




Efficacy of Selected Pesticides against Citrus Brown Mite, *Eutetranychus orientalis* and their Side Effects on the Honey Bee, *Apis mellifera* L. under Field Conditions

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ABSTRACT

This study evaluated the effectiveness of seven pesticides against the citrus brown mite, *Eutetranychus orientalis*, and assessed their impact on honey bees, *Apis mellifera*, under citrus orchard conditions. The toxicity of these pesticides to honey bee workers was also investigated using oral and contact exposure methods in a laboratory setting. The results showed that all tested pesticides achieved significant reductions in *E. orientalis* populations, with mean reduction percentages ranging from 88.3 to 92.6%. Toxicity tests showed Mancozeb 64% + Metalaxyl 8% was most toxic to honey bee workers, with the lowest LC₅₀ and LC₉₀ values (0.3 and 555.4 ppm orally; 1.7 and 217.2 ppm via contact) and shortest LT₅₀ and LT₉₀ values. Toxicity followed by Fenbutatin oxide, Acetamiprid, Flufenoxuron, and Chlorfenpyr. Spirodeclofen and Azadirachtin were the least toxic, showing the highest LC₅₀ and LC₉₀ values (283.9 and 8637.6 ppm orally; 334.9 and 164609.9 ppm via contact for Spirodeclofen; 32.2 and 5314.2 ppm orally; 73.9 and 5412.9 ppm via contact for Azadirachtin) and the longest LT₅₀ and LT₉₀ values. Under field conditions, all pesticides significantly increased honey bee worker mortality compared to the control. The tested pesticides also significantly reduced bee foraging activities. Notably, Acetamiprid and Fenbutatin oxide resulted in the highest mortality rates among worker bees, 52.5 and 41.6%, respectively. In contrast, Acetamiprid and Flufenoxuron led to the most significant decline in foraging activity, 56.1 and 54.6%, respectively. Acetamiprid resulted in the most significant reduction in nectar collection 40% and pollen gathering 50% among worker bees. As well as, Acetamiprid recorded the highest decrease in Area of worker brood/ colony, Pollen grains/ trap and Honey/colony 33.8, 43.8, and 30.6%, respectively. Spirodeclofen and Azadirachtin were found to be the safest pesticides for honey bee workers in both laboratory and field settings, making them suitable candidates for inclusion in integrated pest management (IPM) programs for citrus pests.

Keywords: *Eutetranychus orientalis*, *Apis mellifera* L., Citrus orchard, Pollinator safety, Toxicity, and Integrated Pest Management (IPM).

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INTRODUCTION

The citrus brown mite, *Eutetranychus orientalis* (Klein), is a highly destructive phytophagous pest posing a significant threat to citrus crops and various other economically important horticultural and ornamental plants (Kamali et al., 2001). Citrus species serve as the primary hosts for *E. orientalis* (Márquez et al., 2006).

Al Amin et al. (2020) reported that Gat Fast (2% Abamectin + 10% Thiamethoxam) demonstrated strong efficacy against *Eutetranychus orientalis*, with minimal adverse effects on *Euseius scutalis* over three week under field conditions. Additionally, Assouguem et al. (2022) demonstrated that binary mixtures of four essential oils (*Mentha pulegium* L., *Lavandula stoechas* L., *Rosmarinus officinalis* L., and *Origanum compactum*) with acaricides

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achieved high efficacy against *Tetranychus urticae* and *Eutetranychus orientalis*. These natural products can be applied at low concentrations, reducing costs and environmental risks, thus supporting integrated pest management strategies. Recently, Al Dhafar et al. (2024) reported that the evaluated pesticides, Fenpyroximate, Hexythiazox, Congest, Spirodiclofen, Abamectin, and Chlorfenapyr, demonstrated high efficacy against *E. orientalis* and exhibited safety and selectivity towards the associated predatory mites. In contrast, imidacloprid was found to be highly detrimental to all tested predatory mite species.

The honey bee, *Apis mellifera* L., plays a crucial role in crop pollination (Garibaldi et al., 2013). However, the global honey bee population has been declining, and several factors have been identified as potential contributors to this decline, including the use of organosynthetic pesticides (Lebuhn et al., 2013; Van der Sluijs et al., 2013). When bee larvae and adults come into contact with pollen and nectar contaminated with insecticides, they may suffer mortality or experience various sublethal effects, such as impaired growth, development, reproduction and behavior (Desneux et al., 2007; Koskór et al., 2009). Organosynthetic insecticides have been shown to have adverse effects on the environment and non-target organisms, including bees (Biondi et al., 2012; Decourtye et al., 2013). Honey bees are exposed to various levels of pesticide residues while foraging and collecting nectar and pollen from flowers (Peach et al., 1993). Workers may transport contaminated nectar and pollen back to their hive, potentially exposing the entire colony to pesticides. Exposure to neonicotinoid pesticides, in particular, has been linked to increased mortality in bee larvae and adults, as well as sublethal effects on colony behavior, including reduced foraging, egg-laying, and brood care (Cresswell, 2011). Pesticide exposure can occur through various routes, including contaminated nectar, pollen, and water, as well as direct contact with spray applications (Kubik et al., 1999; David et al., 2016). In response to the risks posed by synthetic pesticides, biopesticides have been explored as a safer alternative, as they pose less risk to humans and the environment and are often more targeted in their effects (Mehrotra et al., 2017). Previous studies have demonstrated that certain pesticides, such as imidacloprid, can have significant impacts on honey bee workers, while others, like azadirachtin, appear to be less toxic (Aljedani, 2017). Pesticide-exposed bees exhibited delayed morning foraging activity and erratic pollen collection, disrupting plant-pollinator synchronization (Bloch et al., 2017). Abbassy et al. (2020) found that various insecticides, including indoxacarb, esfenvalerate, thiamethoxam, and imidacloprid, were harmful to honey bees. Traynor and Lamas (2021) found that colonies fed sublethal levels of neonicotinoid-contaminated pollen experienced disrupted trophallactic exchanges, impairing larval feeding and brood development. Worker bees displayed reduced feeding interactions, indicating that neonicotinoids compromise social cohesion and cooperation within the colony. Ben Abdelkader et al. (2021) reported that the timing of pesticide exposure significantly influenced larval

mortality rates. Exposure during early larval stages resulted in higher mortality, whereas later exposure led to developmental delays. Recent research has also highlighted the negative effects of neonicotinoids, pyrethroids and other pesticides on honey bee colonies, including impaired growth, development, and foraging activity (Zhao et al., 2022). Also, Crall and Raine (2023) noted that neonicotinoid exposure disrupts coordination among worker bees, leading to delay recruitment responses and impaired collective foraging efficiency. This compromised coordination hinders the colony's ability to effectively utilize food resources, ultimately diminishing productivity and increasing mortality risk. Recently, Zhang et al. (2024) found that insecticides, herbicides, and fungicides have harmful effects on pollinators, threatening bee colony stability, biodiversity, and sustainable agriculture. Their presence in HBPs highlights risks associated with their use and potential contribution to bee colony decline. Additionally, Swiatly-Błaszkiwicz et al. (2025) found that pesticides might penetrate honeybee products, affecting bee health and potentially harming human consumers. Since pesticide combinations may increase toxicity, all detected pesticides should be monitored continuously as they pose a potential threat.

