamectin benzoate, and fluxametamide. Our findings indicated that susceptibility and resistance to insecticides is different between the populations, and that different sensitivities to different kinds of insecticides are evident even within the same population. Most of the collected populations showed high resistance ratios when exposed to acrinathrin, dinotefuran, and chlorfenapyr. Overall, the proportion of susceptible strains with a resistance ratio of 1 or less was 83% for fluxametamide in 10 of the 12 regions. For dinotefuran, only 3 regions (25%) showed a resistance ratio of 1 or less, and for emamectin benzoate, only 1 region (8.3%) showed a susceptible strain. On the other hand, there were no susceptible strains to acrinathrin and chlorfenapyr. In the previous study on the *F. occidentalis* in tomato cultivation areas in the Yeongnam region, the overall resistance rate to fluxametamide was low (Lee et al., 2023). In contrast, the Gimhae population in the current study was found to be susceptible to chlorfenapyr treatment, for which no susceptible strains were identified in the previously study (Lee et al., 2023).

The decreased susceptibility of *F. occidentalis* to these commonly applied insecticides could be attributed to the frequent exposure of insect populations in these regions to a variety of insecticides. Correlations between decreased susceptibility of *F. occidentalis* and application frequency of various insecticides have already been reported in various findings (Bielza et al., 2007; Wang et al., 2016; Fan et al., 2023). However, since this study was unable to investigate the history of pesticide use in each farm, it is believed that additional research will be needed in this area in the future.

As already elucidated in various detoxification enzyme activity studies and reports (Jensen, 2000; Zhang, et al., 2017; Hassan et al., 2022; Fan et al., 2023), the development of insecticide resistance in *F. occidentalis* and other insect pests is primarily regulated by the activity of detoxifying enzymes. The ability of insects to counteract pesticides is enhanced by the apparent increased synthesis of detoxifying enzymes that continuously enhance their metabolic activity resistance. Detoxification enzymes such as GST, AChE, CarE, and CYP450 are important in mediation of metabolic resistance to different insecticide classes, including pyrethroids, neonicotinoids, carbamates, organophosphates, organochlorines and avermectins (Jensen, 2000; Cao et al., 2021; Zhi et al., 2021). The enhanced oxidative metabolism mediated by these enzymes, especially the CYP450 monooxygenases has been implicated in cross-resistance potential between insecticides (Yoo et al., 2002; Chen et al., 2011; Gao et al., 2014).

On the other hand, emamectin benzoate and fluxametamide produced positive results. Particularly, emamectin benzoate was highly effective against all the populations. Despite its effectiveness against the currently studied populations, literature is not short of resistance development in some *F. occidentalis* populations in Korea and worldwide. In Korea, emamectin benzoate was first used in 2001, and by 2005, resistance to emamectin benzoate was already evident (Choi et al., 2005). In the past few years, cases of emamectin benzoate resistance have been on a rapid increase (Kwon et al., 2015; Gao et al., 2022). Recently, a detailed investigation done by Gao et al. (2022) on potential mechanisms of emamectin benzoate resistance in *F. occidentalis* revealed that mutations in, and the overexpression of FoGluClc play major roles in emamectin benzoate resistance, in addition to partial involvement of the overexpressed Cyps as metabolic factors. Therefore, despite the promising results demonstrated in the current study, continous and regular studies to monitor sensitivity of various *F. occidentalis* populations to emamectin benzoate is vital to limit further development of resistance.

Fluxametamide is a newer isoxazoline insecticide that acts via antagonism of insect ligand-gated chloride channels (Asahi et al., 2018). It has been recommended as a suitable insecticide to control *F. occidentalis,* especially in greenhouse conditions (Nateq Golestan et al., 2021). In the current study, except in the Cheorwon and Yeoju population where higher LC_{90} was recorded, fluxametamide is still a recommendable insecticide to control *F. occidentalis.* However, contrary to our findings, Lee et al. (2023) recorded significant resistance levels in *F. occidentalis* populations sampled from tomato plantations against this newer insecticide. Roy et al. (2023) identified some considerable level of cross-resistance between fluxametamide and emamectin-benzoate in *Spodoptera frugiperda.* These findings call for further extensive research to explore and validate potential cross-resistance in *F. occidentalis* populations. It is also important to note that in the current study, the laboratory strain demonstrated signs of resistance to insecticides (acrinathrin, dinotefuran and fluxametamide), indicating that populations that have not been exposed to insecticides for a long time may still show some level of resistance. In conclusion, proactive implementation of resistance management strategies is a prerequisite for maintaining the field efficacy of these key insecticides against *F. occidentalis*. Additionally, integrated pest management (IPM) should also be explored as an option for sustainable management of *F. occidentalis*.

