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Comparative Toxicity of Selected Acaricides and Essential Oils to *Tetranychus Urticae* Koch and its Predatory Mite *Phytoseiulus persimilis* Athias-Henriot Under Controlled Laboratory Conditions

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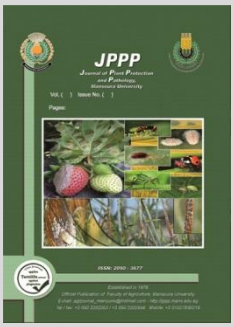

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ABSTRACT

A laboratory study was performed to assess the acute toxicity of four synthetic acaricides (emamectin benzoate, chlorfenapyr, hexythiazox, and acequinocyl) and four essential oils: eucalyptus oil (*Eucalyptus globulus*), thyme oil (*Thymus vulgaris*), garlic oil (*Allium sativum*), and cinnamon oil (*Cinnamomum zeylanicum*) against the two-spotted spider mite (*Tetranychus urticae*) and its natural predator *Phytoseiulus persimilis* after 24 and 48 hours of exposure. Among all tested compounds, emamectin benzoate showed the highest toxicity across both time points, with the lowest LC_{50} values (2.86 and 2.42 mg/L, respectively). Chlorfenapyr followed with moderate toxicity and delayed lethal effects. Hexythiazox and acequinocyl demonstrated low toxicity after 24 hours but slightly improved efficacy by 48 hours, reflecting their mode of action and slow adulticidal effects. Among essential oils, eucalyptus oil showed the highest toxicity followed by thyme oil although both required much higher concentrations than synthetic acaricides. Garlic oil and cinnamon oil exhibited weak acaricidal activity. Comparative toxicity on the predatory mite *P. persimilis* indicated that both emamectin benzoate and chlorfenapyr had low selectivity as they caused high mortality and had low LC_{50} values on the predator. In contrast, hexythiazox and acequinocyl were more selective and safer to the predatory mite. These results highlight the potential of integrating selective acaricides and essential oils within Integrated Pest Management (IPM) programs, emphasizing the need to balance efficacy against *T. urticae* with safety to natural enemies.

Keywords: *Tetranychus urticae*, acaricides, essential oils, *Phytoseiulus persimilis*, toxicity index, IPM.

INTRODUCTION

The two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is among the most destructive and polyphagous pests infesting a wide range of economically important crops worldwide. It feeds on the mesophyll layer of leaves, causing yellowing, bronzing, reduced photosynthesis, and ultimately leading to significant yield losses in both field and greenhouse crops (Grbić *et al*., 2011; Attia *et al*., 2013). Its high reproductive potential, rapid development of resistance to conventional acaricides, and ability to thrive in hot, dry environments make it a persistent challenge for pest management programs (Van Leeuwen *et al*., 2010). To mitigate the damage caused by *T. urticae*, synthetic acaricides have been widely used over the past decades. However, their extensive application has led to several adverse consequences including the emergence of acaricide-resistant populations, environmental contamination, residual toxicity on agricultural products, and detrimental effects on non-target organisms, particularly natural enemies (Stumpf and Nauen, 2001; Dermauw *et al*., 2012). Among these natural enemies, the predatory mite *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) plays a crucial role as a specialized and highly effective biocontrol agent of *T. urticae* (McMurtry *et al*., 2013). This predator has been commercially used in integrated pest management (IPM) programs due to its voracious appetite, high searching efficiency, and specificity to spider mites (Sabelis, 1981). Nonetheless, the application of chemical pesticides in cropping systems where *P. persimilis* is used may pose a threat to its survival and predation efficiency. Therefore, the compatibility of pest control measures with natural enemies is an essential consideration for sustainable pest management. One promising alternative to conventional acaricides is the use of essential oils, which have gained considerable attention as eco-friendly, biodegradable, and selective pest control agents with low mammalian toxicity and reduced environmental persistence (Isman, 2000; Pavela and Benelli, 2016). Essential oils, obtained from aromatic plants, mainly contain volatile compounds such as terpenoids and phenylpropanoids. These compounds exhibit a broad spectrum of biological activities including insecticidal, acaricidal, repellent, antifeedant, and growth-regulatory effects (Bakkali *et al*., 2008). In particular, several essential oils have been shown to possess acaricidal activity against *T. urticae*, often through contact toxicity, fumigant action, and disruption of neurotransmission or cellular respiration (Prates *et al*., 1998; Kostić *et al*., 2008). Among essential oils with known acaricidal activity, thyme oil (*Thymus vulgaris*), garlic oil (*Allium sativum*), eucalyptus oil (*Eucalyptus globulus*), and cinnamon oil (*Cinnamomum zeylanicum*) have shown promising results against various mite species (Kostić *et al*., 2008; Cetin *et al*., 2009; Wang *et al*., 2010; Pavela, 2015). These oils contain bioactive compounds such as thymol, allicin, eucalyptol, and cinnamaldehyde, which contribute to their toxicity and repellent effects. Recently, many studies have evaluated the efficacy of various essential oils against *T. urticae*. For instance, thyme oil (*T. vulgaris*), rich in thymol