Kopparthi (2020) reported that microbial formulations and biopesticides such as *Bacillus thuringiensis* can be combined with conventional insecticides without harming honeybee populations. This allows for effective pest control while reducing reliance on harmful neonicotinoids. Moreover, Main et al. (2020) found that risks to bees can be reduced by using less toxic pesticides or lowering application rates. Significant progress has been made in developing bee-friendly pesticide formulations such as polymer coatings and stereoisomeric chemicals. These modified structures aim to minimize disruption to honeybee metabolic pathways and detoxification, offering a promising approach for safer pesticides (Zhang et al., 2022).

Integrated Pest Management (IPM) promotes awareness among farmers about pollinator conservation and encourages the adoption of environmentally friendly farming practices (Arif et al., 2025; Haider et al., 2025). Smagge et al. (2023) highlighted biological alternatives such as bacterial formulations, fungal-based biopesticides, and plant-derived insecticides that are safer for honeybees and non-target species. Their research supports integrating these biopesticides and sustainable practices into pollinator-friendly IPM strategies to reduce reliance on harmful neonicotinoids and protect bee colonies. Recently, Ahsan et al. (2025) proposed strategies to reduce honeybee exposure to neonicotinoids, including implementing integrated pest management (IPM), imposing timing restrictions on pesticide application, utilizing biopesticides, conducting field trials and testing to assess pesticide impact, establishing strict regulations on neonicotinoid use, adopting precision agriculture techniques, reducing pesticide doses, reforming agricultural policies, and providing training programs for farmers on bee conservation.

Given the scarcity of studies evaluating the impact of pesticides on *E.orientalis* in field conditions, along with assessing their toxicity to honeybees and their activities,

this study was conducted to evaluate the efficacy of 7 novel pesticides from different chemical groups against *E. orientalis* and their side effect on *A.mellifera* and its activities under laboratory and field conditions, aiming to identify environmentally friendly and pollinator-safe pesticides for integrated pest management (IPM) programs.

MATERIALS & METHODS

Insecticides

Seven pesticides with novel modes of action were chosen for assessment against the citrus brown mite, *Eutetranychus orientalis*, and the honey bee, *Apis mellifera* L. The following table provides detailed information on the recommended dose rates, chemical groups, trade names, and modes of action for these pesticides.

Citrus Brown Mite, *Eutetranychus orientalis*

Field experiments were conducted at a private farm located in Shebin Elkom, El menoufia Governorate, Egypt Fig. 1, during April and May 2024. The study focused on Citrus sinensis variety Navel orange trees that were naturally infested with *E. orientalis*. The primary objective of the study was to assess the efficacy of seven pesticides against the citrus brown mite, as well as their potential side effects on honey bees, *Apis mellifera* forage workers.

The experimental design consisted of 24 trees distributed across a one-feddan (4000m²) area. A completely randomized block design was employed, with seven treatments, each replicated three times, and three trees serving as untreated controls. Each pesticide was applied to three trees using a manually operated knapsack sprayer equipped with a Duromist nozzle, applied at the recommended field dose, and sprayed to the point of slight runoff. Before pesticide application, the total number of mite adults on each leaf was counted using a 10 x magnifying glass lens. Subsequent counts were taken after pesticide application to assess the efficacy of the treatments.

Honey Bee, *Apis mellifera*

Acute and contact toxicity tests were conducted on young foraging worker bees, aged 3-7 days post-emergence, which were obtained from the apiary of the Economic Entomology Department, Faculty of Agriculture, and Menoufia University. The bees were transported to the laboratory in plastic boxes covered with screen mesh and maintained at a temperature of 25 ± 2°C and a relative humidity of 65 ± 5%. They were provided with a 50% sugar cane solution as food until they were used for the experiment. The experiment was carried out at the Pesticides Department laboratory, Faculty of Agriculture, Menoufia University.

Tested pesticides

Common name & formulation	Trade name	Group	Mode of action
Mancozeb 64 % + metalaxyl 8 % (72 % WP)	Sand plower	Benzenoid fungicide	Metalaxyl disrupts the synthesis of nucleic acids. Mancozeb effects on the nervous system via its main metabolite, carbon disulfide. It disrupts enzymes with sulphhydryl groups, impairing various biochemical processes in the fungal cell's cytoplasm and mitochondria.
Spirodeclofen 24 % SC	Listomid	Ketoenols or tetrionic acids	Disrupts lipid synthesis.
Flufenoxuron 10 % EC	Cascade	Benzoylureas	Inhibitors of chitin biosynthesis affecting.
Chlorfenpyr 24 % SC	Shallenger super	Pyrroles	Disrupting the production of adenosine triphosphate in the insect nervous system.
Acetamidrid 20 % SP	Aceta x	Neonicotinoids	A nicotinic agonist that reacts with nicotinic acetylcholine receptors (nACh-R).
Fenbutatin oxide 50 % SC	Loramik	Organotin	Inhibits oxidative phosphorylation at the site of dinitrophenol uncoupling (the production of energy in the form of adenosine triphosphate, ATP)
Azdirachtin 1 % EC	Gycaneem	Natural products	Antifeedant and disrupt insect growth by blocking the release of the morphogenic peptide hormone.

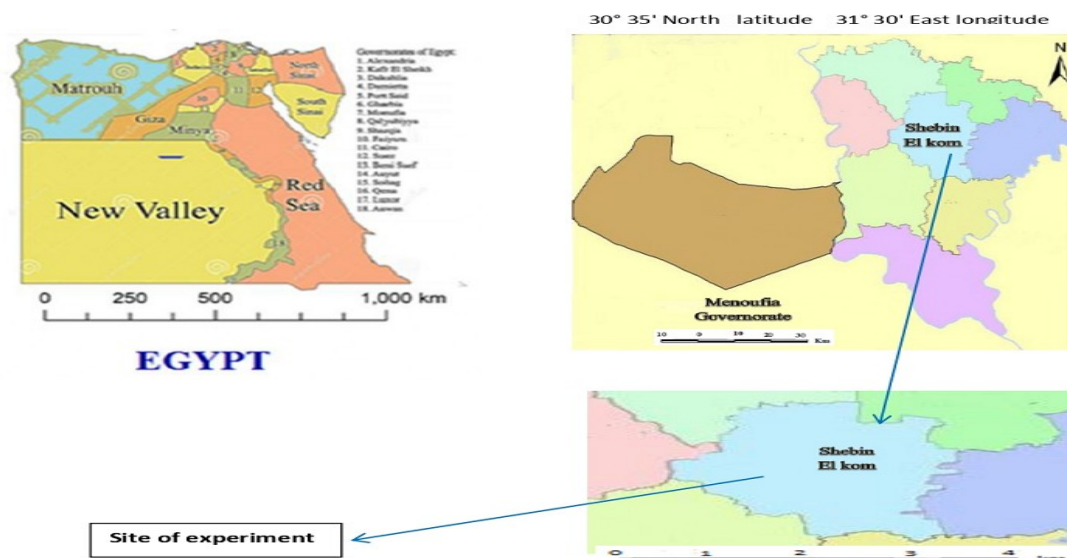


Fig. 1: Location map of the study area in Shbin El kom, Menoufia Governorate, Egypt.

