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Acaricidal activities of three acaricides on *Tetranychus urticae* (Acari: Tetranychidae) with emphasis on residual effects in cucumber

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ABSTRACT

Pesticides are broadly used in the control of *Tetranychus urticae* Koch populations. In the present study, the toxicity and residual activities of abamectin, spirodiclofen, and pyridaben against *T. urticae* on cucumber plants were assessed under laboratory and greenhouse conditions. Furthermore, the influences of tested pesticides on some biological aspects of this pest were studied. In laboratory experiments, LC_{50} values of abamectin, spirodiclofen, and pyridaben to females were 0.71, 41.04, and 28.56 ppm, respectively. Treated females presented low fecundities ranging from 0.18 to 3.81 eggs/female/day versus 8.4 eggs/female/day in control. Spirodiclofen and pyridaben were found to be have much stronger ovicidal activity as compared to abamectin. Abamectin and spirodiclofen had an elongation effect on the developmental durations of immatures with a mean pre-adult of 14.60 and 10.04 days, respectively, compared to 8.75 days in the control. The highest reduction effect of spirodiclofen and pyridaben on *T. urticae* populations were 100 and 87.14 %, respectively at 3 days post-treatment compared to 100% in abamectin at all tested durations. In the residual efficacy test, abamectin caused 100% mortality of *T. urticae* at 7 days after spraying compared to 63.27 and 47.96 % in the case of spirodiclofen and pyridaben, respectively. However, no phytotoxicity was observed on treated plants at recommended rates. The determined residues of spirodiclofen and abamectin in cucumber fruits were above the maximum residue limit (MRL) amounts after 10 days of treatment, so the preharvest intervals (PHI) for both compounds were 15 days, while PHI for pyridaben was 10 days. Therefore, the cucumber fruits could be consumed safely after these periods.

KEYWORDS

Acaricides efficiency, chemical control, residues, risk assessment, *Tetranychus urticae*, toxicity

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INTRODUCTION

Vegetables are important nutritional items for people. They are recommended to be eaten fresh, unpeeled, and unprocessed because of their high nutritional value and high content of minerals, vitamins, fibers, and antioxidants. However, this is one of the main ways through which humans are exposed to pesticides at a rate five times higher than that of other foods (El-Sheikh *et al.* 2022). In this regard, cucumber plants (*Cucumis sativus* L.) were found to be attacked by many mites and insect pests during the growing season. Although chemical pesticides can be effective against these pests, their continued use can promote pests' resistance (Schmidt-Jeffris *et al.* 2021b). In addition, pesticide residues can lead to acute or chronic health risks and affect the nutritional quality of cucumbers (Shalaby *et al.* 2021).

One of the most dominant pests infesting cucumber is the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). This mite is a serious pest that infests around 1200 plants, including over 150 economically important plant species (Jeppson *et al.* 1975; Xie *et al.* 2006). This mite pest feeds on contents of the cells in the mesophyll of plant leaf (Nachman and Zemek 2002). The heavy infestation gives rise to leaf yellowing, leaf fall, and loss in quality and quantity of crops (Kuma *et al.* 2015).

There are several approaches to the management of spider mites such as chemical and biological methods (Farahani et al. 2018; Wang et al. 2018). Despite some progress in the control of these mites, pesticides are still the main and widely utilized control technique for this pest (van Leeuwen *et al.* 2004; Uddin *et al.* 2015). Among these pesticides, abamectin, pyridaben, and spirodiclofen are utilized as acaricides in Egypt. Abamectin is considered as an effective miticide and insecticide (Hamedi *et al.* 2011). This compound is a product of the natural fermentation of *Streptomyces avermitilis* bacterium and acts in the nervous system as a regulator of chloride channels, paralyzing mites (Saber *et al.* 2018). Although abamectin was demonstrated to be not harmful to some phytoseiid species (Hardman *et al.* 2003; Gradish *et al.* 2011), it was found to be very toxic to other phytoseiids (Shipp *et al.* 2000; Kim *et al.* 2005; Bostanian and Akalach 2006; You *et al.* 2016). In open fields, abamectin is considered, to some extent, harmless to natural enemies due to its quick degradation and quick absorption in plants (Lasota and Dybas 1991). Pyridaben acts as an inhibitor of mitochondrial electron transport (Saber *et al.* 2018) and provides good efficiency against tetranychid pests (Stumpf and Nauen 2001; Marcic 2012). This pesticide is allowed for use in the EU countries (Badawy *et al.* 2022). A noticeable decrease in *T. urticae* damage was achieved when Iwassaki *et al.* (2015) used pyridaben with *Neoseiulus californicus* (McGregor), even though this pesticide was indicated to be extremely toxic to a range of phytoseiid mites (Childers *et al.* 2001; Da Silva et al. 2015). Spirodiclofen is an acaricide that inhibits lipid biosynthesis (Bretschneider *et al.* 2007) and is commercially marketed as a highly effective acaricide against many plant feeder mites (Saber *et al.* 2018). It successfully controls mite populations that are resistant to other chemicals (Elbert et al. 2002; Marcic 2007). This acaricide was reported to be not harmful to some predatory mites (Bostanian *et al.* 2009; Kaplan *et al.* 2012; Doker and Kazak 2020), while it was reported to be harmful to *N. californicus* (Sarbaz *et al.* 2017).

