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EVALUATION OF FIVE ACARICIDES AND THREE ESSENTIAL OILS AGAINST THE TWO-SPOTTED SPIDER MITE, *TETRANYCHUS URTICAE* KOCH (ACARI: TETRANYCHIDAE) UNDER LABORATORY CONDITIONS

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ABSTRACT: The toxicological effects of five acaricides (Abamectin, Cyflumetofen, Fenpyroximate, Ethoxazole, and Bifenazate) and three essential oils (Neem, Peppermint, and Clove) were evaluated against adult females and immature stages of Tetranychus urticae (Acari: Tetranychidae) under controlled laboratory conditions. The results revealed that synthetic acaricides exhibited superior acute toxicity compared to essential oils at 24 and 48 hours post-treatment. Abamectin consistently showed the highest toxicity across all life stages and time points, with the lowest LC_{50} values of 0.85 and 0.654 ppm for adult females, and 0.739 and 0.625 ppm for larvae at 24 and 48 hours, respectively, indicating rapid and potent acaricidal action. Both Cyflumetofen and Fenpyroximate showed steep dose-response slopes and enhanced efficacy over time. Essential oils were significantly less effective, with Neem oil being the most potent among them, with LC_{50} values above 5000 ppm. All treatments exhibited time-dependent increases in toxicity, especially among botanical extracts. These findings suggest that while synthetic acaricides are more effective for rapid mite control, essential oils may contribute to long-term integrated pest management strategies due to their lower toxicity and environmental compatibility. This comparative analysis provides a basis for selecting appropriate agents based on the target stage and required speed of action in *T. urticae* management programs.

Keywords: *Tetranychus urticae*, acaricides, essential oils, laboratory bioassay, integrated pest management

INTRODUCTION

The two-spotted spider mite (*Tetranychus urticae* Koch) is a cosmopolitan and economically destructive pest that attacks a broad range of crops, including vegetables, fruit trees, ornamentals, and field crops (Pavela *et al.* 2016, Kim *et al.* 2021). It is estimated to infest more than 1,100 plant species globally, making it one of modern agriculture's most significant polyphagous pests. The mite causes damage by feeding on the contents of mesophyll cells through piercing-sucking mouthparts, leading to reduced photosynthetic capacity, chlorosis, leaf bronzing, and ultimately, premature senescence and defoliation (Grbić *et al.*, 2011; Van Leeuwen *et al.*, 2010; Jonckheere *et al.*, 2016). Infestations under favorable environmental conditions (such as warm temperatures and low relative humidity) can develop rapidly due to the mite's short developmental cycle, high reproductive rate, and ability to reproduce parthenogenetically (Van Leeuwen and Tirry, 2007). A major challenge in managing *T. urticae* is its exceptional adaptability and capacity to develop resistance to nearly every class of acaricides introduced, including organophosphates, pyrethroids, carbamates, avermectins, and ketoenols (Stumpf and Nauen, 2002; Dermauw *et al.*, 2013; Van Pottelberge *et al.*, 2009; Kim *et al.*, 2021). While effective in the short term, synthetic acaricides are becoming less reliable due to increasing

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resistance levels and the potential for environmental and ecological harm. Overusing and often misusing these chemicals not only accelerates resistance evolution but also results in harmful residues on crops, negative impacts on pollinators and natural enemies, and regulatory constraints on chemical applications (Bielza, 2020; Sparks and Nauen, 2015). In response to these concerns, recent decades have witnessed a growing emphasis on alternative and sustainable control strategies such as biopesticides and plant-derived essential oils. Biopesticides, including those derived from microbial fermentation products (e.g., *Streptomyces avermitilis* producing abamectin), offer eco-friendly alternatives with specific modes of action, short residual effects, and compatibility with integrated pest management (IPM) programs (Copping and Menn, 2000; Campos *et al*., 2022; Isman, 2020). For instance, in several laboratory and field studies, abamectin and spinosad, both considered bio-rational insecticides, have shown efficacy against T. urticae (Abo-Arab *et al*., 2020; Khan *et al*., 2022).