Laboratory Experiments

Oral Toxicity to Honeybee Workers

For the oral toxicity test, young adult worker bees (3-7 days post-emergence) were utilized. Five concentrations of each tested insecticide were prepared in a 50% (w/v) sucrose solution (sugar cane). Before treatment, the bees were anesthetized by exposure to carbon dioxide gas for 1min. Groups of 20 bees were placed in plastic cups covered with nylon mesh, with three replicates (jars) per treatment (total of 60 bees per treatment). A piece of cotton saturated with 5 ml of each concentration was attached to the upper side of the jar, allowing the bees to feed on the treated sugar solution for 24 hours. After this period, the treated cotton was removed and replaced daily with a new piece of cotton containing only 50% sugar solution until the end of the test. Control groups were fed with 50% sugar cane solution only. The bees were maintained at a temperature of $25 \pm 2^\circ\text{C}$, $65 \pm 5\%$ relative humidity, and a 12:12 (L:D) photoperiod. Bees that were unable to walk when prodded with a fine hairbrush were considered dead. Mortality percentages were recorded 1, 2, 3, 5, and 7 days after treatment and corrected according to Abbott's formula (1925). The data were then analyzed using probit analysis to calculate the lethal concentrations (LC_{50} and LC_{90}) and lethal times (LT_{50} and LT_{90}) with their corresponding fiducial limits at 95% (FL).

Contact Toxicity to Honeybee Workers

For the contact toxicity test, honeybee workers at foraging age (3-7days post-emergence) were utilized. Fresh cotton leaves were washed with water and allowed to dry. The dried leaves were then immersed in the recommended concentration of each tested pesticide, including Mancozeb 64% + Metalaxyl 8%, Spirodeclofen, Flufenoxuron, Chlorfenpyr, Acetamiprid, Fenbutatin oxide, and Azadirachtin, and left to dry at room temperature. The treated leaves were offered to honeybee workers, which had been anesthetized with carbon dioxide gas for 1min. before the test, in cages. Each cage contained 30honeybee workers, and three replicates were prepared for each compound. Control groups were provided with untreated leaves. All cages were supplied with a piece of cotton saturated with 50% sugar cane solution as food for the honeybee workers.

Mortality percentages were recorded 1, 2, 3, 5, and 7 days after treatment and corrected according to Abbott's formula (1925). The data were then analyzed using probit analysis to calculate the lethal concentrations (LC_{50} and LC_{90}) and lethal times (LT_{50} and LT_{90}) with their corresponding fiducial limits (FL) at 95%.

Field Experiments

Effect of Tested Pesticides on Honey Bees Activities

A field study was conducted in an orange orchard (*Citrus sinensis* variety Naval seedless) covering an area of approximately 4000 m². The orchard was divided into eight treatment groups. Plot size: 500m² (each plot containing 25 orange trees). Treatments were randomly assigned to plots using a completely randomized design (CRD). Each group of trees was sprayed with a specific pesticide during

the flowering period to control the citrus brown mite, *Eutetranychus orientalis*, using a dorsal sprayer (20 L). Control trees were treated with water only.

Twenty-four bee colonies, similar in strength, size, and health, were obtained from a private apiary. Three bee colonies were relocated to a distance of approximately 50 m from each experimental citrus tree group (25 trees) to assess the effects of the sprayed pesticides on bee activities, including a control treatment.

The foraging honeybee workers were recorded 1, 3, 5, and 7days after pesticide application, where observations were made at 9am for 3 min. per flower. The number of foraging workers was counted for each treatment and control.

The dead honeybee workers in front of the colonies, as well as the workers collecting nectar, were recorded 1, 3, 5, and 7days after pesticide application. The workers gathering pollen were observed at 6 pm, and the number of dead workers was counted for each treatment.

At the end of the season (August), the scale of worker brood/colony (cm²), pollen grains/trap (g), and honey production/colony (kg) were measured, where the scale of brood/colony was determined using a ruler, while pollen grains/trap was weighed, and honey production/colony was weighed and calculated for each treatment.

The decrease in bee activities was calculated using the formula:

$$\text{Decrease\%} = (\text{Value in control} - \text{Value in treatment}) / \text{Value in control} \times 100$$

Statistical Analysis

Mortality percentages were corrected using Abbott's formula (1925) and analyzed via probit analysis to determine LT_{50} and LT_{90} (lethal concentrations) and LT_{50} and LT_{90} (lethal times) with 95% confidence limits. Field experiment data were subjected to ANOVA and means separated using Duncan's Multiple Range Test (DMRT) in SAS (Version 9.4, 2013) at 95% confidence level.

RESULTS

Effect of Different Pesticides on *Eutetranychus orientalis* Population Infesting Citrus Orchard

The data presented in Table 1 provide insight into the efficacy of two applications of the tested pesticides on the population of *E. orientalis* stages, recorded at 1, 15, 21, and 30 days after spraying, in a citrus orchard during the 2024 season. The results clearly indicate that all the pesticides exhibited significant efficacy in controlling *E. orientalis*, with notable differences observed between the treated plots and the control in terms of the final mean number of stages per leaf. Specifically, the lowest final mean number of *E. orientalis* per leaf was recorded for acetamiprid, flufenoxuron, and mancozeb 64% + metalaxyl 8%, with an average of 3 individuals per leaf. In contrast, the highest final mean number of *E. orientalis* per leaf was recorded for azadirachtin treatment, with an average of 4.8 individuals per leaf.

All pesticides demonstrated high efficacy, achieving reduction percentages between 88.3 and 92.6%.

Table 1: Effect of tested pesticides against *E. orientalis* under the field ecosystem

Tested pesticides	Pre treatment	Mean no. mites / 10 leaf				Final mean / leaf \pm SE	Reduction %				Grand mean R. %
		Days after spraying					Days after spraying				
		1	15	21	30		1	15	21	30	
Spirodeclofen	38	8 ^b	4 ^b	2 ^b	2 ^b	4.0 ^b \pm 0.4	80.7	89.8	95.3	95.0	90.2
Acetamiprid	33	6 ^b	3 ^b	2 ^b	1 ^b	3.0 ^b \pm 0.5	83.3	91.2	94.6	97.5	91.7
Flufenoxuron	30	6 ^b	3 ^b	2 ^b	1 ^b	3.0 ^b \pm 0.5	81.6	90.3	94.0	96.9	90.7
Fenbutatin oxide	35	7 ^b	4 ^b	2 ^b	1 ^b	4.7 ^b \pm 0.3	81.6	88.9	94.9	97.3	90.7
mancozeb 64% + metalaxyl 8%	38	6 ^b	3 ^b	1 ^b	2 ^b	3.0 ^b \pm 0.6	85.5	92.3	97.7	95.0	92.6
Chlorfenpyr	38	8 ^b	5 ^b	2 ^b	2 ^b	4.5 ^b \pm 0.4	80.7	87.2	95.3	95.0	89.6
Azadirachtin	38	9 ^b	5 ^b	3 ^b	2 ^b	4.8 ^b \pm 0.4	78.2	87.2	92.9	95.0	88.3
Control	34	37 ^a	35 ^a	38 ^a	36 ^a	36.5 ^a \pm 0.1	-	-	-	-	-
LSD 5%		2.0	2.2	2	1.3	2.2					

The same letters in the column mean no significant difference.