The presence of baseline data on the acaricidal activity of commercial formulation of acaricide products on target pests is an essential element in regulating the application of acaricides (Badawy *et al.* 2022). Therefore, the present study aimed to evaluate the toxicity of three commercial acaricides on *T. urticae* and their impact in reducing its populations under laboratory and greenhouse conditions; also, the influence of mean lethal concentrations of tested acaricides on the duration of developmental stages and reproduction of the pest was evaluated. The research was extended to determine residues of these compounds in/on cucumber fruits.

MATERIAL AND METHODS

Two-spotted spider mite

The colony of *T. urticae* was raised on leaves of cucumber. The rearing units consist of leaves sitting on moist cotton pads in Petri dishes (9 cm in diameter). To keep cotton pads damp, water was added when necessary. The colony was kept in an incubator at 25 ± 2 °C, 65 ± 5 % RH, and 16 L: 8 D photoperiod. The host plant, cucumber was cultivated in the greenhouse at the farm of National Research Centre (Al-Nobariah region, Al-Beheira Governorate, Egypt).

Acaricides used

The acaricides used in the present study are illustrated in Table 1.

Bioassays procedure

Acaricidal activity of acaricides on mite female

The direct spray technique was used to assess the effectiveness of tested pesticides against *T. urticae* under laboratory conditions at 25 ± 2 °C, 65 ± 5 % RH, and 16 L: 8 D photoperiod. Four concentrations

of each pesticide were prepared via distilled water as a solvent. The experimental units consist of leaf discs of cucumber placed on moistening cotton layers in Petri dishes. Newly emerged mated females with the same age obtained from a synchronized mite culture were used for this experiment. Twenty adult females were transported to each leaf disc and sprayed with tested concentration of pesticides, or with distilled water only as control. Each concentration treatment had six replicates (20 females/replicate). Based on preliminary experiments, females' mortality was recorded at 48 h after treatment. Females were considered dead if they were unable to move after being prodded with a soft brush.

Table 1. Acaricides used, common and trade names, and recommended rates according to APC (2024).

No.	Common name and formulation	Trade name	Recommended rate
1	Spirodiclofen 24% SC	Concor	30 ml/100L
2	Abamectin 8.4% EC	AgriTen	30 ml/100L
3	Pyridaben 20% WP	Pyriden	50g/100L

The ovicidal activity of acaricides

In this experiment, the impact of abamectin, spirodiclofen, and pyridaben on *T. urticae* eggs were evaluated using 2 concentrations of each acaricides (LC_{50} and LC_{90}, estimated for *T. urticae* females). Females of *T. urticae* were moved to cucumber leaf discs and left for 24 h for oviposition, then removed. The leaf discs carrying the newly deposited *T. urticae* eggs were used in this test. These leaf discs containing eggs were sprayed with tested concentrations of each acaricide (LC_{50} and LC_{90}, estimated for *T. urticae* females) separately using a glass atomizer. The leaf discs were placed on saturated cotton pads in Petri-dishes (experimental arenas). Control eggs were sprayed with distilled water. The experimental arenas were kept under laboratory conditions at 25 ± 2 °C, 65 ± 5 % RH, and 16 L: 8 D photoperiod. Egg hatchability was observed daily for a week post-treatment. For each acaricide, each tested concentration and control had six replicates (20 eggs/replicate). Mortality percentages of eggs (where eggs were assumed dead if not hatched) were corrected according to Abbott's formula (Abbott 1925).

Biological aspects

In this trial, newly emerged mated females with the same age were placed on leaf discs and sprayed with LC_{50} of abamectin, spirodiclofen, pyridaben, or distilled water (control) and then kept under laboratory conditions similar to the aforementioned bioassay. Next, thirty treated survived females were selected randomly and placed separately on leaf discs of experimental units. Throughout the next 10 days, female fecundity and mortality were observed. In addition, thirty newly oviposited eggs produced from those experimental females were also observed individually in order to record their incubation period, duration of all immature stages, pre-adult duration, and sex ratio in the case of all treatments and control.

Greenhouse experiments

Effect of acaricides on population density of two-spotted spider mite in greenhouse

Regarding applicability, the efficiency of the tested acaricides was assessed under greenhouse conditions. This trial was performed at the farm of National Research Centre (Al-Nobariah region, Al-Beheira Governorate, Egypt). In this experiment, cucumber was cultivated in the greenhouse under natural photoperiod; then, the plants were infested with *T. urticae*. Four treatments namely abamectin, spirodiclofen, pyridaben, or water (control) were tested in this experiment. The experimental area was divided into four treatments (abamectin, spirodiclofen, pyridaben, or water (control)). Each treatment contained three plots; each plot had 2 rows with 20 plants/row. Before treatment, thirty plant leaves (10 leaves/plot) were randomly collected from each treatment. Using a stereoscopic microscope, the numbers of *T. urticae* on each leaf were recorded. For performing the treatments, plants were sprayed

with the recommended rates of the tested acaricides using a knapsack sprayer. The control plants were sprayed with water. After 1, 3, 5, and 7 days of spraying, thirty plant leaves (10 leaves/plot) were randomly collected from each treatment, and the numbers of *T. urticae* were also recorded. The reduction percentages in *T. urticae* populations were estimated according to Henderson and Tilton (1955).