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and carvacrol, has been reported to have potent acaricidal activity (Kostić *et al*., 2008). Similarly, cinnamon oil (*C. zeylanicum*), containing cinnamaldehyde. Other oils such as rosemary (*Rosmarinus officinalis*), eucalyptus (*E. globulus*), and tea tree (*Melaleuca alternifolia*) have also demonstrated variable levels of efficacy depending on the tested concentrations, exposure time, and life stages of the mites (Kim *et al*., 2013; Khater, 2012). On the other hand, conventional acaricides remain a cornerstone in mite management. Despite their high efficacy, the use of chemical acaricides may negatively impact beneficial arthropods such as *P. persimilis*, necessitating rigorous laboratory evaluation before integration into IPM programs. Therefore, assessing the toxicity of both synthetic and botanical compounds against both the pest and its natural enemy is essential to develop sustainable control strategies. The objective of this study is to evaluate and compare the acute toxicity of four essential oils (thyme, garlic, eucalyptus, and cinnamon) and four synthetic acaricides (hexythiazox, acequinocyl, chlorfenapyr, and emamectin benzoate) against the two-spotted spider mite, *T. urticae* and its natural predator, *P. persimilis* under controlled laboratory conditions. This research aims to determine the relative selectivity of each compound, providing insight into their compatibility with biological control agents and their potential use in IPM.

MATERIALS AND METHODS

Preparation of Cultures

This study was conducted under controlled laboratory conditions Plant Protection Research Institute Laboratory, Agricultural Research Center, Dokki, Egypt during the 2024–2025 season to evaluate the comparative toxicity of selected synthetic acaricides and essential oils against *T. urticae* and its natural enemy *P. persimilis*. The initial colony of *T. urticae* was established from individuals collected from unsprayed castor bean plants (*Ricinus communis* L.) The mites were maintained in the laboratory on healthy castor bean plants grown individually in 40 cm-diameter plastic pots in mesh-covered cages. Plants were cultivated under greenhouse conditions for 30 days before being artificially infested. To maintain the culture, mites were transferred every two to three days from old to fresh leaves. Rearing was under controlled conditions of 25 ± 2 °C temperature, 65 ± 5% relative humidity, and a photoperiod of 16:8 (light:dark). *Phytoseiulus persimilis* was reared separately under the same environmental conditions using *T. urticae*-infested bean leaves as a food source. The colony was maintained in ventilated plastic containers lined with moist paper and fresh infested leaves, which were replenished regularly to ensure predator development. Only healthy adult females were used in the bioassays.

Tested Compounds

Eight compounds were evaluated: four synthetic acaricides and four essential oils. The synthetic acaricides were:

- Acequinocyl (Kanemite 15% SC), as a mitochondrial electron transport inhibitor
- Chlorfenapyr (Chalenger 36% SC), a pro-insecticide disrupting mitochondrial respiration.
- Hexythiazox (Maccomite 10% WP), an ovicidal and larvicidal growth regulator,
- Emamectin benzoate (Excellent 1.9% EC), an avermectin derivative with neurotoxic effects.

All acaricides were obtained from commercial sources approved by the Agricultural Pesticide Committee, Ministry of Agriculture and Land Reclamation, Egypt.

The essential oils included:

- Thyme oil (*Thymus vulgaris*),
- Eucalyptus oil (*Eucalyptus globulus*),
- Garlic oil (*Allium sativum*),
- Cinnamon oil (*Cinnamomum zeylanicum*).

All oils were purchased in pure form from a certified herbal supplier in Alexandria, Egypt, and stored at 4 °C in dark glass bottles until use.

Bioassay Procedure

Toxicity was assessed using the leaf-disc dip method described by Busvine (1971), with slight modifications. For essential oils, stock solutions were prepared using 0.1% Tween-80 as an emulsifier and diluted with distilled water to serial concentrations. For acaricides, aqueous dilutions were made to obtain the different concentrations.

Circular leaf discs (2.5 cm in diameter) were excised from clean, healthy castor bean leaves and immersed in each solution for 5 seconds. After air-drying, treated discs were placed (lower surface upward) on moist cotton in 9 cm Petri dishes. Twenty adult females of either *T. urticae* or *P. persimilis* were transferred to each disc using a fine brush. Each treatment was replicated four times per concentration and species. Control discs were treated with distilled water (acaricides) or 0.1% Tween-80 solution (essential oils) only. All dishes were incubated at 25 ± 2 °C, 65 ± 5% RH, and a 16:8 (L:D) photoperiod. Mite mortality was assessed at 24 and 48 hours post-treatment. Mites were classified as dead if they did not respond to gentle stimulation with a fine brush.