Table 2: Toxicity of tested pesticides to Honey bee (*A. mellifera*) using oral treatment technique

Treatments	Periods (day)	LC ₅₀ (ppm)	Fiducial limits (95 %)	LC ₅₀ (ppm)	Fiducial limits (95 %)	Slope \pm SE	
Spirodeclofen	1	283.9	58.7-1914.2	8637.6	1471.7-11559.9	0.4 \pm 0.1	
	2	7.4	2.5-19.4	1668.1	330.8-46792.6	0.5 \pm 0.1	
	3	0.2	0.01-0.8	47.2	13.7-525.3	0.6 \pm 0.1	
	5	0.01	-	0.5	-	0.4 \pm 0.1	
	7	100% dead	-	12.1	-	0.04 \pm 0.1	
	Acetamiprid	1	0.6	0.03-3.3	706.6	52.3-44550.7	0.4 \pm 0.1
		2	0.02	-	123.3	-	0.3 \pm 0.1
3		0.01	-	60.4	-	0.3 \pm 0.1	
5		100% dead	-	100% dead	-	-	
7		100% dead	-	100% dead	-	-	
Flufenoxuron		1	1.8	0.6-4.3	184.3	61.3-1248.0	0.6 \pm 0.1
		2	0.2	0.024-0.6	21.5	7.6-125.3	0.6 \pm 0.1
	3	0.02	0-0.2	18.4	4.2-359.6	0.4 \pm 0.1	
	5	100% dead	-	100% dead	-	-	
	7	100% dead	-	100% dead	-	-	
	Fenbutatin oxide	1	0.5	0.1-1.6	244.5	54.94-5623.9	0.5 \pm 0.1
		2	0.002	-	22.0	-	0.3 \pm 0.12
3		0.0006	-	5.9	-	0.3 \pm 0.14	
5		100% dead	-	29.32	-	0.2 \pm 0.11	
7		100% dead	-	100% dead	-	-	
mancozeb 64% + metalaxyl 8%		1	0.3	0.003-1.9	555.4	37.8-8288.8	0.4 \pm 0.1
		2	0.05	-	4.3	-	0.3 \pm 0.1
	3	0.004	-	199.7	-	0.3 \pm 0.1	
	5	100% dead	-	100% dead	-	-	
	7	100% dead	-	100% dead	-	-	
	Chlorfenpyr	1	3.2	0.253-14.39	1331.84	146.63-2109634.70	0.5 \pm 0.2
		2	0.5	-	1688.8	-	0.4 \pm 0.1
3		0.05	-	210.6	-	0.4 \pm 0.2	
5		0.0004	-	3.41	-	0.3 \pm 0.1	
7		100% dead	-	100% dead	-	-	
Azadirachtin		1	32.2	13.1-101.2	5314.2	898.1-5037.0	0.6 \pm 0.1
		2	0.7	0.08-2.4	301.4	64.0-9804.4	0.5 \pm 0.1
	3	0.4	0.06-1.2	51	16.9-370.9	0.6 \pm 0.1	
	5	0.08	0.003-0.4	31.9	10.1-181.7	0.9 \pm 0.0.1	
	7	0.008	0 - 0.1	15.6	0.01-2.1	0.008-0.1	

Toxicity of Pesticides on Honey Bee, *Apis mellifera* Treated using an Oral Technique

The data presented in Table 2 indicate that all tested compounds, except spirodeclofen and azadirachtin, exhibited high toxicity to honey bee workers. Where, Mancozeb 64 % + metalaxyl 8% were the most toxic compound with LC₅₀ values of 0.3 after 24 hrs of treatment, respectively. Followed by, fenbutatin oxide (0.5 ppm), acetamiprid (0.6 ppm), flufenoxuron (1.8 ppm), and chlorfenpyr (3.2 ppm). In contrast, spirodeclofen and azadirachtin exhibited relatively low toxicity, with LC₅₀ values of 283.9 and 32.2 ppm, respectively, after 24 hr. of treatment. Nearly all treated honey bee workers died after 7 days of treatment.

The data in Table 3 revealed that the lethal times (LT₅₀ and LT₉₀) of the tested pesticides for orally treated honey bee workers varied among the tested pesticides and concentrations. The LT₅₀ values were (83.9 & 0.0004h),

(74.1 & 37.9h), (56.7h & 100% dead), (67.9 & 39.4h), (18.3h & 100% dead), (90.5h & 100% dead), and (110.4 & 0.06h), for spirodeclofen, acetamiprid, Flufenoxuron, Fenbutatin oxide, Mancozeb 64% + metalaxyl 8%, Chlorfenpyr, and Azadirachtin after 24h of treatment at a concentration of 0.1 and 500 ppm, respectively.

Toxicity of Pesticides on Honey Bee, *A. mellifera* using a Contact Technique

The toxicity of seven insecticides against honey bee workers after 1, 2, 3, 4, and 7 h of contact treatment is presented in Table 4. Data show that fenbutatin oxide was the most toxic compound recording LC₅₀ values of 1.3 ppm after 24 h of treatment. Nearly all treated honeybee workers died after 5 and 7 days of treatment. Mancozeb 64% + metalaxyl 8%, acetamiprid, chlorfenpyr, and, flufenoxuron, recorded LC₅₀ values (1.7, 2.2, 6.2, and 6.5 ppm) after 24 h of treatment, respectively.

Table 3: lethal times of tested insecticides on *Apis mellifera* .the data expressed as LT₅₀ and LT₉₀ (hrs.) together with the corresponding 95 % fiducial limits (FL 95 %) after treated with oral technique.