Another promising category of alternatives is essential oils, which are volatile aromatic compounds extracted from medicinal or aromatic plants such as clove (*Syzygium aromaticum*), neem (*Azadirachta indica*), and peppermint (*Mentha piperita*). These oils exhibit acaricidal activity through multiple mechanisms, including neurotoxicity, fumigation, disruption of hormonal balance, and cuticular damage (Regnault-Roger *et al.*, 2012; Pavela and Benelli, 2016; Benelli *et al.*, 2018). Unlike synthetic insecticides, essential oils are biodegradable and rapidly decompose, making them well-suited for organic farming systems. Additionally, their complexity and mixture of active compounds reduce the likelihood of resistance development in pest populations (Isman, 2020). Despite the growing popularity of essential oils and biopesticides, their comparative performance against synthetic acaricides under standardized laboratory conditions remains underexplored. A detailed comparison of their toxicity levels, such as LC_{50} values, is essential to assess their real potential and practical application. Laboratory bioassays using leaf dip or spraying techniques offer a reliable framework for evaluating initial toxicological profiles, which can be validated in greenhouse or field environments (Van Leeuwen *et al.*, 2005). Given the urgent need for sustainable pest control options, this study was designed to evaluate and compare the acaricidal effectiveness of five compounds representing different chemical groups (including one biopesticide) and three essential oils (clove, neem, and peppermint) against *T. urticae* under controlled laboratory conditions. The aim is to determine the most promising candidates for inclusion in integrated pest management (IPM) strategies, reduce dependency on synthetic acaricides, and support the transition to safer and more environmentally sound pest control methods.

MATERIALS AND METHODS

Source and rearing of *T. urticae*

This study used a laboratory strain of the two-spotted spider mite T. urticae. Mites were originally collected from castor bean plants (Ricinus communis) in the Beheira Governorate, Egypt. The colony was established and maintained under controlled laboratory conditions (25 ± 2°C, 65 ± 5% RH, and a photoperiod of 16:8 L:D) at the Faculty of Agriculture, Benha University. The strain had no known prior exposure to acaricides and was maintained for several generations on unsprayed castor bean leaves to ensure sensitivity.

Tested acaricides and essential oils

Five acaricides from distinct chemical groups and three essential oils were selected for laboratory evaluation against both larval and adult female stages of *T. urticae*. These products included one biopesticide, four conventional synthetic acaricides, and three botanical oils commonly available in the Egyptian market.

Table 1. Tested acaricides and essential oils with chemical and trade information

Trade Name	Active Ingredient	Chemical Group	Type	Supplier
Vertimec® 1.8% EC	Abamectin	Avermectins	Biopesticide	Novartis Agro,. Swithzerland
Ortus® 5% SC	Fenpyroximate	METI acaricides	Chemical	Shura Company, Egypt.
Danisaraba® 24% SC	Cyflumetofen	Benzoyl acetonitrile	Chemical	Otsuka AgriTechno Co., Ltd.
Acramite® 48% SC	Bifenazate	Carbazate acaricides	Chemical	Shura Company, Egypt.
Baroque® 10% SC	Ethoxazole	Oxazoline derivatives	Chemical	Agrimatco Co,Egypt

Preparation of Concentrations

Each tested pesticide and essential oil was applied in five serial concentrations**,** selected based on preliminary range-finding assays to ensure measurable mortality between 0% and 100%. The concentrations were prepared using distilled water as a diluent for chemical pesticides, and 0.1% Tween-80 was added as an emulsifier for essential oils to improve solubility and dispersion. The synthetic pesticides and biopesticides were formulated at different concentrations as detailed below: Fenpyroximate and Ethoxazole were prepared at concentrations of 10, 20, 40, 60, and 100 ppm; Abamectin was prepared at 0.25, 0.5, 1, 1.5, and 2 ppm; Cyflumetofen was prepared at 1, 2, 4, 6, and 10 ppm; and Bifenazate was prepared at 20, 40, 60, 80, and 100 ppm. Essential oils were prepared at 0.25%, 0.5%, 1%, 2%, and 5% (v/v) or 2500, 5000, 10000, 20000, and 50000 ppm (for neem oil, and 10000, 20000, 50000, 75000, and 100000 (1, 2, 5, 7.5 and 10 %) for clove and peppermint oils, respectively. All solutions were freshly prepared just before application to ensure stability.

Bioassay Procedure

Leaf Disc Dipping Method

The leaf dip bioassay was adopted to evaluate each treatment's toxic effects following IRAC standard methods (IRAC Method No. 003). Fresh castor bean leaves were cut into discs (2.5 cm in diameter), and each disc was individually immersed in the test solution for 5 to 10 seconds, ensuring full submersion.