Five serial concentrations of each tested pesticide and essential oil were selected based on preliminary range-finding assays to ensure measurable mortality ranging from 0% to 100%. The concentrations for the synthetic pesticides were as follows: hexythiazox and acequinocyl at 100, 150, 200, 250, and 300 mg/L; emamectin benzoate at 1, 2, 4, 6, and 8 mg/L; and chlorfenapyr at 10, 20, 30, 40, and 50 mg/L. Essential oils were prepared at concentrations of 2500, 5000, 10000, 20000, and 30000 mg/L for *T. vulgaris* and *E. globulus*, while *A. sativum* and *C. zeylanicum* oils were prepared at 5000, 10000, 20000, 30000, and 50000 mg/L, respectively. All solutions were freshly prepared immediately before application to ensure stability and effectiveness during the bioassays.

Statistical Analysis

Abbott's formula (Abbott, 1925) was employed to calculate corrected mortality to adjust for control mortality as follows

$$\text{Corrected Mortality (\%)} = [(T - C) / (100 - C)] \times 100$$

where T represents the mortality percentage in the treatment group, and C represents the mortality percentage in the control group.

Lethal concentration values (LC50, LC25, and LC90) and their 95% confidence intervals were estimated using probit analysis based on Finney's method (Finney, 1971), which was conducted using LdP-Line software (Ehab Software, http://www.ehabsoft.com/ldpline/). Additionally, toxicity index values were calculated using the formula of Sun (1950) allowing for a comparative assessment of relative toxicity among tested compounds as follows;

$$TI = (A / B) \times 100$$

Where; A: LC_{50} **of most toxic compound and B:** LC_{50} **of tested compound**

The selectivity of each treatment was determined by comparing its LC_{50} value for the predator versus the pest.

RESULTS AND DISCUSSIONS

Toxicity of acaricides and essential oils against *T. urticae* After 24 Hours

The laboratory bioassay conducted 24 hours after treatment with four acaricides and four essential oils against *T. urticae* revealed a wide range of toxicities, as reflected in the LC_{50} values and their corresponding toxicity indices (Table 1 and Fig. 1).

Emamectin benzoate was the most potent among all tested substances, with an LC_{50} of 2.86 mg/L and a steep slope (2.072 ± 0.219), indicating a consistent mortality pattern among tested mites. Its toxicity index (T.I. = 100) set the benchmark for comparison. These findings align well with previous reports that emphasized the strong acaricidal action of emamectin benzoate due to its interference with GABA and glutamate-gated chloride channels, causing rapid paralysis and death (Xu *et al*., 2019).

Table 1. Comparative toxicity of acaricides and essential oils to *T. urticae* females after 24-hour laboratory exposure.

Treatments	LC_{25} ± 95% CL	LC_{50} ± 95% CL	LC_{90} ± 95% CL	Slope ± SE	Chi^2	T.I.
Emamectin benzoate	1.35 (1.016-1.66)	2.86 (2.434-3.318)	11.89 (9.177-17.272)	2.072±0.219	6.473	100
Chlorfenapyr	15.21 (12.94-17.19)	23.646 (21.39-25.92)	54.67 (47.58-65.99)	3.521±0.329	6.329	12.1
Hexythiazox	99.78 (85.6-110.95)	136.754 (125.18-147.24)	248.929 (223.83-290.25)	5.549±0.557	5.549	2.09
Acequinocyl	107.52 (93.1-119.39)	151.714 (139.32-163.19)	291.85 (308.78-336.89)	4.511±0.447	5.264	1.89
Eucalyptus globulus	2989.66 (2202-3746)	6627.56 (5524-7803)	30079.43 (23337-42722)	1.951±0.191	4.171	0.043
Thymus vulgaris	4008.99 (3003-4972)	9394.71 (7891-11157)	47383.05 (34847-73539)	1.824±0.186	3.904	0.03
Allium sativum	6531.61 (4791-8155)	14734.6 (12387-17306)	69130.04 (51957-104760)	1.909±0.205	4.777	0.019
Cinnamomum zeylanicum	9746.12 (7657-11693)	20942.988 (17972-24620)	89589.41 (66372-138790)	2.03±0.213	4.194	0.014

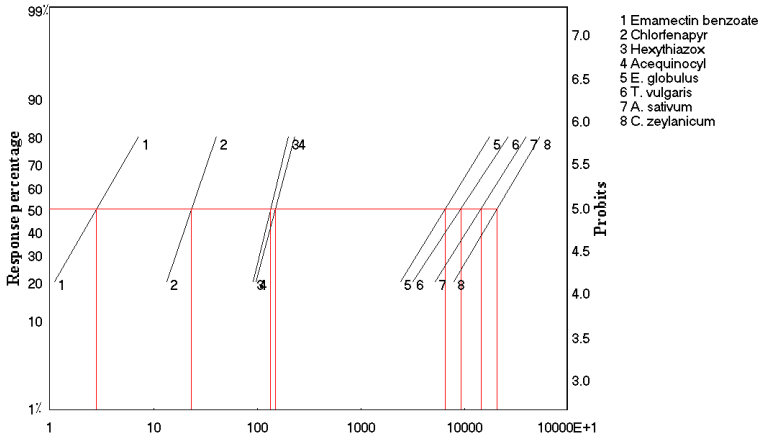

Fig. 1. Comparative toxicity of acaricides and essential oils to *T. urticae* females after 24-hour laboratory exposure.