treatments	Conc. (ppm)	LT ₅₀ (hrs)	Fiducial limits (95%)	LT ₉₀ (hrs)	Fiducial limits (95%)	Slope ± SE
Spirodeclofen	0.1	83.9	65.9-109.8	249.1	170.3-550.7	2.7 ± 0.5
	1	54.5	44.6-75.8	181.9	129.1-357.9	2.6 ± 0.5
	5	47.1	32.0-61.6	157.5	109-351	2.4 ± 0.5
	10	45.2	32-57.2	138.5	102.3-248.6	2.6 ± 0.5
	50	32.4	19.9-42.7	99.9	75.3-164.9	2.6 ± 0.5
	100	24.2	9.3-35.4	93.1	65-216.2	2.2 ± 0.6
	500	0.0004	-	91.7	-	0.2 ± 0.6
Acetamidrid	0.1	74.1	-	196.4	3.0 ± 0.6	-
	1	62.5	-	166.7	-	3.0 ± 0.6
	5	57.5	-	161.1	-	2.9 ± 0.5
	10	54.6	41.4-68.4	150.4	111.7-260.7	2.9 ± 0.5
	50	50.3	36.9-64.7	154.1	111.6-287.8	2.7 ± 0.5
	100	40.7	-	162.9	-	2.1 ± 0.5
	500	37.9	21.7-51.6	152.2	103.4-364.6	2.1 ± 0.5
Flufenoxuron	0.1	56.7	36.8-78.2	266	159-1004.8	1.9 ± 0.5
	1	32.9	14.6-47.6	165.6	105.8-539.2	1.8 ± 0.5
	5	18.9	-	99.1	-	1.78 ± 0.6
	10	13.3	-	64.1	-	1.9 ± 0.6
	50	0.09	-	33.5	-	0.5 ± 0.1
	100	100% dead	-	100% dead	-	-
	500	100% dead	-	100% dead	-	-
Fenbutatin oxide	0.1	67.9	-	184.2	-	3 ± 0.5
	1	62.3	-	168.9	-	3 ± .54
	5	56.9	-	189.4	-	2.7 ± 0.5
	10	53.8	-	161.9	-	2.7 ± 0.5
	50	49.8	-	166.6	-	2.4 ± 0.5
	100	46.7	-	157.9	-	2.4 ± 0.5
	500	39.4	24.5-52.3	140.1	98.6-291.9	2.3 ± 0.5
mancozeb 64% + metalaxyl 8%	0.1	18.3	-	177.7	-	1.3 ± 0.5
	1	6.1	-	97.1	-	1.1 ± 0.5
	5	0.8	-	89.35	-	0.6 ± 0.1
	10	0.09	-	33.5	-	0.5 ± 0.1
	50	0.09	-	34.5	-	0.5 ± 0.1
	100	0.2	-	40.0	-	0.5 ± 0.1
	500	100% dead	-	100% dead	-	-
Chlorfenpyr	0.1	90.5	68.4-129.2	358.4	203.7-1143.6	2.2 ± 0.5
	1	70.1	53.1-91.5	228.7	154.6-521.5	2.5 ± 0.5
	5	43.2	31.9-54	111.6	85.5-178.9	3.1 ± 0.6
	10	30.3	16.8-41.2	101.4	73.8-190.5	2.4 ± 0.6
	50	14.4	-	68.4	-	1.89 ± 0.41
	100	0.005	-	12.9	-	0.38 ± 0.10
	500	100% dead	-	100% dead	-	-
Azadirachtin	0.1	110.4	-	896.0	-	1.4 ± 0.5
	1	60.9	39.1-86.8	319.4	178.1-1649.6	1.8 ± 0.5
	5	41.3	29.2-52.3	114.6	86.3-192.1	2.9 ± 0.6
	10	33.4	21.2-43.6	98.4	74.1-164.9	0.273 ± 0.56
	50	22.7	9.6-32.7	76.1	55.5-140.5	2.4 ± 0.6
	100	14.4	-	68.4	-	1.9-0.6
	500	0.06	-	35.9	-	0.5-0.5

The obtained data revealed that all treated honeybee workers died after 5 and 7 days of treatment with (mancozeb 64% + metalaxyl 8%) and acetamidrid. On the other side, spirodeclofen and azadirachtin were the lowest toxic tested compounds, recording LC₅₀ values of 334.9 and 73.9 ppm after 24h of treatment, respectively.

The lethal times (LT₅₀ and LT₉₀) of tested pesticides for honey bee workers treated with the contact technique are presented in Table 5. The LT₅₀ and LT₉₀ of the tested pesticides for contact treated honey bee workers varied among the tested pesticides and concentrations. The LT₅₀ values were (71.7 & 14.6h), (47.8 & 0.2h), (71.1 & 100% dead), (42.5h & 100% dead), (46.9h & 100% dead), (97.1h & 100% dead), and (144.4 & 2.7h) for Spirodeclofen, Acetamidrid, Flufenoxuron, Fenbutatin oxide, mancozeb 64% + metalaxyl 8%, Chlorfenpyr, and Azadirachtin after 24h of treatment at a concentration of 0.1 and 500 ppm, respectively.

Side Effects of Pesticides on Honey Bee *A. mellifera* under Field Conditions

The data presented in Table 6 illustrate the number of dead honey bee workers per colony as a side effect of citrus orchard application of some insecticides over a period of 30days. The results reveal significant differences in the numbers of dead bee workers between all insecticides and the control group. The mean percentages of dead bee workers range from 12.7 to 52.5%. Acetamidrid achieved the highest mortality rate 52.5%, after 30 days of application, followed by fenbutatin oxide 41.6% and flufenoxuron 26.7%. In contrast, the lowest mortality rates are observed with azadirachtin 12.7% and spirodeclofen 14% treatments.

The data presented in Table 7 show the side effects of some pesticides applied on citrus trees on the number of foraging workers over 30 days. The data indicate significant differences in foraging numbers between the tested insecticides and the control group. The decrease in

Table 4: Toxicity of tested pesticides to Honey bee (*A. mellifera*) using contact treatment technique

Treatments	Period (day)	LC ₅₀ (ppm)	Fiducial limits (95%)	LC ₉₀ (ppm)	Fiducial limits (95%)	Slope ± SE
Spirodeclofen	1	334.9	86.9-6687.3	164609.9	7720.8-848569.3	0.5 ± 0.1
	2	14.5	4-601.2	17175	1356.2-136973.5	0.4 ± 0.1
	3	0.8	0.13-2.5	238	59.9-3935.6	0.5 ± 0.1
	5	0.1	-	52.1	12.7-1265.4	0.5 ± 0.1
	7	0.002	-	11.3	-	0.3 ± 0.1
Acetamidrid	1	2.2	0.5-6.2	638.8	166.1-27397.8	0.4 ± 0.1
	2	0.2	0.02-0.6	23.8	8.7-117	0.6 ± 0.1
	3	0.02	0 - 0.2	22.4	5.0-571.5	0.1 ± 0.1
	5	100% dead	-	100% dead	-	-
	7	100% dead	-	100% dead	-	-
Flufenoxuron	1	6.5	2.9-13.5	311.0	107.7-1992	0.7 ± 0.1
	2	0.6	0.1-1.5	47.3	17.3-263.1	0.7 ± 0.1
	3	0.04	0.0002-0.3	23.4	6.0-368.6	0.6 ± 0.1
	5	0.0004	-	10.9	-	0.283 ± 0.1
	7	100% dead	-	100% dead	-	-
Fenbutatin oxide	1	1.3	0.2-3.8	497	106.5-13663.7	0.5 ± 0.1
	2	0.12	0.2-0.6	110.0	23.4-4674.0	0.4 ± 0.1
	3	0.02	-	112	-	0.3 ± 0.1
	5	0.0004	-	13.7	-	0.3 ± 0.1
	7	100% dead	-	100% dead	-	-
mancozeb 64% + metalaxyl 8%	1	1.7	0.5-4.2	217.2	65.0-2019.6	0.6 ± 0.1
	2	0.11	0.002-0.5	52.1	12.7-1265.4	0.5 ± 0.1
	3	0.02	0 - 0.2	22.4	5.0-571.5	0.4 ± 0.1
	5	100% dead	-	2.1	-	0.2 ± 0.1
	7	100% dead	-	100% dead	-	-
Chlorfenpyr	1	6.2	2.92-13.6	46.5	20.2-171.4	0.8 ± 0.1
	2	0.6	0.2-1.3	63.8	25.4-271.6	0.6 ± 0.1
	3	0.04	0.002-0.2	37.5	17.8-1040.0	0.4 ± 0.1
	5	0.009	0 - 0.05	4.7	1.2-51.1	0.5 ± 0.1
	7	100% dead	-	0.6	0.2-0.1	0.2 ± 0.1
Azadirachtin	1	73.9	32.9-235.7	5412.9	1081.9-145318.6	0.7 ± 0.1
	2	14.5	6.8-31.6	800.5	245.8-6676.3	0.7 ± 0.1
	3	6.4	-	1230.4	-	0.6 ± 0.1
	5	0.4	0.1-1.3	61.3	21.5-345.2	0.6 ± 0.1
	7	0.05	0.001-0.3	29.7	8.39-251.9	0.5 ± 0.1

foraging workers ranges from 10.6 to 56.1% after 30 days of application. Acetamidrid showed the highest decrease 56.1% in bee foraging 30 days after application. Followed by, flufenoxuron 54.6% and (mancozeb 64% + metalaxyl 8%) 40.6 %. Conversely, azadirachtin records the lowest decrease in foraging workers 10.6%, followed by spirodeclofen 15.2%.