Treated discs were allowed to air dry for 30–45 minutes on sterile tissue paper at room temperature before being placed on moist cotton pads inside 9-cm diameter Petri dishes.

Mite Transfer and Experimental Design

After drying, twenty individuals of *T. urticae* (either larvae or adult females, depending on the test) were carefully transferred onto each leaf disc using a fine camel hairbrush. Each concentration for each treatment was replicated four times (n = 4), and separate experiments were conducted for larvae and adult females to evaluate stage-specific susceptibility. A completely randomized design (CRD) was followed for the experiment. Control treatments were prepared using only distilled water (with 0.1% Tween-80 for essential oils). Petri dishes were incubated at 25 ± 2°C**,** 65 ± 5% RH, and 16:8 h light: dark cycle throughout the bioassay period.

Mortality Assessment and Toxicity Indices

Mortality was assessed at 24 and 48 hours post-treatment. Individuals were considered dead if they failed to respond to gentle probing with a fine brush. Corrected mortality values were calculated using Abbott's formula (Abbott, 1925) to account for natural death in the control group:

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

where T = mortality in treatment group, C = mortality in control

Lethal concentrations (LC_{50}, LC_{25}, and LC_{90}) and their 95% confidence intervals, along with slope values, were calculated using LdP-Line software (Ehab Software, http://www.ehabsoft.com/ldpline/), following the method of Finney (1971). In addition, Toxicity Index (TI) values were calculated following Sun (1950) to compare relative toxicity among treatments:

TI = (LC_{50} of most toxic compound / LC_{50} of tested compound) × 100

RESULTS

Toxicity of selected acaricides and essential oils against adult females of *T. urticae* under laboratory conditions

The toxicity of the tested acaricides and essential oils after 24 hours

The toxicity of tested acaricides and essential oils against adult females of *T. urticae* 24 hours post-treatment is presented in Table 2 and Fig. 1. The obtained data revealed substantial variability in the effectiveness of the tested compounds, as evidenced by the estimated LC_{50} values and their respective confidence limits. Abamectin exhibited the highest toxicity with an LC_{50} of 0.85 ppm (95% CL: 0.729–0.99). Its steep slope (2.042 ± 0.221) suggests a consistent mortality response across concentrations, indicating a high level of homogeneity in mite susceptibility. The relatively low chi-square value (X^2 = 5.446) confirms a good fit of the probit model, followed by cyflumetofen, which recorded an LC_{50} of 3.9 ppm (CL: 3.354–4.56), demonstrating notable toxicity and a steep slope (2.074 ± 0.213). Fenpyroximate ranked third in toxicity with an LC_{50} of 26.786 ppm (CL: 22.752–31.06). Ethoxazole, with LC_{50} of 33.324 ppm (CL: 29.05–38.07), displayed moderate acaricidal activity. Ethoxazole is known to act as a growth regulator and chitin synthesis inhibitor, which may partly explain its reduced efficacy against adults compared to juveniles (Kwon *et al.*, 2013). This reinforces the need to target earlier stages when using such compounds. Bifenazate, a carbazate acaricide, showed relatively low toxicity with an LC_{50} of 55.174 ppm (CL: 49.25–61.76). Though widely used for its dual activity on eggs and adults, this result suggests a comparatively lower efficacy in short-term exposure scenarios against adult females. The slope (2.771 ± 0.306) indicates a steep mortality gradient with increasing concentration.

Table 2. Toxicity of selected acaricides and essential oils against adult females of *T. urticae* after 24 hours of exposure under laboratory conditions.

Treatment	LC_{25} (ppm) (95% CL)	LC_{50} (ppm) (95% CL)	LC_{90} (ppm) (95% CL)	Slop ± SE	X^2	TI
Fenpyroximate	12.918 (9.79-15.84)	26.786 (22.752-31.06)	107.078 (84.43-149.22)	2.13±0.212	1.017	3.17
Abamectin	0.397 (0.304-0.483)	0.85 (0.729-0.99)	3.61 (2.72-5.48)	2.042±0.221	5.446	100
Ethoxazole	17.502 (14.14-20.64)	33.324 (29.05-38.07)	113.281 (91.19-152.35)	2.412±0.224	1.309	2.55
Bifenazate.	31.499 (25.8-36.37)	55.174 (49.25-61.76)	160.063 (129.3-219.77)	2.771±0.306	4.63	1.54
Cyflumetofen	1.845 (1.449-2.214)	3.9 (3.354-4.56)	16.177 (12.2-24.31)	2.074±0.213	3.676	21.79
Neem oil	3318 (2401-4223)	8269.193 (6806-9949)	20606 (16599-72967)	1.701±0.17	0.061	0.01
Peppermint oil	20061 (15464-24395)	44787.97 (38105-52900)	206020 (15179-320700)	1.934±0.201	5.503	0.0019
Clove oil	23773 (18612-28643)	53083.967 (45184-63358)	244250 (175670-397260)	1.933±0.207	5.247	0.0016