Residual effect of acaricides on spider mite

In this trial, at 2, 24, 72, 120, and 168 h after treatment, cucumber leaves, free of mites, were selected randomly from each treatment, where leaf discs were cut from the control and treated leaves. These discs were positioned on saturated cotton in Petri dishes. Twenty mite females were put on the treated and control leaf disc. Based on preliminary experiments, mite mortality was detected at 48 h following exposing to acaricide residues aged 2, 24, 72, 120, and 168 h. For each treatment and control, 30 replicates were used (20 females/replicate). Corrected mortality is estimated according to Abbott's formula (Abbott 1925).

Phytotoxicity

A visual assessment of phytotoxicity was performed by inspecting the whole plants. Phytotoxicity was inspected after 1, 3, 5, 7, and 14 days of treatment. Any changes in plant appearance between treated and control plants have been considered an indicator of plant toxicity.

Residues determination of tested acaricides on/in treated cucumber fruits

Sampling

One kg of cucumber fruits was collected randomly per replicate at 1h and at 1, 3, 5, 7, 10, and 15 days after acaricides application. Samples were put in polyethylene bags and transferred to the Pesticides Laboratory (Pests and Plant Protection Department, National Research Centre, Cairo, Egypt). The samples were homogenized using a speed blender and stored frozen until analysis.

Chemical reagents

The Central Agricultural Pesticides Laboratory (CAPL), Giza, Egypt, provided the standards for spirodiclofen, abamectin, and pyridaben acaricides, and their purity ranged from 98.2 to 99.1%. Also, all chemicals used for residue analysis were HPLC grade and supplied by Sigma-Aldrich (USA). While, Interchim, USA provided QuEChERS chemicals and kits for cleanup, containing primary secondary amine (PSA) and magnesium sulfate anhydrous (MgSO4).

Preparation of standard solutions

For HPLC analysis, 100 ml/L stock solutions of tested compounds were dissolved individually with ethyl acetate and acetonitrile according to their polarity and solubility. The stock solutions were diluted accordingly to prepare consecutive working dilutions and spike standard solutions. To determine the technique's effectiveness, we established its linearity based on the concentrations of the tested pesticides, which were diluted in a suitable solvent.

Extraction and clean-up

The QuEChERS method was used for extraction and clean-up (ILNAS-EN 15662: 2018) with slight modifications. 10 g of the homogenized samples were weighed into 50 mL centrifuge tubes. 15 mL acetonitrile and 4g of $MgSO_4$ were added, then the tube was shaken using a vortex for 1 min. The mixture was centrifuged at 4,000 rpm for 5 min at 5 °C. The upper layer was transferred to a falcon tube (15 mL)

and cleaned using PSA and $MgSO_4$, vortexed for 1 min, and centrifuged at 4,000 rpm for 5 min. The extract was then filtered using a 0.22 µm PTFE filter and transferred to a vial for HPLC determination.

Estimation

The final determination of spirodiclofen, abamectin, and pyridaben samples was performed by HPLC at the Pesticides Laboratory, Pests and Plant Protection Department, National Research Centre, Cairo, Egypt. The HPLC apparatus was an Agilent 1260 series equipped with a quaternary pump, a variable-wavelength diode array detector (DAD), and an auto sample with an electric sample valve. The column was Nucleosil C18 (30 × 4.6 mm (i.d.) × 5 µm) film thickness.

Table 2. HPLC conditions for determining the tested pesticide residues, mobile phase, retention time (Rt.), flow rate, and wave length.

Pesticides	Mobile phase	Rt. (min)	Flow rate (ml/min)	Wave length (nm)
Spirodiclofen	ACN: water (30:70)	6.14	1	246
Abamectin	ACN: MeOH: water (45: 40:15)	3.2	1	254
Pyridaben	ACN: water (60 :40)	5.1	1	280

ACN: Acetonitrile; water = deionized water; MeoH = Methanol

Recovery experiment

Before analyzing the test samples for each treatment, a recovery study for cucumber fruits was conducted to ensure quality assurance information, such as the accuracy, trueness, and precision of the analytical procedure. The accuracy of the analytical method was examined by fortifying cucumber samples from untreated plants with known amounts of tested compound standards at three concentrations (0.05, 0.1, and 1.0 mg/kg). Blank samples were kept at room temperature for 2 h, and analyzed as previously described to evaluate the reliability and precision of the method. These samples were analyzed under the same previous conditions.

The residual half-lives (RL_{50}) values of spirodiclofen, abamectin, and pyridaben acaricides were calculated using the Moye *et al.* (1987) equation.

Statistical analysis

The LC_{50}, LC_{90}, and concentration slope were calculated using the Ldp-line computer program to estimate the lethal concentrations (LC values) of each tested acaricide against *T. urticae*. Data from the biological aspects and greenhouse experiments were analyzed by one-way analysis of variance (ANOVA) using SPSS, where statistical differences between means were revealed by Tukey's test ($P < 0.05$).