Its fast action makes it a valuable option for controlling high-density populations in early infestations. Chlorfenapyr displayed moderate toxicity with an LC_{50} of 23.646 mg/L and a relatively steep slope (3.521 ± 0.329), indicating a sharp transition between low and high mortality responses. Its toxicity index was 12.1, significantly lower than emamectin benzoate but still notable. Chlorfenapyr functions as a pro-insecticide that disrupts mitochondrial oxidative phosphorylation (Black *et al*., 1994), which may explain its delayed yet effective toxic action. Previous studies have confirmed its high efficacy against resistant strains of spider mites (Van Leeuwen *et al*., 2006), supporting its utility as a rotational compound in IPM programs. Hexythiazox showed low acute toxicity at 24 hours, with an LC_{50} of 136.75 mg/L and a toxicity index of only 2.09. However, Hexythiazox is primarily known as an ovicidal and larvicidal compound with limited immediate effect on adults (Dekeyser, 2005). Its relatively high slope (5.549 ± 0.557) suggests a strong dose–response relationship among sensitive individuals, but its low short-term mortality confirms its suitability for long-term population suppression rather than rapid knockdown. Acequinocyl exhibited the lowest toxicity among synthetic acaricides in the 24-hour test, with an LC_{50} of 151.714 mg/L and a T.I. of 1.89 (its toxicity of was 1.89% of that of the reference acaricide, emamectin benzoate). Like Hexythiazox, it acts by disrupting mitochondrial function but shows delayed effects (Kumrungsee *et al*., 2014). This reduced acute efficacy may be misleading in short-term assays, and its actual field performance is often enhanced when used preventively or in combination with faster-acting agents.

E. globulus oil showed the highest toxicity among the plant-derived treatments, with an LC_{50} of 6627.56 mg/L. Although much less potent than synthetic acaricides (T.I. = 0.043 of emamectin benzoate), its relatively narrower confidence intervals suggest moderate consistency in response. Previous studies attributed the acaricidal activity of

eucalyptus oils to compounds like 1,8-cineole and limonene (Pavela, 2014), which affect the nervous and respiratory systems of mites. Nevertheless, the high required dose limits its standalone application. *T. vulgaris* exhibited slightly lower efficacy (LC_{50} = 9394.71 mg/L) than *E. globulus*, with a comparable slope value (1.824 ± 0.186). The main components of thyme oil, such as thymol and carvacrol, are known to have neurotoxic and fumigant effects (Isman, 2006). Although its high LC_{50} may reduce its practical value, thyme oil remains promising in integrated organic management systems where synthetic pesticide use is restricted. Garlic oil (*A. sativum*) showed weaker toxicity (LC_{50} = 14734.6 mg/L) with broader confidence intervals, reflecting less uniform responses among mite populations. Allicin and other sulfur-containing compounds may contribute to its activity (Rahman, 2007), yet its use may be hindered by strong odor and phytotoxicity concerns at high concentrations. Cinnamon oil was the least effective treatment overall, with an LC_{50} of 20942.99 mg/L (represented only 0.014% of the toxicity of the reference compound emamectin benzoate). This is consistent with the results of other laboratory studies that showed limited contact toxicity of cinnamon oil on adult *T. urticae* unless used in combination or as a fumigant. The mode of action may involve disruption of the mite's cuticle and inhibition of enzyme systems, but its effectiveness is clearly limited in acute contact scenarios.

After 48 Hours of Exposure

After 48 hours of exposure (Table 2 and Fig. 2), emamectin benzoate remained the most effective acaricide against *T. urticae*, exhibiting the lowest LC_{50} value of 2.422 mg/L (95% CL: 2.0–2.89).

Table 2. Comparative toxicity of acaricides and essential oils to *T. urticae* females after 48-hour laboratory exposure.

Treatment	LC_{25} ± 95% CL	LC_{50} ± 95% CL	LC_{90} ± 95% CL	Slope ± SE	X^2	T.I.
Emamectin benzoate	1.069 (0.727-1.369)	2.422 (2-2.89)	11.47 (8.1-20.35)	1.898±0.256	1.72	100
Chlorfenapyr	12.714 (10.6-14.51)	19.581 (17.53-21.63)	44.49 (38.28-55.02)	3.596±0.379	5.138	12.37
Hexythiazox	89.329 (75.67-100.3)	121.77 (110.1-131.67)	219.38 (200.98-246.9)	5.013±0.532	5.401	1.99
Acequinocyl	94.87 (79.36-106.9)	133.479 (120.87-144.6)	255.38 (227.37-303.6)	4.548±0.545	2.057	1.81
Eucalyptus globulus	2033.11 (1366-2646)	4359.283 (3507-5202)	18570.4 (14215-27805)	2.036±0.249	0.453	0.056
Thymus vulgaris	3052.95 (2197-3877)	7211.676 (5957-8567)	36928.74 (27708-55533)	1.807±0.186	5.111	0.034
Allium sativum	5319.32 (3303-7064)	13902.704 (11257-17289)	86276.44 (53826-203450)	1.617±0.253	1.35	0.017
Cinnamomum zeylanicum	7517.6 (5731-9181)	16177.906 (13790-18860)	69398.37 (52901-102400)	2.026±0.209	2.097	0.015