TI: Toxicity index; X^2: Chi-square; CL: Confidence Limit

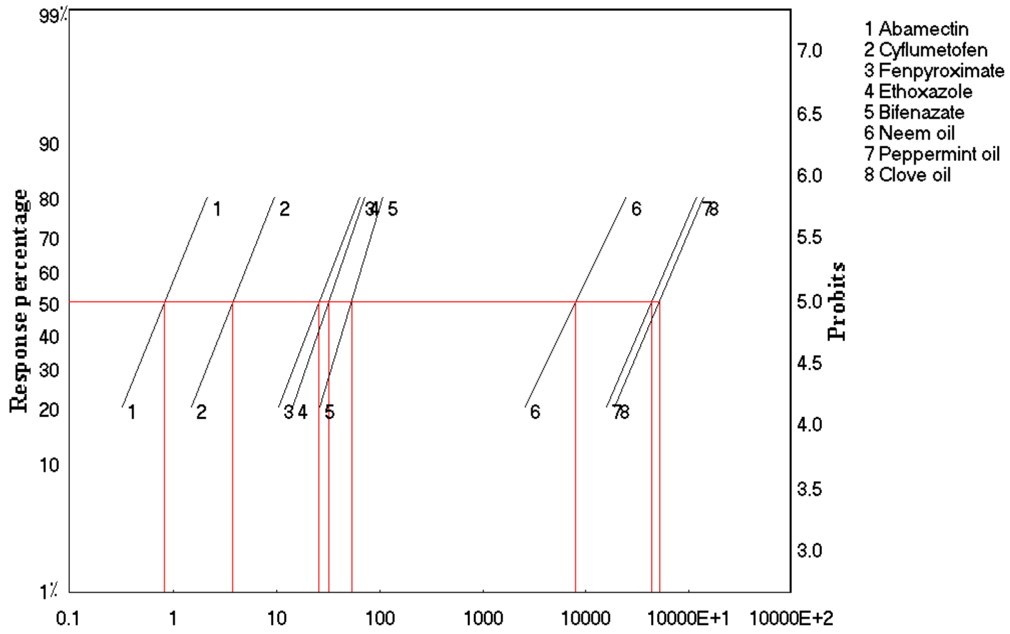

Figure 1. Toxicity lines of the tested pesticides and essential oils against adult females of *T. urticae* after 24 hours of exposure.

In contrast, essential oils exhibited significantly higher LC_{50} values, reflecting much lower acaricidal potency within 24 hours of exposure. Neem oil showed the highest efficacy among the three oils, with an LC_{50} of 8269.193 ppm (CL: 6806–9949). However, their slow-acting nature and physical properties may limit acute toxicity. Peppermint and Clove oils had LC_{50} values of 44787.97 ppm and 53083.967 ppm, respectively.

Toxicity of tested acaricides and essential oils after 48 hours

The toxicological assessment of the tested substances after 48 hours of exposure to adult *T. urticae* females (Table 3 and Fig. 2) indicates an overall enhancement in efficacy across all treatments compared to the 24-hour data. This temporal increase in toxicity is evident through the reduced LC_{50} values for all synthetic acaricides and essential oils, signifying a time-dependent mortality effect.

Once again, Abamectin proved to be the most potent treatment with an LC_{50} of 0.654 ppm (95% CL: 0.552–0.76), slightly lower than its 24-hour value. The slope (2.046 ± 0.218) and chi-square value (X^2 = 7.076) indicate a strong and consistent dose-response relationship. The slight decrease in LC_{50} reflects cumulative toxicity over time. Cyflumetofen, a mitochondrial complex II inhibitor, also showed improved performance, with an LC_{50} of 2.946 ppm (CL: 2.5–3.43), down from 3.9 ppm at 24 hours. Its effectiveness remained robust, characterized by a slope of 2.03 ± 0.208. The relatively sharp dose-response suggests this compound maintains a high lethality over time. Fenpyroximate also exhibited enhanced toxicity with an LC_{50} of 19.925 ppm (CL: 16.68–23.22), a significant drop from its 24-hour value. The slope value (2.275 ± 0.269) supports an increasingly effective kill rate at rising concentrations. As a METI acaricide, its action on mitochondrial complex I may require time to cause energy depletion, explaining the improved results after 48 hours.