RESULTS

Toxicity of tested acaricides against two-spotted spider mite

The results in Table 3 display that LC_{50} values of abamectin, spirodiclofen, and pyridaben against *T. urticae* were 0.71, 41.04, and 28.56 ppm, respectively. However, LC_{90} of the abovementioned acaricides were 4.96, 81.12, and 742.39 ppm, respectively. Our results revealed that when *T. urticae* eggs were sprayed with LC of each tested acaricide (LC_{50} and LC_{90}, estimated for *T. urticae* females) spirodiclofen and pyridaben showed much stronger ovicidal activity as compared to abamectin (Fig. 1).

Biological aspects

Females of *T. urticae* treated with LC_{50} of tested acaricides presented low fecundity ranging from 0.18 to 3.81 eggs/female/day versus 8.4 eggs/female/day in the untreated mites ($F_{3, 116} = 95.908$; $P =$

0.000). On the other hand, the significantly lowest egg hatchability percentage was observed in the case of spirodiclofen (45.20%) and pyridaben (49.68%) treatments compared to the abamectin treatment (69.90%) ($F_{3, 116}$ = 72.951; P = 0.000). During this experiment, the highest female mortality was achieved by abamectin treatment (83.00 %) (Table 4).

Table 3. Toxicity of tested acaricides against *Tetranychus urticae* females under laboratory conditions.

Treatments	LC_{50} (95% CL*)	LC_{90} (95% CL)	Slope ± SE	χ^2	*p*
Abamectin	0.71 (0.38–0.95)	4.96 (3.29–12.72)	1.51 ± 0.33	1.098	0.295
Spirodiclofen	41.04 (35.36–45.84)	81.12 (71.50–97.61)	4.33 ± 0.57	0.889	0.346
Pyridaben	28.56 (17.36–40.25)	742.39 (372.43–2678.24)	0.91 ± 0.15	1.459	0.482

* Confidence limits.

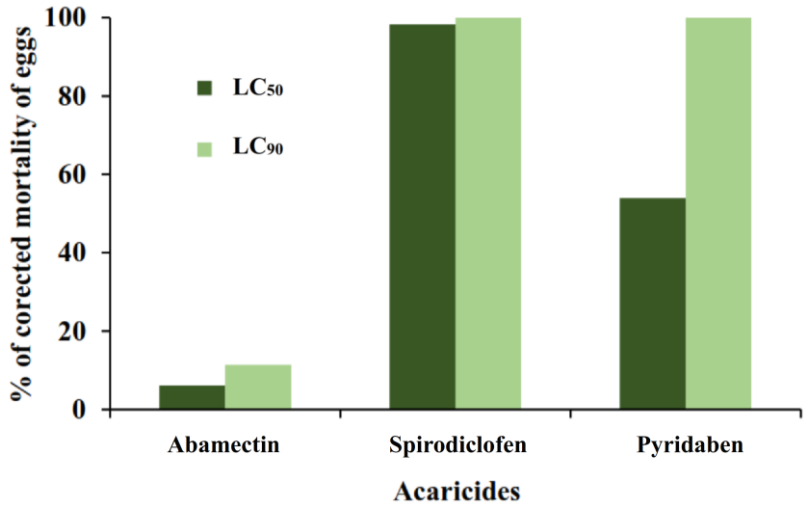

Figure 1. Percentages of corrected mortality of *Tetranychus urticae* eggs after being treated with LC (LC_{50} and LC_{90}, estimated for *T. urticae* females) of tested acaricides.

Table 4. Fecundity, female mortality, and egg hatchability of *Tetranychus urticae* treated with tested acaricides.

Treatments	No. of eggs/female/day*	Egg hatchability (%)	Female mortality* (%)
Abamectin	0.18 ± 0.04c	69.90 ± 2.00b	83.0
Spirodiclofen	0.54 ± 0.16c	45.20 ± 3.95c	50.0
Pyridaben	3.81 ± 0.51b	49.68 ± 2.85c	53.0
Control	8.40 ± 0.57a	95.82 ± 1.23a	20.0
F	95.908	72.951	
P	0.000	0.000	

* During 10 days.
Similar letters in a column showed no significant differences between tested treatments ($P < 0.05$).

Table 5 represents data on the effect of acaricides on the developmental durations of offspring produced by treated females. Compared with the untreated mites, treatment with abamectin caused a significant extended effect on the developmental durations of larvae ($F_{3, 116}$ = 40.620; P = 0.000), protonymphs ($F_{3, 116}$ = 83.413; P = 0.000), and deutonymphs ($F_{3, 116}$ = 45.102; P = 0.000) of *T. urticae*. No considerable differences were detected between pyridaben treatment and control in the protonymph, deutonymph, and pre-adult durations of *T. urticae*. However, abamectin and spirodiclofen had a prolonged impact on *T. urticae* pre-adult that recorded 14.60 and 10.04 days, respectively, compared to 8.75 days in control ($F_{3, 116}$ = 73.076; P = 0.000).

Table 5. The developmental periods of the progeny of *Tetranychus urticae* females treated with tested acaricides.