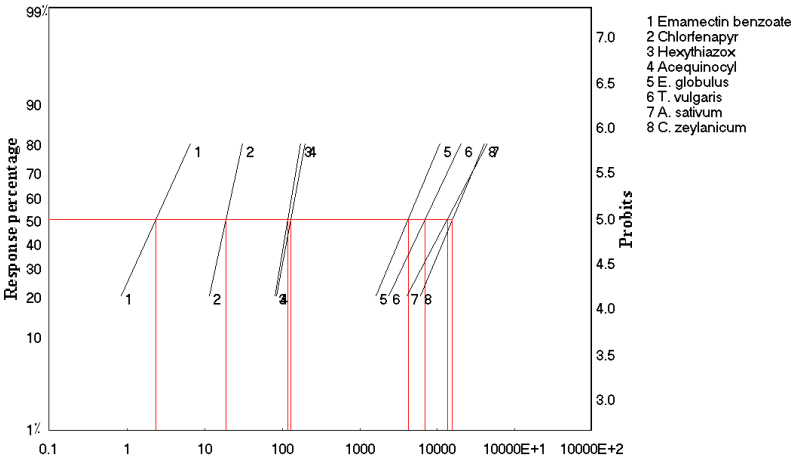

Fig. 2. Comparative toxicity of acaricides and essential oils to *T. urticae* females after 48-hour laboratory exposure.

The slope of the concentration–mortality regression (1.898 ± 0.256) indicates a consistent response among the tested individuals. Compared to the 24-hour data (LC_{50} = 2.86 mg/L), emamectin benzoate demonstrated slightly increased toxicity over time, suggesting cumulative effects. These findings are consistent with earlier studies reporting the high efficacy of emamectin benzoate due to its dual mode of action, targeting both chloride channels and neurotransmitter receptors in mites. Chlorfenapyr ranked second in toxicity, with an LC_{50} of 19.581 mg/L (12.37 % of emamectin benzoate toxicity). This value was lower than the 24-hour LC_{50} (23.646 mg/L), confirming its delayed toxic action, a known characteristic of chlorfenapyr which functions as a pro-insecticide requiring metabolic activation. The slope (3.596 ± 0.379) and relatively high chi-square (χ^2 = 5.138) suggest a steeper dose-response curve, possibly indicating variability in susceptibility among mite individuals. In contrast, hexythiazox and acequinocyl showed moderate efficacy with LC_{50} values of 121.77 mg/L and 133.479 mg/L, respectively, and TI values of 1.99 and 1.81. Compared to

their 24-hour values (136.754 mg/L and 151.714 mg/L), both compounds exhibited improved activity after 48 hours, but the enhancement was marginal. Hexythiazox acts mainly as an ovicide and larvicide by inhibiting chitin synthesis, hence its limited adulticidal action may explain the relatively high LC_{50} values observed (Van Leeuwen *et al*., 2006). Acequinocyl, known for disrupting mitochondrial electron transport, often shows moderate activity on adult mites, which aligns with current results (Nauen and Bretschneider, 2002). Among the essential oils tested, *E. globulus* demonstrated the highest acaricidal effect, with an LC_{50} of 4359.283 mg/L (0.056% of emamectin benzoate toxicity), outperforming the other oils slightly. This trend persisted from the 24-hour results (LC_{50} = 6627.56 mg/L), indicating its moderate volatility and increasing effect over time. The active components, such as 1,8-cineole, have been shown to possess fumigant and contact toxicity against several arthropods (Isman, 2000; Pavela and Benelli, 2016). *T. vulgaris* oil followed closely, showing an LC_{50} of 7211.676 mg/L, which again indicates limited but time-enhanced toxicity (24-hour LC_{50} was 9394.71 mg/L). Thymol and carvacrol, the primary constituents, are known to disrupt mite nervous systems, though typically at high concentrations (Koul *et al*., 2008). The increase in efficacy after 48 hours is likely related to prolonged exposure to vapors or residual contact. *A. sativum* and *C. zeylanicum* were the least toxic, with LC_{50} values of 13902.704 mg/L and 16177.906 mg/L, respectively. Their TIs remained extremely low (0.017 and 0.015), and although their LC_{50} values decreased slightly from the 24-hour results, the oils still demonstrated limited effectiveness against adult spider mites. This could be due to lower volatility or less penetration ability of the active sulfur and phenolic compounds (Asawalam *et al*., 2007). Overall, all essential oils required significantly higher concentrations to achieve similar levels of mortality compared to synthetic acaricides. However, their eco-friendly nature and lower resistance risk make them promising candidates for integration into pest management programs, especially in greenhouse or organic systems. Yet, their use may be more suitable as repellents or in rotation with synthetic acaricides to delay resistance development, as recommended by Pavela (2015).