Similarly, Ethoxazole (with an LC_{50} of 25.336 ppm) showed improved activity compared to 33.324 ppm at 24 hours. The slope

(2.493 ± 0.224) indicates a stable toxic response. This improvement suggests that its mode of action, possibly involving chitin synthesis inhibition and other physiological disruptions, becomes more pronounced over time, even in adults where it is typically less effective than in juveniles.

Bifenazate displayed moderate improvement with an LC_{50} of 44.465 ppm (CL: 39.15–49.76), down from 55.174 ppm. Though it remains less potent than the other synthetic acaricides, it maintained a strong slope (2.757 ± 0.295), indicating reliable performance at higher concentrations. Known for its rapid knockdown and long residual action, Bifenazate's delayed but increasing effectiveness supports its inclusion in longer-acting treatment regimes.

Regarding essential oils, all tested oils showed improved efficacy after 48 hours of exposure; however, their toxicity remained significantly lower compared to the synthetic insecticides. Neem oil stood out again among the oils with a considerably reduced LC_{50} of 5848.924 ppm (CL: 4775–6988), indicating time-dependent toxicity. The slope (1.845 ± 0.184) remains shallower than the synthetics, but the trend affirms its multi-modal effects, including antifeedant, oviposition deterrent, and hormonal disruption, which may intensify with prolonged exposure. Peppermint oil and Clove oil also showed improved toxicity, with LC_{50} values of 34405.065 ppm and 37609.884 ppm, respectively. Although the magnitude of their LC_{50} values still indicates weak acute toxicity, the temporal improvement is noteworthy. The slope values (1.98 and 2.099) suggest more defined mortality curves. Essential oils' volatility and lipophilic penetration may take time to disrupt physiological processes such as respiration or enzyme regulation.

Table 3. Toxicity of selected acaricides and essential oils against adult females of *T. urticae* after 48 hours of exposure under laboratory conditions.

Treatment	LC_{25} (ppm) (95% CL)	LC_{50} (ppm) (95% CL)	LC_{90} (ppm) (95% CL)	Slop ± SE	X^2	TI
Fenpyroximate	10.066 (7.3-12.53)	19.925 (16.68-23.22)	72.917 (56.97-105.57)	2.275±0.269	0.97	3.28
Abamectin	0.306 (0.226-0.38)	0.654 (0.552-0.76)	2.766 (2.144-3.991)	2.046±0.218	7.076	100
Ethoxazole	13.59 (10.8-16.2)	25.336 (21.91-28.91)	82.74 (68.28-106.9)	2.493±0.224	4.408	2.58
Bifenazate.	25.31 (20.13-29.78)	44.465 (39.15-49.76)	129.672 (107.4-170.28)	2.757±0.295	7.565	1.47
Cyflumetofen	1.371 (1.03-1.69)	2.946 (2.5-3.43)	12.605 (9.702-18.31)	2.03±0.208	6.309	22.2
Neem oil	2520 (1791-3234)	5848.924 (4775-6988)	28961.137 (22171-41.939)	1.845±0.184	2.164	0.011
Peppermint oil	15699 (11881-19321)	34405.065 (29116-40276)	152760 (117030-222130)	1.98±0.196	7.506	0.0019
Clove oil	17944 (7501-24040)	37609.884 (22793-59052)	153440 (119200-515120)	2.099±0.202	7.437	0.0017