Treatments	Egg	Larva	Protonymph	Deutonymph	Pre-adult	Sex ratio% (♀/total)
Abamectin	5.10 ± 0.38a	2.90 ± 0.10a	2.90 ± 0.23a	3.70 ± 0.30a	14.60 ± 0.45a	60.0
Spirodiclofen	4.57 ± 0.23ab	2.13 ± 0.07b	1.35 ± 0.10b	2.00 ± 0.06b	10.04 ± 0.26b	83.0
Pyridaben	4.81 ± 0.21a	1.46 ± 0.10c	1.00 ± 0.00c	1.81 ± 0.08b	9.08 ± 0.21c	69.0
Control	3.93 ± 0.14b	2.04 ± 0.04b	1.00 ± 0.00c	1.79 ± 0.08b	8.75 ± 0.18c	82.0
F	5.134	40.620	83.413	45.102	73.076	
P	0.003	0.000	0.000	0.000	0.000	

Similar letters in a column showed no significant differences between tested treatments ($P < 0.05$).

Effect of acaricides in reducing spider mite population in greenhouse

The highest reduction percentages of spirodiclofen and pyridaben in *T. urticae* population were 100 and 87. 26%, respectively at day 3 post-treatment compared to 100% in abamectin treatment on the 3rd, 5th, and 7th days after treatment (Fig. 2). Treatment with abamectin resulted in significantly higher reduction percentage than the other acaricides at fifth ($F_{2, 87} = 116.276$; $P = 0.000$) and seventh days post-treatment ($F_{2, 87} = 90.401$; $P = 0.000$). For spirodiclofen and pyridaben treatments, the toxicity was decreased gradually over time till the seventh day post-treatment.

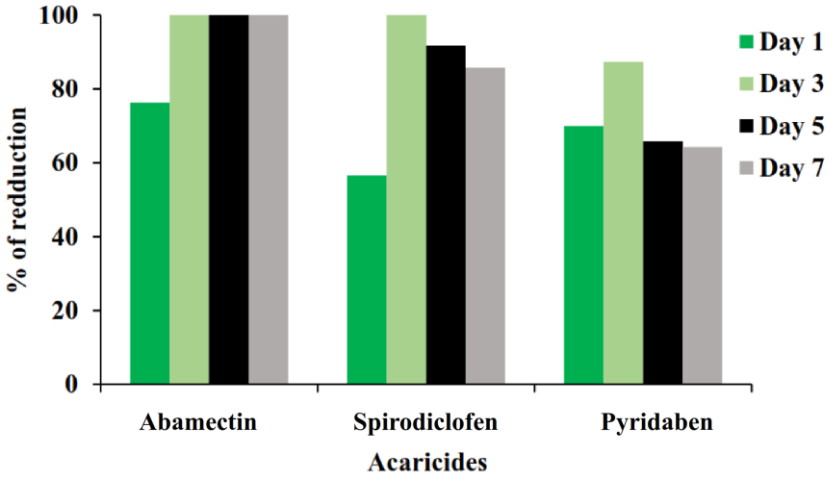

Figure 2. Reduction percentages of *Tetranychus urticae* population after acaricides application under greenhouse conditions.

Residual effect of acaricides on spider mite

The corrected mortality percentages of *T. urticae* at 48 h following exposure to acaricide residues aged 2, 24, 72, 120, and 168 h are presented in Table 6. Herein, abamectin caused 100% mortality of *T. urticae* in all tested cases. For acaricide residues aged 24 h, both spirodiclofen and pyridaben showed similar toxicity against *T. urticae*, with mortality rates of 59.32 and 59.32%, respectively. Pyridaben exhibited the lowest toxicity against *T. urticae* as compared to the other acaricides for the residues aged 72 ($F_{2, 87} = 79.983$; $P = 0.000$), 120 ($F_{2, 87} = 150.082$; $P = 0.000$), and 168 h ($F_{2, 87} = 130.966$; $P = 0.000$) (Table 6).

Table 6. Residual activity of tested acaricides on *Tetranychus urticae*.

Treatments	Corrected mortality (%) after exposure to acaricide residues aged				
	2 h	24 h	72 h	120 h	168 h
Abamectin	100.00 ± 0.00a	100.00 ± 0.00a	100.00 ± 0.00a	100.00 ± 0.00a	100.00 ± 0.00a
Spirodiclofen	80.89 ± 2.04c	59.32±2.73b	86.06 ± 1.97b	71.23 ± 2.27b	63.27 ± 2.96b
Pyridaben	87.71 ± 1.85b	59.32±2.73b	66.67 ± 2.57c	50.68 ± 2.67c	47.96 ± 2.76c
F	37.219	111.344	79.983	150.082	130.966
P	0.000	0.000	0.000	0.000	0.000

Similar letters in a column showed no significant differences between tested treatments ($P < 0.05$).

Phytotoxicity

The plants treated with the recommended concentration of each acaricide showed no symptoms of plant toxicity for 14 days after spraying. These suggested that the tested acaricides could be able to control *T. urticae* pest without causing damage to the treated plant.

Residues determination of tested acaricides on/in treated cucumber fruits

Method validation

The recovery percentage and Relative Standard Deviation (RSD) indicate the trueness and precision of any analytical method used for the quantitative measurement of pesticides, according to the SANTE guidelines (SANTE 2020). Data in Table 7 showed that the recovery and RSD% for cucumber fruits were within acceptable levels for the analysis of current acaricide residues, leading to high precision. The obtained data were satisfactory; according to the European Commission, the accepted recovery percentage ranged from 80 to 110% and the relative standard deviation (RSD) was < 20% (Sanco 2021).