Comparative toxicity of acaricides and essential oils to *P. persimilis*

After 24 Hours

The toxicity assessment of four acaricides and four essential oils against *P. persimilis* after 24 hours revealed distinct variations in lethal concentration values, indicating differences in susceptibility and selectivity compared to the target pest, *T. urticae* (Table 3 and Fig. 3).

Table 3. Comparative toxicity of acaricides and essential oils to *P. persimilis* females after 24-hour laboratory exposure.

Treatments	LC_{25} ± 95% CL	LC_{50} ± 95% CL	LC_{90} ± 95% CL	Slope ± SE	Chi^2	T.I.
Emamectin benzoate	1.28 (0.942-1.581)	2.752 (2.327-3.205)	11.88 (9.114-17.451)	2.018±0.217	6.641	100
Chlorfenapyr	10.972 (8.066-13.452)	21.484 (18.42-24.496)	77.02 (60.51-111.87)	2.311±0.282	5.928	12.81
Hexythiazox	116.49 (101.58-128.75)	165.919 (153.17-178.25)	324.92 (289.7-381.61)	4.391±0.442	3.164	1.66
Acequinocyl	135.56 (122.07-146.9)	184.57 (172.72-196.7)	331.74 (299.1-382.41)	5.033±0.474	3.103	1.49
Eucalyptus globulus	3453.14 (2572-4299)	7824.74 (6560-9226)	37023.98 (28126-54417)	1.899±0.188	2.787	0.035
Thymus vulgaris	4715.61 (3623-5763)	10821.8 (9152-12860)	52453.28 (38422-81865)	1.87±0.189	1.525	0.025
Allium sativum	6560.11 (7554-11431)	20054.206 (17272-23412)	81948.395 (61831-122940)	2.096±0.215	1.297	0.014
Cinnamomum zeylanicum	11148.28 (8920-13237)	23535.75 (20248-27784)	97351.09 (71711-152350)	2.078±0.219	1.645	0.012

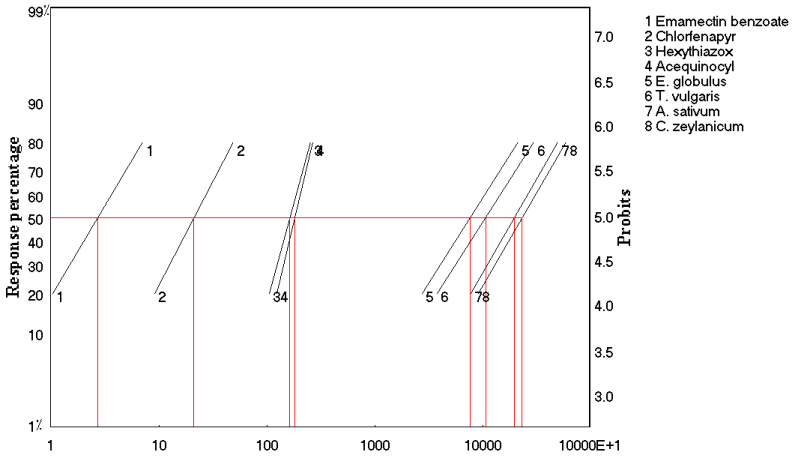

Fig. 3. Comparative toxicity of acaricides and essential oils to *P. persimilis* females after 24-hour laboratory exposure.

Emamectin benzoate exhibited the highest toxicity to the predator, with LC_{50} of 2.75 mg/L, closely comparable to its effect on the red spider mite (LC_{50} = 2.86 mg/L). This suggests limited selectivity of emamectin benzoate, posing

potential risks to natural enemies, as previous studies reported high toxicity of emamectin to phytoseiid predators in laboratory bioassays. Chlorfenapyr showed moderate toxicity to the predator, with LC_{50} = 21.48 mg/L (95% CI: 18.42–24.50), which was slightly lower than its LC_{50} for *T. urticae* (23.65 mg/L), indicating poor selectivity. Although both chlorfenapyr and emamectin benzoate exhibited low selectivity and posed significant risks to *P. persimilis*, chlorfenapyr appeared to be even more hazardous due to its relatively higher toxicity to the predator compared to the pest. This highlights its inferior selectivity profile relative to emamectin benzoate. The acaricides hexythiazox and acequinocyl demonstrated substantially reduced toxicity to *P. persimilis*, with LC_{50} values of 165.92 mg/L and 184.57 mg/L respectively, which are approximately 1.3 times higher than those observed for the pest mites (hexythiazox LC_{50} = 136.754 mg/L; acequinocyl LC_{50} = 151.714 mg/L). The corresponding toxicity indices (1.66 and 1.49) reflect improved selectivity, suggesting these compounds may be safer for IPM programs involving predatory mites.