The results presented in Table 8 demonstrate the side effects of certain insecticides applied to citrus orchards on the number of nectar-collecting workers over 30day. The data indicate significant differences in the number of nectar-collecting workers between all tested insecticides and the control. The decrease in the number of nectar-collecting workers ranges from 12 to 40 %. Acetamidrid recorded the highest decrease 40 % in nectar-collecting workers after 30 days of application, followed by fenbutatin oxide 32%. In contrast, the lowest decrease (12 and 16%) was observed with azadirachtin treatments spirodeclofen, respectively.

The data in Table 9 revealed that there were significant differences in the number of foraging workers between the tested insecticides and the control. The decrease in foraging workers ranges from 16.7 to 50 % after 30 days of application.

The highest decrease in workers gathering pollen grains (50 and 44.4 %) was recorded with acetamidrid and mancozeb 64 % + metalaxyl 8 % treatments, whereas the lowest decreases were observed with azadirachtin 16.7%, followed by spirodeclofen 22.2%.

The data presented in Table 10 illustrate the side effects of the applied insecticides on various honey bee

activities, including the area of worker brood per colony (cm²), pollen grains per trap (g), and honey production per colony (kg), over 30days. The results indicate significant differences between the tested compounds and the control group in terms of the area of worker brood per colony. Acetamidrid is associated with the highest decrease in the area of worker brood per colony, 33.8%, whereas azadirachtin and spirodeclofen treatments result in the lowest decreases, 9.7% and 13.3%, respectively.

Regarding the weight of pollen grains per trap, the highest decreases are recorded with acetamidrid 43.8% and (mancozeb 64% + metalaxyl 8%) 40.6%, while azadirachtin and spirodeclofen treatments exhibit the lowest decreases 12.5% and 15.6%, respectively.

In terms of honey yield per colony, significant differences are observed between the tested pesticides and the control. Acetamidrid induced the highest decrease in honey yield 30.6%, whereas azadirachtin and spirodeclofen treatments result in the lowest decreases, 18.4% and 20.4%, respectively.

DISCUSSION

The results showed that all tested pesticides demonstrated high efficacy against *Eutetranychus orientalis* stages under field conditions. These findings align with previous research, which reported that pesticides can be more toxic to mites than insects for unclear reasons. Different mite species respond variably due to behavior, cuticle thickness, detoxification capacity, and biochemical or morphological differences. Pesticide formulations also

Table 5: lethal times of tested insecticides on *Apis mellifera* .the data expressed as LT₅₀ and LT₉₀ (hrs.) together with the corresponding 95% fiducial limits (FL 95 %) after treated with contact technique

Treatments	Conc. (ppm)	LT ₅₀ (h)	Fiducial limits (95 %)	LT ₉₀ (h)	Fiducial limits (95%)	Slope ± SE
Spirodeclofen	0.1	71.7	59.2-85.8	149.3	118.6-221.6	4.0 ± 0.7
	1	63.4	5198-75.7	140.7	112.5-199.5	3.7 ± 0.6
	5	56.8	45.2-68.7	136.2	107.4-200.1	3.4 ± 0.5
	10	44.3	32.7-55.4	116.3	88.7-188.8	3.1 ± 0.5
	50	39.8	27.8-50.7	11.05	83.7-186.3	2.9 ± 0.6
	100	33.1	18.5-44.9	113.7	78.9-270.5	2.4 ± 0.6
Acetamidiprid	500	14.6	1.3-27.4	88.4	57.8-235.8	1.6 ± 0.5
	0.1	47.8	31.5-63.3	180.6	121.8-429.3	2.2 ± 0.5
	1	36.1	20.8-49	136.9	95.3-300.8	2.2 ± 0.5
	5	14.9	1.8-27.3	84.5	56.4-185.5	1.7 ± 0.5
	10	10.6	-	61.3	-	1.7 ± 0.6
	50	5.1	-	52.9	-	1.3 ± 0.6
Flufenoxuron	100	1.3	-	51.0	-	0.8 ± 0.1
	500	0.2	-	43.0	-	0.5 ± 0.1
	0.1	71.1	55.8-89.5	197.3	142.2-371.6	3.0 ± 0.5
	1	44.6	30.1-58.3	148.4	104.4-310.2	246 ± 0.5
	5	27.3	13.2-38.3	98.4	70.6-195	2.46 ± 0.5
	10	11.0	-	34.6	-	1.4 ± 0.5
Fenbutatin oxide	50	0.09	-	33.5	-	0.5 ± 0.3
	100	100% dead	-	100% dead	-	-
	500	100% dead	-	100% dead	-	-
	0.1	42.53	15.5-65	350.3	169.7-6307.1	2.0 ± 0.5
	1	29.4	9.4-44.9	178.8	108.2-836.7	1.6 ± 0.5
	5	25.4	8.5-38.6	126.5	83.9-359.1	1.8 ± 0.5
mancozeb 64% + metalaxyl 8%	10	16.9	2.4-29.4	90.8	60.8-260.8	1.8 ± 0.6
	50	11.1	-	100.6	-	1.34 ± 0.6
	100	100% dead	-	100% dead	-	-
	500	100% dead	-	100% dead	-	-
	0.1	46.9	29.42-63.30	196.4	127.6-541.2	2.1 ± 0.5
	1	32.9	16.06-45.66	145.4	100.1-363.3	2.0 ± 0.5
Chlorfenpyr	5	21.1	7.08-32.66	91.5	65.1-174.8	2.01 ± 0.5
	10	14.4	-	32.7	-	1.9 ± 0.6
	50	1.34	-	51.0	-	0.8 ± 0.6
	100	100% dead	-	100% dead	-	-
	500	100% dead	-	100% dead	-	-
	0.1	97.1	79.6-130.9	286.8	190.5-694.6	2.7 ± 0.6
Azadirachtin	1	69.2	53.8-87.8	197.9	141.4-38.1	2.8 ± 0.5
	5	49.1	35.8-62.2	143.5	105.4-256.9	2.8 ± 0.5
	10	17.4	17.5-41.5	100.2	73.4-184.7	2.5 ± 0.6
	50	1.3	3-29.6	90.7	61.0-226.8	1.8 ± 0.5
	100	1.3	-	51.0	-	0.8 ± 0.2
	500	100% dead	-	100% dead	-	-
Control	0.1	144.4	105.1-282.7	574.8	290.1-4197.9	2.1 ± 0.6
	1	101.9	76.0-157.5	413.8	231.2-1874.4	2.1 ± 0.5
	5	66.2	47.12-90.1	269.4	166.4-846.5	2.1 ± 0.5
	10	47.2	31.9-61.8	166.7	115.5-361.3	2.3 ± 0.5
	50	31.8	19.7-41.9	95.8	72.5-156.9	2.7 ± 0.6
	100	20.8	5.9-33	46.6	27.9-67.7	1.9 ± 0.5
500	2.7	-	13.5	-	1.0 ± 0.6	