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Disclosure of Potential Conflicts of Interest

The authors declare that they have no conflict of interest.

Literature Cited

Asahi M, Kobayashi M, Kagami T, Nakahira K, et al. 2018. Fluxametamide: A novel isoxazoline insecticide that acts via distinctive antagonism of insect ligand-gated chloride channels. Pestic. Biochem. Physiol. 151:67-72.

Bielza P, Quinto V, Fernandez E, Gravalos C, et al., 2007. Genetics of spinosad resistance in *Frankliniella occidentalis* (Thysanoptera: Thripidae). J. Econ. Entomol. 100(3):916-920.

Cao Y, Yang H, Gao Y, Wang L, et al. 2021. Effect of elevated CO_2 on the population development of the invasive species *Frankliniella occidentalis* and native species *Thrips hawaiiensis* and activities of their detoxifying enzymes. J. Pest Sci. 94:29-42.

Chen X, Yuan L, Du Y, Zhang Y. et al. 2011. Cross-resistance and biochemical mechanisms of abamectin resistance in the western flower thrips, *Frankliniella occidentalis*. Pestic. Biochem. Physiol. 101(1):34-38.

Cho SW, Kyung Y, Cho SR, Shin S, et al., 2018. Evaluation of susceptibility of western flower thrips (*Frankliniella occidentalis*) and garden thrips (*F. intonsa*) to 51 insecticides. Korean J. Appl. Entomol. 57(3):221-231. (In Korean)

Choi BR, Park HM, Yoo JK, Kim SG, et al. 2005. Monitoring on insecticide resistance of major insect pests in plastic house. Korean J. Pestic. Sci. 9(4):380-390.

Choi JH, Lee HW, Lee JW, Kim YS, et al., 2023. Evaluation of insecticide activites against the western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripdae), collected from greenhouse pepper cultivation areas in Gyeongsangbuk-do. Korean J. Pestic. Sci. 27(3):232-241. (In Korean)

Fan R, Fan Z, Sun Z, Chen Y. et al., 2023. Insecticide susceptibility and detoxification enzyme activity of *Frankliniella occidentalis* under three habitat conditions. Insects, 14(7):643.

Gao Y, Lei Z, Reitz SR, 2012. Western flower thrips resistance to insecticides: detection, mechanisms and management strategies. Pest Manage. Sci. 68(8):1111-1121.

Gao CF, Ma SZ, Shan CH, Wu SF. 2014. Thiamethoxam resistance selected in the western flower thrips *Frankliniella occidentalis* (Thysanoptera: Thripidae): cross-resistance patterns, possible biochemical mechanisms and fitness costs analysis. Pestic. Biochem. Physiol. 114:90-96.

Gao Y, Yoon KA, Lee JH, Kim JH. Et al. 2022. Overexpression of glutamate-gated chloride channel in the integument is mainly responsible for emamectin benzoate resistance in the western flower thrips *Frankliniella occidentalis*. Pest Manage. Sci. 78(10):4140-4150.

Hassan ZN, Kassim Mohanad A, Shafeeq MAA. 2022. Evaluation of insecticides resistance: review article. South Asian Res. J. Bio. Appl. Biosci. 4(4):86-93.

He Z, Guo JF, Reitz SR, Lei ZR, et al., 2020. A global invasion by the thrip, *Frankliniella occidentalis*: Current virus vector status and its management. Insect science, 27(4):626-645.

Insecticide Resistance Action Committee (IRAC), 2024. Standard,validated and easy-to-run methods for resistance detection in the world's major insect pests. https://irac-online.org (Accessed Sep. 1. 2024).

Jensen SE. 2000. Insecticide resistance in the western flower thrips, *Frankliniella occidentalis*. Integrated Pest Manage. Rev. 5(2):131-146.