Regarding essential oils, all tested oils showed significantly lower toxicity to the predator compared to chemical acaricides. *E. globulus* oil had an LC_{50} of 7,824.74 mg/L (95% CI: 6,560–9,226), markedly higher than the corresponding LC_{50} for *T. urticae* (6,627.56 mg/L). Similarly, *T. vulgaris*, *A. sativum*, and *C. zeylanicum* oils demonstrated low toxicity levels, consistent with their low T.I. values (≤ 0.035). The differences in slope values also suggest variation in population heterogeneity and response sensitivity among treatments. For example, emamectin benzoate and chlorfenapyr exhibited relatively steep slopes (2.0–3.6), indicating a more uniform response, whereas oils displayed lower slope values (1.8–2.1), suggesting more variable susceptibility within the predator populations. Overall, the selectivity pattern indicates that hexythiazox and acequinocyl acaricides and essential oils, particularly eucalyptus and thymus oils, are potentially compatible with biological control agents such as predatory mites. This selectivity is crucial for sustainable IPM programs aiming to minimize non-target impacts, as noted by Desneux *et al*. (2007) who stressed the importance of selective pesticides to conserve natural enemy populations.

In contrast, the high toxicity of emamectin benzoate and chlorfenapyr to both pests and predators emphasizes the need for cautious application timing and possibly avoiding its use when natural enemies are active in the crop ecosystem.

After 48 Hours of Exposure

After 48 hours of exposure (Table 4 and Fig. 4), emamectin benzoate exhibited the highest toxicity to the predatory mite, with an LC_{50} value of 2.524 mg/L (95% CI: 2.148–2.912), closely followed by chlorfenapyr with an LC_{50} of 18.215 mg/L (95% CI: 8.387–25.63).

Table 4. Comparative toxicity of selected acaricides and essential oils to *P. persimilis* females after 48-hour laboratory exposure.

Treatment	LC_{25} ± 95% CL	LC_{50} ± 95% CL	LC_{90} ± 95% CL	Slope ± SE	Chi^2	T.I.
Emamectin benzoate	1.25 (0.946-1.527)	2.524 (2.148-2.912)	9.61 (7.672-13.185)	2.206±0.222	6.765	100
Chlorfenapyr	9.85 (2.179-15.94)	18.215 (8.387-25.63)	58.58 (55.21-78.11)	2.526±0.287	7.193	13.86
Hexythiazox	102.24 (86.79-114.27)	144.145 (131.73-155.69)	276.83 (244.58-333.53)	4.522±0.539	1.5	1.75
Acequinocyl	119.29 (106.36-130.13)	161.667 (150.46-172.41)	288.038 (262.53-326.05)	5.109±0.469	7.307	1.56
Eucalyptus globulus	2837.13 (2119-3526)	5970.327 (4995-6989)	24544.24 (19533-33436)	2.087±0.198	4.817	0.042
Thymus vulgaris	3409.68 (2509-3274)	7927.779 (6619-9387)	39392.74 (29540-59210)	1.841±0.186	3.708	0.032
Allium sativum	7674.47 (5977-9256)	15686.837 (13477-18126)	61021.56 (47815-85851)	2.172±0.214	2.699	0.016
Cinnamomum zeylanicum	8671.16 (6935-10291)	17009.9 (14762-19533)	61194.24 (48526-84356)	2.305±0.22	2.783	0.0015

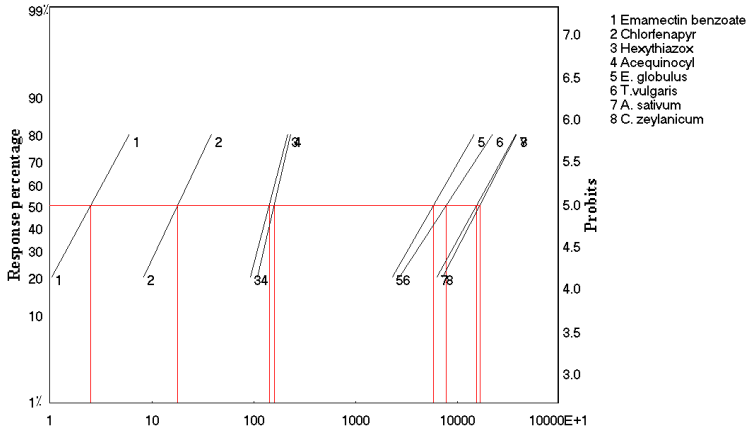

Fig. 4. Comparative toxicity of acaricides and essential oils to *P. persimilis* females after 48-hour laboratory exposure.

The other acaricides, hexythiazox and acequinocyl, showed significantly lower toxicity with LC_{50} values of 144.145 mg/L and 161.667 mg/L, respectively. Among the tested essential oils, *E. globulus* showed the highest toxicity

to *P. persimilis*, with an LC_{50} value of 5970.33 mg/L after 48 hours. In contrast, *T. vulgaris*, *A. sativum*, and *C. zeylanicum* exhibited significantly lower toxicity levels, with LC_{50} values ranging from approximately 7900 to 17000 mg/L. These results indicate that, although all tested oils were relatively safe compared to synthetic acaricides, *E. globulus* was the most harmful to the predatory mite among them.