Table 6: The side effect of tested pesticides applied in citrus orchards on the number of dead honey bee workers

Treatments	Pre treatment	Post treatment (no of dead bees / colony)								Mean ± SE	D%
		1 day		7 day		14 day		30 day			
		no	D %	no	D %	no	D %	no	D %		
Spirodeclofen	15	18 ^f	3.5	36 ^e	23.8	35 ^d	19.8	28 ^d	8.9	29.3 ± 0.06d	14
Acetamidiprid	14	52 ^a	43.5	73 ^a	67.9	65 ^a	56.8	54 ^a	41.8	61.0 ± 0.03a	52.5
Flufenoxuron	17	35 ^c	23.5	45 ^c	34.5	41 ^c	27.2	38 ^c	21.5	39.8 ± 0.04c	26.7
Fenbutatin oxide	15	46 ^b	36.5	61 ^b	53.6	52 ^b	40.7	49 ^b	35.4	52 ± 0.03b	41.6
Mancozeb 64% + Metalaxyl 8%	19	25 ^d	11.8	35 ^e	22.6	39 ^{cd}	24.7	26 ^d	6.3	31.3 ± 0.05d	16.4
Chlorfenpyr	16	22 ^e	8.2	40 ^d	28.6	37 ^{cd}	22.2	28 ^d	8.9	31.8 ± 0.05d	17
Azadirachtin	16	21 ^e	7.1	41 ^d	29.8	22 ^e	3.7	29 ^d	10.1	28.3 ± 0.06d	12.7
Control	18	15 ^g	-	16 ^f	-	19	-	21 ^e	-	17.6 ± 0.1e	-
F-value	-	202.5	-	183.0	-	136.9	-	95.1	-	214.1	-
LSD 5%	-	2.9	-	3.8	-	3.8	-	3.6	-	2.9	-

D % = Dead bee worker; The same letters in the column mean no significant difference.

Table 7: The side effect of tested pesticides applied in citrus orchards on the number of foraging workers

Treatments	Pre treatment	No foraging bee workers/ colony/ 3 minutes				Total	Mean ± SE	% Decrease in bee foraging
		Days post treatment						
		1 day	7 day	14 day	30 day			
Spirodeclofen	18	15	15	14	12	56	14 ± 0.1b	15.2
Acetamidiprid	17	7	8	6	8	29	7.3 ± 0.2d	56.1
Flufenoxuron	14	8	7	8	7	30	7.5 ± 0.2d	54.6
Fenbutatin oxide	13	12	10	9	9	40	10 ± 0.2c	39.4
Mancozeb 64% + Metalaxyl 8%	16	10	10	11	8	39	9.8 ± 0.2c	40.6
Chlorfenpyr	15	13	12	9	8	42	10.5 ± 0.2c	36.4
Azadirachtin	16	16	15	14	14	59	14.8 ± 0.1b	10.6
Control	16	17	18	15	16	66	16.5 ± 0.1a	-
F-value	-	-	-	-	-	-	32.6	-
LSD 5%	-	-	-	-	-	-	1.8	-

The same letters in the column mean no significant difference.

Table 8: The side effects of tested pesticides applied in citrus orchards on the number of nectar collecting workers

Treatments	Pre treatment	Mean no. nectar collecting workers / flower/ 3 minutes				Total	Mean \pm SE	% decrease in bee collecting nectar
		Days post treatment						
		1	7	14	30			
Spirodeclofen	7	6	5	5	5	21	5.3 \pm 0.3cb	16
Acetamidiprid	7	5	4	3	3	15	3.8 \pm 0.4e	40
Flufenoxuron	6	4	5	5	6	20	5 \pm 0.3bcd	20
Fenbutatin oxide	6	5	4	4	4	17	4.3 \pm 0.4de	32
Mancozeb 64% + Metalaxyl 8%	6	5	5	5	4	19	4.8 \pm 0.3bcd	24
Chlorfenpyr	7	5	4	5	4	18	4.5 \pm 0.3cde	28
Azadirachtin	7	6	6	5	5	22	5.5 \pm 0.3b	12
Control	7	7	7	6	5	25	6.3 \pm 0.3a	-
F-value	-	-	-	-	-	-	13.7	-
LSD 5%	-	-	-	-	-	-	0.6	-

The same letters in the column mean no significant difference.

Table 9: The side effects of tested pesticides applied in citrus orchards on the number of workers gathering pollen grains

Treatments	Pre treatment	No workers gathering pollen grain / flower/ 3 minutes				Total	Mean \pm SE	%decrease in pollen workers
		Days post treatment						
		1	7	14	30			
Spirodeclofen	4	4	4	3	3	14	3.5 \pm 0.4bc	22.2
Acetamidiprid	4	3	2	2	2	9	2.3 \pm 0.7d	50.0
Flufenoxuron	5	4	3	2	2	11	2.8 \pm 0.5d	38.9
Fenbutatin oxide	4	3	3	3	2	11	2.8 \pm 0.5d	38.9
Mancozeb 64% + Metalaxyl 8%	4	3	3	2	2	10	2.5 \pm 0.6d	44.4
Chlorfenpyr	5	4	4	2	2	12	3.0 \pm 0.5cd	33.3
Azadirachtin	4	4	4	4	3	15	3.8 \pm 0.4b	16.7
Control	5	5	5	4	4	18	4.8 \pm 0.3a	-
F-value	-	-	-	-	-	-	20.1	-
LSD 5%	-	-	-	-	-	-	0.5	-

The same letters in the column means no significant difference at 5% level.

Table 10: The side effects of tested pesticides applied in citrus orchards on some honey bee activities

Treatments	Area of worker brood/ colony cm ² \pm SE	% decrease	Pollen grains/ trap (g) \pm SE	% decrease	Honey / colony (kg) \pm SE	% decrease
Spirodeclofen	2400 \pm 0.001bc	13.3	27 \pm 0.6b	15.6	3.9 \pm 0.4b	20.4
Acetamidiprid	1832 \pm 0.001e	33.8	18 \pm 0.9e	43.8	3.4 \pm 0.5b	30.6
Flufenoxuron	2100 \pm 0.001cde	24.2	23 \pm 0.7cd	28.1	3.8 \pm 0.4b	22.5
Fenbutatin oxide	1980 \pm 0.001de	28.5	21 \pm 0.8de	34.4	3.5 \pm 0.4b	28.6
Mancozeb 64% + Metalaxyl 8%	2200 \pm 0.001cd	20.6	19 \pm 0.9e	40.6	3.6 \pm 0.4b	26.5
Chlorfenpyr	2145 \pm 0.001cd	22.5	25 \pm 0.7bc	21.9	3.5 \pm 0.4b	28.6
Azadirachtin	2500 \pm 0.001b	9.7	28 \pm 0.6b	12.5	4.0 \pm 0.4b	18.4
Control	2769 \pm 0.001a	-	32 \pm 0.5a	-	4.9 \pm 0.3a	-
F value	16.4	-	27.6	-	3.2	-
LSD 5%	223.1	-	2.7	-	0.8	-