Table 7. Recovery percentage ± relative standard deviation (RSD) of tested acaricides in cucumber fruits.

Pesticide concentrations	Spirodiclofen	Abamectin	Pyridaben
0.05	90.3 ± 3.13	88.7 ± 3.21	91.2 ± 3.55
0.1	92.4 ± 3.65	90.4 ± 2.51	91.8 ± 4.05
1.0	95.2 ± 4.21	92.18 ± 3.15	90.4 ± 3.15
Average	92.63 ± 3.67	90.4 ± 2.95	91.13 ± 3.58

Dissipation and residue analysis of tested acaricides in/on cucumber fruits

Data in Table 8 revealed that the initial deposits (1 h) of spirodiclofen, abamectin, and pyridaben were 1.16, 0.92, and 1.78 ppm, the variation of these values may refer to different applied rates; these amounts decreased to 0.78, 0.61, and 1.24 ppm after 24 h of application, with dissipation rate was 32.75, 33.7 and 43.5 %, respectively. After 3 days, these compound residues were 53.44, 48.9 and 46.06% dissipated. These values declined gradually to reach 0.08 and 0.03 ppm for spirodiclofen and pyridaben after 15 days of spraying; with dissipation rates of 93.1 and 98.3%, respectively. No abamectin residues were detected during the same period. Figure 3 shows the dissipation pattern of spirodiclofen, abamectin and pyridaben acaricides in cucumber fruits. The dissipation kinetics of spirodiclofen, abamectin, and pyridaben in cucumber fruits followed first-order kinetics with half-life (RL_{50}) periods 2.7, 2.5 and 2.5 days with decomposition rates of 0.254, 0.273 and 0.267 ppm/day, respectively; this means that spirodiclofen dissipated slowly in cucumber fruits compared with other two compounds.

Table 8. Residue amounts and dissipation percent of tested acaricides in/on cucumber fruits under greenhouse conditions.

Pesticide / Periods	Spirodiclofen		Abamectin		Pyridaben	
	ppm	Dissipation (%)	ppm	Dissipation (%)	ppm	Dissipation (%)
Initial deposits*	1.16	…..	0.92	……	1.78	……
1 day	0.78	32.75	0.61	33.7	1.24	43.5
3 days	0.54	53.44	0.47	48.9	0.96	46.06
5 days	0.42	63.8	0.31	66.3	0.57	68.0
7 days	0.18	84.5	0.16	82.6	0.21	88.2
10 days	0.12	89.65	0.08	91.3	0.15	91.57
15 days	0.08	93.1	ND	> 99.9	0.03	98.3
RL_{50} (days)	2.7	K = 0.254	2.5	K = 0.273	2.5	K = 0.267
MRL	0.1		0.02		0.15	
ADI	0.03		0.0012		0.01	
ARfD	2.0		0.0012		0.05	
PHI (days)	15		15		10	

* = one hour after application; RL_{50} = the half-life; MRL = maximum residue limit according to EU codex (2024); PHI = preharvest interval; K = decomposition rate; ADI = acceptable daily intake; ARfD according to EU Pesticide Database (2024).

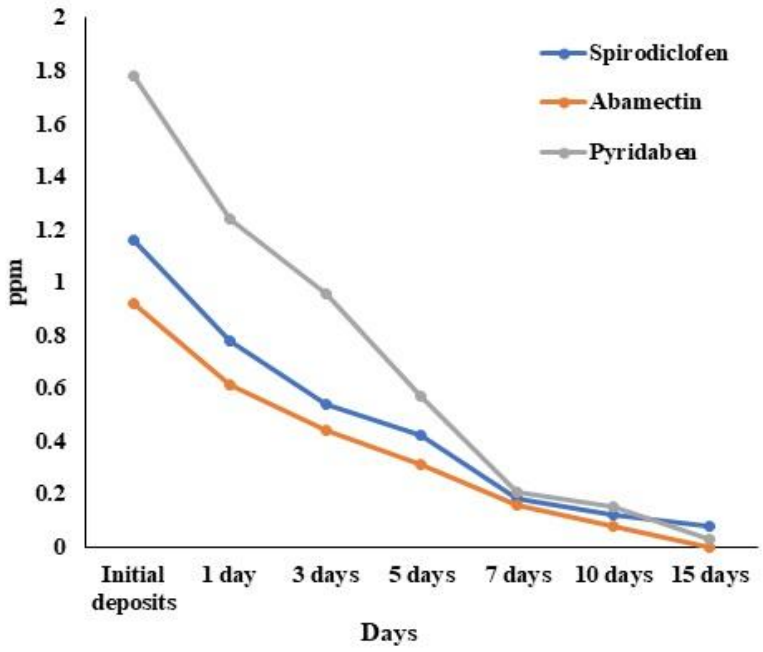

Figure 3. Dissipation pattern of spirodiclofen, abamectin, and pyridaben acaricides in cucumber fruits.

The maximum residue limits (MRL) for spirodiclofen, abamectin, and pyridaben in cucumber fruits, according to EU Codex (2024) were 0.1, 0.02, and 0.15 mg/kg; accordingly, the determined residues of spirodiclofen and abamectin in cucumber fruits were above the MRL amounts after 10 days, so the preharvest intervals (PHI) for both compounds were 15 days, while PHI for pyridaben was 10 days. Therefore, the cucumber could be consumed safely after these periods.