When compared to the 24-hour exposure data, a slight decrease in LC_{50} values for emamectin benzoate (from 2.752 mg/L to 2.524 mg/L) and chlorfenapyr (from 21.484 mg/L to 18.215 mg/L) indicates an increasing toxicity trend over time. This time-dependent increase in toxicity aligns with previous findings by Elzen *et al*. (2001) who observed that prolonged exposure to these acaricides can amplify adverse effects on predatory mite populations. Conversely, the LC_{50} values for the oils remained relatively stable or slightly decreased, suggesting that their mode of action causes minimal cumulative harm, which supports studies by Isman (2006) and Regnault-Roger *et al*. (2012) who reported the safer profile of essential oils on beneficial arthropods.

The toxicity index (T.I.) values further emphasize the difference in selectivity; emamectin benzoate was set as the reference with 100, while chlorfenapyr had a T.I. of 13.86, showing moderate risk to the predator. In contrast, hexythiazox, acequinocyl, and all tested oils displayed T.I. values below 2, reflecting relatively low acute toxicity. This selectivity is crucial in IPM programs, where conservation of natural enemies like predatory mites is essential for sustainable mite control. The slope values and chi-square tests indicated acceptable model fits, suggesting reliable dose–response relationships. However, the wide confidence intervals in some oil treatments underscore variability possibly due to their complex chemical composition and volatility (Isman, 2000). These results highlight the importance of considering both chemical and essential oiles acaricides' differential impacts when selecting acaricides in mite management strategies, balancing effective pest control and predator safety.

CONCLUSION

This study demonstrated significant variation in the toxicity and selectivity of tested synthetic acaricides and essential oils against *T. urticae* and its predatory mite *P. persimilis*. Emamectin benzoate and chlorfenapyr were the most effective against *T. urticae*, but their low selectivity poses a high risk to beneficial mites. In contrast, hexythiazox and acequinocyl showed moderate acaricidal activity with higher selectivity, making them more compatible with IPM programs. Among essential oils, eucalyptus and thyme oils exhibited promising acaricidal effects, though at higher concentrations, while garlic and cinnamon oils were less effective. The findings highlight the importance of selecting control agents that not only suppress pest populations but also preserve natural enemies. Therefore, incorporating selective synthetic acaricides and essential oils alternatives could enhance the sustainability of mite management strategies under laboratory and potentially field conditions.

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السمية المقارنة لبعض المبيدات الأكاروسية والزيوت العطرية ضد العنكبوت الأحمر ذو البقعتين *Tetranychus urticae* والمفترس *Phytoseiulus persimilis* تحت الظروف المعملية

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الملخص

أُجريت دراسة معملية لتقييم السمية الحادة لأربعة مبيدات أكاروسية هي: إيمامكتين بنزوات(emamectin benzoate) ، كلورفينابير(chlorfenapyr) ، هيكسيثيازوك (hexythiazox)، وأسكوينوكيل (acequinocyl) ، بالإضافة إلى أربعة زيوت عطرية هي: زيت الكافور(*Eucalyptus globulus*) ، زيت الزعتر(*Thymus vulgaris*) ، زيت الثوم(*Allium sativum*) ، وزيت القرفة (*Cinnamomum zeylanicum*) ، وذلك ضد العنكبوت الأحمر ذي البقعتين *Tetranychus urticae* والمفترس *Phytoseiulus persimilis*، بعد مرور ٢٤ و٤٨ ساعة من التعرض. أظهر المبيد الكيميائي إيمامكتين بنزوات أعلى سمية في كلا التوقيتين، حيث سجل أقل قيم للـ LC_{50} (٢,٨٦ و ٢,٤٢ ملجم/لتر على التوالي). تبعه مبيد كلورفينابير في السمية. أما هيكسيثيازوك وأسكوينوكيل فقد أظهرا سمية منخفضة بعد ٢٤ ساعة، إلا أن فعاليتهما تحسنت بشكل طفيف بعد ٤٨ ساعة، مما يعكس آلية تأثيرهما البطيئة على الأطوار البالغة. من بين الزيوت العطرية، أظهر زيت الكافور أعلى سمية يليه زيت الزعتر، رغم أن كلاهما تطلب تركيزات أعلى بكثير مقارنة بالمبيدات الاكاروسية. أما زيت الثوم وزيت القرفة فقد أظهرا نشاطًا أكاروسيًا ضعيفًا. أظهرت دراسات السمية المقارنة على المفترس الحيوي *P. persimilis* أن مبيدي إيمامكتين بنزوات وكلورفينابير يتمتعان بانتقائية منخفضة، حيث تسببا في معدلات موت مرتفعة وسجلت لهما قيم LC_{50} منخفضة على المفترس. في المقابل، أظهر كل من هيكسيثيازوك وأسكوينوكيل انتقائية أعلى وكانا أكثر أمانًا على المفترس الحيوي. تبرز هذه النتائج إمكانية دمج المبيدات الانتقائية والزيوت النباتية ضمن برامج الإدارة المتكاملة للآفات (IPM) ، مع التأكيد على ضرورة تحقيق توازن بين الكفاءة ضد *T. urticae* وسلامة الكائنات النافعة.