The same letters in each column means no significant difference at 5% level.

impact toxicity differently (Capinera 2006). In addition, significant reductions in *E. orientalis* populations with pesticides like Dicofol, Propargite, Hexitiazox, Etoxazol, and Fenpyroximate, achieving efficacy rates of 100, 98.85, 85.05, 83.92, and 100% on Valencia-late oranges, and 97.82, 85.92, 81.87, 100, and 100% on Fine lemon after 1 week. Similarly, Alhewairini (2018) found that *E. orientalis* populations decreased by 76.68 and 79.56% in field conditions, and by 78.52 and 80.12% in lab conditions, one week after applying Abamectin and Bifenthrin at recommended doses. Assouguem et al. (2022) demonstrated that binary mixtures of four essential oils (*Mentha pulegium* L., *Lavandula stoechas* L., *Rosmarinus officinalis* L., and *Origanum compactum*) with acaricides achieved high efficacy against *Tetranychus urticae* and *Eutetranychus orientalis*. These natural products can be applied at low concentrations, reducing costs and environmental risks, thus supporting integrated pest management strategies. Additionally, Al Amin et al. (2020) and Al Dhafar et al. (2024) found that chlorfenapyr was highly effective against *E. orientalis*, achieving significant control after the first and second sprays in the 2022 season, respectively.

All tested compounds showed high toxicity to honeybee workers and reduced their activities (foraging, nectar collection, pollen gathering, brood production, and honey yield) under lab and field conditions, except spirotetramat and azadirachtin, which exhibited lower toxicity. This aligns with previous studies showing that the sub-lethal doses of imidacloprid can affect the foraging behavior and learning ability of honey bees, *Apis mellifera*, without causing immediate mortality (Bortolotti et al., 2003; Colin et al., 2004; Decourtye et al., 2004; Ramirez-Romero et al., 2005). Specifically, Medrzycki et al. (2003) found that even low concentrations of imidacloprid (20 ppb) can decrease foraging activity in honey bee colonies, and that foraging behavior is suppressed at levels above 100 ppb after 30-60 minutes. Furthermore, Iwasa et al. (2004) reported that neonicotinoids, including imidacloprid and thiamethoxam, are more toxic to honey bees when applied topically. Moreover, several studies have noted that exposure to imidacloprid at the colony level (50 μ g/liter) can impact foraging efficiency and memory (Cresswell, 2011). The exposure of bees to neonicotinoid insecticides has also been linked to various adverse effects, including increased mortality, reduced foraging, egg-laying, and

brood care (Cresswell, 2011). Additionally, studies have reported that exposure to imidacloprid can decrease winter survival of colonies (Dively et al., 2013) and that the presence of pesticide residues in pollen and nectar poses a risk to bee pollinators (Sanchez-Bayo & Goka, 2014). Thiamethoxam, imidacloprid, and clothianidin have been identified as posing the highest risk to worker bees and larvae (Sanchez-Bayo & Goka, 2014). Xavier et al. (2015) evaluated the toxicity of botanical insecticides to honey bees and found that andiroba oil was not lethal to adult workers, but was toxic to larvae. Aljedani (2017) reported that imidacloprid had a significant impact on forager honey bee workers, while azadirachtin was less effective. Recent studies have also reported that indoxacarb, esfenvalerate, thiamethoxam, and imidacloprid are harmful to honey bees (Abbassy et al., 2020). Roudsari et al. (2022) found that imidacloprid and ethion disrupt the physiology of honey bees, reducing their efficiency as pollinators.

Additionally, temperature fluctuations amplify neonicotinoid toxicity, with cold-stressed bees exhibiting impaired pesticide metabolism, leading to prolonged adverse effects. Environmental stressors, including habitat destruction and climate variability, further exacerbate these negative impacts, contributing to elevated bee mortality rates (Siviter et al. 2018). Additionally, Crall and Raine (2023) found that neonicotinoid exposure disrupts worker bee coordination, delaying recruitment and impairing collective foraging. This hinders food resource use, diminishing productivity and increasing mortality risk. Pesticides in HBPs highlight risks to bee colonies. Furthermore, temporal and spatial isolation strategies, like adjusting planting schedules or separating treated areas from pollinator crops, can minimize exposure. Site-specific management is the key due to geographical variability in pesticide contamination of pollen and nectar (Lu et al., 2023). Contamination of these products can compromise their quality and undermine their health benefits, thereby posing a risk to human health (Carrera et al. 2024). Recently, Swiatly-Błaszkiwicz et al. (2025) revealed that pesticides might penetrate honeybee products, potentially impacting not only bee health but also human consumers. Given that combinations of different pesticides may increase toxicity due to interactions, all detected pesticides should be considered a potential threat and monitored continuously.

Kopparthi (2020) reported that microbial formulations like *Bacillus thuringiensis* can be integrated with conventional insecticides, allowing effective pest control while reducing reliance on harmful neonicotinoids and minimizing impact on honeybee populations. The risks to bees can be effectively mitigated by using less harmful pesticides or reducing application rates (Main et al. 2020). Additionally, significant advancements have been made in developing bee-friendly pesticide formulations, including polymer coatings and stereoisomeric chemicals (Shakir, 2025; Ullah, 2024). These modified structures are designed to minimize disruption to honeybee metabolic pathways and detoxification mechanisms, offering a promising approach for producing safer pesticides (Zhang et al., 2022). As well as, Smaghe et al. (2023) highlighted

biological alternatives less hazardous to honeybees, like bacterial formulations, fungal-based biopesticides, and plant-derived insecticides. Their research supports integrating these into pollinator-friendly IPM strategies to reduce reliance on neonicotinoids and protect honeybee colonies. Further research is needed on biopesticides' long-term efficacy and compatibility with conventional insecticides. Recently, Swiatly-Błaszkiwicz et al. (2025) found thiacloprid and acetamiprid are less toxic to bees than other neonicotinoids, making them common in flowering crops. Their concentrations were within permissible limits for honey, but may still impact bee health.

Practical citrus orchard management recommendations include utilizing biopesticides that effectively control mites without harming honeybees. Implementing integrated pest management (IPM) strategies can balance pest control with bee protection. Conduct field trials to assess pesticide impacts on bees before widespread application. Provide honeybee forage resources, such as flowers and beneficial plants, within orchards to enhance bee health. Train farmers on pollinator-friendly practices and the importance of protecting pollinators, contributing to protecting honeybees and, enhancing citrus orchard sustainability.

Conclusion

The results showed that the tested pesticides were effective against the citrus brown mite, *E. orientalis*, under field conditions, but were toxic to honey bees, adversely affecting various aspects of their activities, including increased worker mortality, reduced foraging activity, impaired nectar collection, decreased brood production, reduced pollen collection, and lower honey yields under both laboratory and field conditions. In contrast, azadirachtin and spiroticlofen were effective against *E. orientalis* with minimal adverse effects on honey bee activities in the field. Therefore, it is recommended to incorporate azadirachtin and spiroticlofen into integrated pest management (IPM) programs for the citrus brown mite as environmentally friendly and bee-safe options, maintaining effective control while protecting pollinators. Citrus growers can apply these compounds during periods of low bee activity to achieve an ecological balance between crop protection, bee conservation, and environmental protection.

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