DISCUSSION

Various authors have reported the impact of pesticides on mite pests (Stumpf and Nauen 2001; Raudonis 2006; Abdelmaksoud *et al.* 2020; El-Gammal *et al.* 2022; Gaber *et al.* 2023; Shinde *et al.* 2023; Hamedi *et al.* 2024). In addition to the direct toxicity effects, the present work studied the impacts of three acaricides on productiveness and egg viability of *T. urticae*. In our study, the acute toxicity of abamectin, spirodiclofen, and pyridaben on *T. urticae* is pronounced. However, the tested pesticides displayed different potency against *T. urticae*. This finding is compatible with that of Kim *et al.* (2006) who observed that *T. urticae* exhibited different susceptibility to pyridaben and fenpyroximate. Pyridaben exhibited the lowest adulticidal activity against *T. urticae* compared with the other two acaricides. Similarly, based on the LC50 value, abamectin was found to be the more toxic compound against *T. urticae* compared to spirodiclofen and pyridaben (Saber *et al.* 2018). Also, by the slid-dip technique, Badawy *et al.* (2022) reported that abamectin had a lower LC_{50} value than that of pyridaben against adult *T. urticae*. In contrast to our results, high ovicidal effect of abamectin on *T. urticae* was reported by Rabbi *et al.* (2022). The different concentrations tested may be one explanation for these different results. Previous studies revealed that spirodiclofen had an effective ovicidal activity against spider mites, nevertheless, it showed lower adulticidal action which is consistent with our results (Nauen *et al.* 2003; Bretschneider *et al.* 2007).

Currently, females of *T. urticae* exposed to the three acaricides revealed a marked decrease in egg production as compared to those in control. In line with our study, spirodiclofen was found to reduce survival rates and fecundity of *T. urticae* (Marcic *et al.* 2009; Saryazdi *et al.* 2013). Our results are consistent with previous studies on the influences of pesticides on the survivorship and reproduction of spider mites (Alinejad *et al.* 2014; Saber *et al.* 2018). In harmony with the results of Ahmed and Abdelwines (2021), spirodiclofen treatment can cause a reduction in *Panonychus citri* McGregor (Acari: Tetranychidae)

reproduction.

Variations in egg hatchability between treated and control mites were also reflected in our study. The hatching rate was reduced by abamectin to 69.90% compared with control (95.82%), while the rate was cut by pyridaben to 49.68%. Likewise, pyridaben was found to reduce the hatchability of *T. urticae* by 67% compared with control mites (Kim *et al.* 2004). Spirodiclofen was also reported to influence spider mite fertility (Wachendorff *et al.* 2002; Marcic 2007). Because of that the decline in fertility and reproduction in treated mites leads to a considerable decrease in population development compared to control mites (Marcic 2007). Actually, the usage of pesticides at sublethal concentrations could be used to make conditions suitable for an incorporation of chemical application and biocontrol agents, for instance, predatory mites, a system that has previously been found useful as an effective control tactic (Lilly and Campbell 1999; Cheon *et al.* 2007).

The evaluation of three acaricides for one week after application exhibited that abamectin and spirodiclofen had good effectiveness in reducing *T. urticae* population. Compatible with that, spirodiclofen treatment has been reported to cause a reduction in populations of *T. urticae* and *Tarsonemus pallidus* Banks (Acari: Tarsonemidae) on strawberries at 7 days post treatments (Raudonis 2006). Also, Abdelmaksoud *et al.* (2020) demonstrated that at 7 days post application, spirodiclofen 24% SC and Biomectin 5% EC (abamectin) caused 87.9 and 79.8% reduction of *T. urticae* on strawberry, respectively. In addition, spirodiclofen has been recorded to cause a higher reduction in *P. citri* population than pyridaben on lemon trees (El-Gammal *et al.* 2022). During 2022, abamectin and pyridaben treatments caused 100 and 90% reduction in *T. urticae* population on sweet potatoes at one-week post-treatments, respectively (Gaber *et al.* 2023) which is in agreement with the current study. Under field conditions, Shinde *et al.* (2023) revealed that abamectin can reduce *T. urticae* population. In addition, Hamedi *et al.* (2024) reported that spirodiclofen + abamectin could be recommended for the control of *T. urticae.*

Here, the residual activity of abamectin on *T. urticae* was expanded for one week after application causing 100% mortality of this mite. In a previous study, two abamectin treatments were found to decrease spider mite populations to approximately zero, in addition, the effect continued for over one month after application (Fouche *et al.* 1997). Likewise, Sparks and Rucker (2005) concluded that all the acaricides they tested can decrease spider mite populations compared to control, even at 20 days post-application, with abamectin statistically outperforming the other tested acaricides. Also, abamectin and bifenazate were stated to be promising acaricides under field tests, whereas these compounds caused high adulticidal activity and showed long-lasting residues (Schmidt-Jeffris *et al.* 2021a). The residues of bifenazate and abamectin persisted at approximately 100% efficiency in females until 21 days post-application (Schmidt-Jeffris *et al.* 2021a). Similarly, pyridaben 20% WP was reported to be an effective acaricide in reducing *T. urticae* and *Panonychus ulmi* (Koch) for nearly two weeks after treatment (Singh *et al.* 2023). Several factors may affect the dissipation of pesticides, including physical and chemical factors, such as light, heat, and moisture (Malhat *et al.* 2013; Shalaby *et al.* 2021). The variations in half-life periods of tested compounds may be attributed to varying climatic conditions, crop types, application doses, formulation types, and stages at which the application was conducted (Abdallah *et al.* 2023). Moreover, the fate of pesticide residues on crops depends on climatic conditions, methods of pesticide treatment, plant species, rate of use, and the interval between application time and harvest (Tulail and Mohammadali 2021; Shalaby et al. 2024). As expected, the gradual and continuous degradation of the residual amounts of the tested acaricides was a function of the time after pesticide application. The obtained results of dissipation and residue analysis of tested acaricide in/on cucumber fruits contrast with those obtained by Shams El Din *et al.* (2012), who reported that tomato and cucumber fruits could be used safely after acetamiprid and dinotefuran application.