Kang DH, Koo HN, Kim GH, 2024. Evaluation of resistance using control efficacy index and cross-resistance analysis of 11 insecticides in field populations of cotton aphids, *Aphis gossypii* (Hemiptera: Aphididae). Korean J. Pestic. Sci. 28:160-170. (In Korean)

Kim CY, Khan F, Kim Y, 2023. A push-pull strategy to control the western flower thrips, *Frankliniella occidentalis*, using alarm and aggregation pheromones. Plos one, 18(2), e0279646.

Kim MJ, Lee HW, Lee DG, Kim KW, et al. 2025. Insecticide resistance of chilli thrips (*Scirtothrips dorsalis*) during mango cultivation in the Republic of Korea. Hortic. Sci. Technol. 43(5):623-636.

Kim YS, Park CG, Kwon T, Lee DW, 2024. An improved mass rearing method for western flower thrips, *Frankliniella occidentalis*. Korean, J. Appl. Entomol. 63(4):367-371. (In Korean)

Kirk WD, 2002. The pest and vector from the West: *Frankliniella occidentalis*. In Thrips and Tospoviruses: Proceedings of the 7th international symposium on thysanoptera (Vol. 2, pp. 33-42). Canberra, Australia: Australian National Insect Collection.

Korean Statistical Information Center, 2024. Vegetable production (fruits and vegetables) [Electronic data]. Statistics Korea, Agricultural Area Survey. Retrieved April 5, 2024, from https://kosis.kr/statHtml/statHtml.do?orgId=101&tblId=DT_1ET0027&conn_path=I3 (In Korean)

Kwon DH, Kim K, Kang TJ, Kim SJ, et al. 2015. Establishment of an insecticide resistance monitoring protocol based on the residual contact vial bioassay for *Frankliniella occidentalis*. J. Asia-Pacific Entomol. 18(2):311-314.

Lange WH, Bronson L, 1981. Insect pests of tomatoes. Ann. Rev. Entomol. 26(1):345-371.

Lee HW, Choi JH, Lee JW, Kim YS, et al., 2023. Response of 5 Insecticides to *Frankliniella occidentalis* occurring on tomato cultivation at the greenhouse in Gyeongsang area.

Korean J. Pestic. Sci. 27(4), 352-360. (In Korean)

Mota-Sanchez D. Wise JC, 2023. The Arthropod Pesticide Resistance Database. Michigan State University. On-line at: http://www.pesticideresistance.org

Mouden S, Sarmiento KF, Klinkhamer PG, Leiss KA, 2017. Integrated pest management in western flower thrips: past, present and future. Pest Manage. Sci. 73(5):813-822

Nateq Golestan M, Shafaghi F. Sheikhi Gorjan A. 2021. Efficacy of several insecticides against western flower thrips *Frankliniella occidentalis* by introducing its two new effectiveness indices in greenhouse cucumber. J. Appl. Res. Plant Protec. 10(4):17-23.

Reitz SR, 2009. Biology and ecology of the western flower thrips (Thysanoptera: Thripidae): the making of a pest. Florida Entomologist, 92(1):7-13.

Roy D, Biswas S, Sarkar S, Adhikary S, et al. 2023. Risk assessment of fluxametamide resistance and fitness costs in fall armyworm (*Spodoptera frugiperda*). Toxics, 11(4):307.

SAS/STAT® 9.3 user's guide, 2011. SAS Institute Inc., Cary, NC, USA

Wang ZH, Gong YJ, Jin GH, Li BY, et al., 2016. Field-evolved resistance to insecticides in the invasive western flower thrips *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) in China. Pest Manag. Sci. 72(7):1440-1444.

Wu S, Xing Z, Ma T, Xu D, et al., 2021. Competitive interaction between *Franklinella occidentalis* and locally present thrips species: a global review. J. Pest Sci. 94:5-16

Yoo JS, Kim JI. Kim GH. 2002. Insecticide susceptibility of flower thrips collected from rose plantations in each region. Korean J. Pestic. Sci. 6(2):80-86. (In Korean)

Zhang X, Liao X, Mao K, Yang P, et al. 2017. The role of detoxifying enzymes in field-evolved resistance to nitenpyram in the brown planthopper *Nilaparvata lugens* in China. Crop Protec. 94:106-114.

Zhi J, Liu L, Hou X, Xie W, et al. 2021. Role of digestive enzymes in the adaptation of *Frankliniella occidentalis* to preferred and less-preferred host plants. Entomol. Exp. Appl. 169(8):688-700.