CONCLUSION

In conclusion, abamectin had a pronounced acute toxicity against adult *T. urticae*, while, spirodiclofen and pyridaben were more stronger ovicides. A schema including the use of one adulticide

in rotation with an ovicide could catch the benefits of successful rapid knockdown of the adult individuals and also decrease progeny, respectively. Our results demonstrated that the three tested products could negatively impact the development and reproduction of *T. urticae* which subsequently can reduce its population. The present study showed that abamectin and spirodiclofen may be promising acaricides in control programs of *T. urticae* on cucumber.

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Availability of data and materials: Data are available upon request from the author(s).

Ethics approval and consent to participate: This study only included arthropod material, and all required ethical guidelines for the treatment and use of animals were strictly adhered to in accordance with international, national, and institutional regulations. No human participants were involved in any studies conducted by the authors for this article.

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فعالیت‌های کنه‌کشی سه کنه‌کش روی *Tetranychus urticae* (Acari: Tetranychidae) با تأکید بر اثرهای باقیمانده در خیار

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آ. فرازمند

چکیده

آفت‌کش‌ها همچنان به طور گسترده در کنترل جمعیت‌های *Tetranychus urticae* Koch استفاده می‌شوند. در بررسی حاضر، سمیت و فعالیت‌های باقیمانده آبامکتین، اسپیرودیکلوفن و پیریدابن علیه کنهٔ تارتن دولکه‌ای روی گیاهان خیار در شرایط آزمایشگاهی و گلخانه‌ای ارزیابی شد. افزون بر این، تأثیر آفت‌کش‌های آزمایش شده بر برخی از جنبه‌های زیستی این آفت مورد مطالعه قرار گرفت. در آزمایش‌های آزمایشگاهی، مقادیر LC_{50} آبامکتین، اسپیرودیکلوفن و پیریدابن برای ماده‌ها به ترتیب ۰/۷۱، ۴۱/۰۴ و ۲۸/۵۶ پی‌پی‌ام بود. ماده‌های تیمار شده، باروری اندکی از ۰/۱۸ تا ۳/۸۱ تخم/ماده/روز در مقایسه با ۸/۴ تخم/ماده/روز در شاهد نشان دادند. اسپیرودیکلوفن و پیریدابن در مقایسه با آبامکتین، فعالیت تخم‌کشی بسیار قوی‌تری داشتند. آبامکتین و اسپیرودیکلوفن اثر افزایشی بر طول دوره رشد نابالغ‌ها داشتند، به طوری که میانگین دورهٔ پیش از بلوغ به ترتیب ۱۴/۶۰ و ۱۰/۰۴ روز بود، در حالی که این رقم در شاهد ۸/۷۵ روز بود. بیشترین اثر کاهشی اسپیرودیکلوفن و پیریدابن بر جمعیت کنه تارتن دولکه‌ای (*T. urticae*) به ترتیب ۱۰۰ و ۸۷/۱۴ درصد در سه روز پس از سمپاشی بود، در حالی که آبامکتین در تمام مدت زمان‌های آزمایش‌شده ۱۰۰ درصد کاهش جمعیت را نشان داد. در آزمایش اثربخشی باقیمانده، آبامکتین باعث مرگ ۱۰۰ درصدی کنه تارتن دولکه‌ای در ۷ روز پس از سم‌پاشی شد، در حالی که اسپیرودیکلوفن و پیریدابن به ترتیب ۶۳/۲۷ و ۴۷/۹۶ درصد کاهش جمعیت را نشان دادند. با این حال، هیچ گونه سمیت گیاهی در گیاهان تیمار شده با غلظت‌های توصیه‌شده مشاهده نشد. باقیمانده‌های تعیین‌شده اسپیرودیکلوفن و آبامکتین در میوه‌های خیار پس از ۱۰ روز تیمار، بالاتر از حداکثر مقدار مجاز باقیمانده (MRL) بود، بنابراین فواصل قبل از برداشت (PHI) برای هر دو ترکیب ۱۵ روز و PHI برای پیریدابن ۱۰ روز بود. بنابراین، میوه‌های خیار را می‌توان پس از این دوره‌ها با خیال راحت مصرف کرد.

واژگان کلیدی: کارایی کنه‌کش‌ها، مهار شیمیایی، باقیمانده‌ها، ارزیابی خطر، *Tetranychus urticae*، سمیت

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