TI: Toxicity index; X^2: Chi-square; CL: Confidence Limit

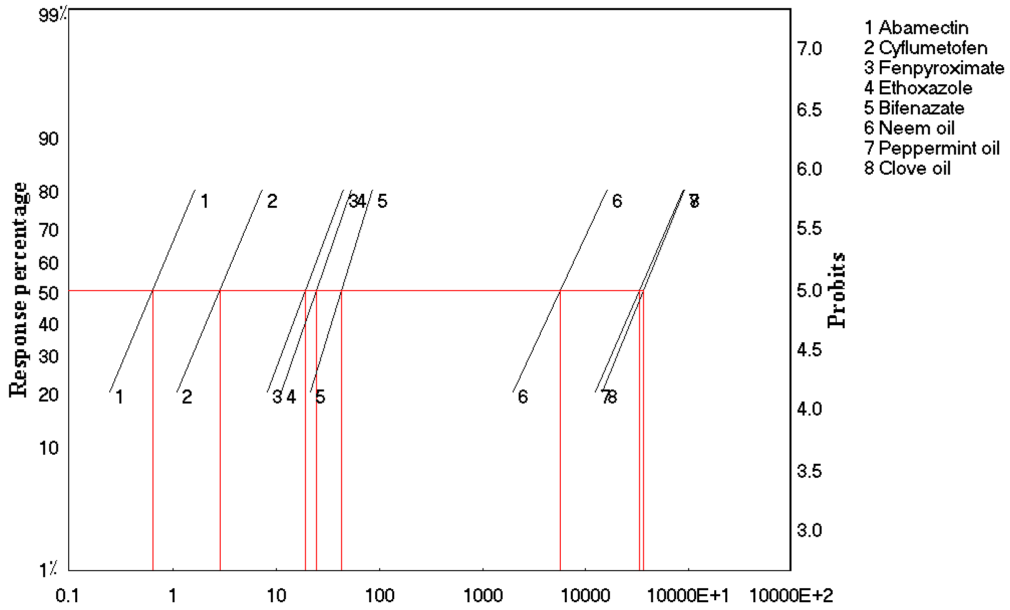

Figure 2. Toxicity lines of the tested pesticides and essential oils against adult females of ***T. urticae*** **after 48 hours of exposure.**

Toxicological assessment of tested treatments against *T. urticae* larvae after 24 hours

The larval toxicity bioassay after 24 hours (Table 4 and Fig. 3) revealed substantial differences in the effectiveness of the evaluated insecticides and oils. Based on LC_{50} values, Abamectin was the most potent treatment, with an LC_{50} of only 0.739 ppm, indicating high larvicidal activity at a very low concentration. This was followed by Cyflumetofen (LC_{50} = 3.434 ppm) and Ethoxazole (LC_{50} = 17.966 ppm), both showing relatively strong activity against the immature stages. These three compounds had steep slope values (2.207, 2.024, and 2.495, respectively), which suggests a consistent toxic response across the treated larval populations. Fenpyroximate displayed moderate toxicity, with an LC_{50} of 22.281 ppm, higher than the above compounds but still significantly lower than Bifenazate and the tested oils. The slope (2.204 ± 0.217) indicates a clear dose-response relationship, and the Chi-square (X^2 = 3.169) suggests an acceptable fit of the probit model. Bifenazate, while generally regarded as an acaricide with ovicidal and adulticidal properties, was less effective against larvae in this study (LC_{50} = 41.587 ppm). However, it exhibited the steepest slope (3.5 ± 0.322), reflecting a highly predictable effect as the dose increases.

Among the essential oils, Neem oil was the most effective larvicidal oil (LC_{50} = 6882.447 ppm), followed by Peppermint oil (LC_{50} = 32122.418 ppm) and Clove oil (LC_{50} = 46906.038 ppm). These high LC_{50} values underscore essential oils' significantly lower efficacy than synthetic pesticides. However, their use may still be justified in integrated pest management (IPM) programs due to their low toxicity to non-target organisms and environmental safety. The relatively narrow 95% confidence limits for most compounds, especially for Abamectin and Cyflumetofen, confirm the statistical robustness of the data. Conversely, wider intervals in oils, particularly for Clove oil (28,481–84,513 ppm), reflect greater variability in their bioactivity, possibly due to volatility or inconsistent larval penetration.

Table 4. Toxicity of selected acaricides and essential oils against the larval stage of *T. urticae* after 24 hours of exposure under laboratory conditions.

Treatment	LC_{25} (ppm) (95% CL)	LC_{50} (ppm) (95% CL)	LC_{90} (ppm) (95% CL)	Slop ± SE	X^2	TI
Fenpyroximate	11.012 (8.25-13.61)	22.281 (18.76-25.86)	85.001 (68.51-114.27)	2.204±0.217	3.169	3.32
Abamectin	0.366 (0.283-0.442)	0.739 (0.636-0.851)	2.815 (2.22-3.95)	2.207±0.223	7.623	100
Ethoxazole	9.641 (7.159-11.863)	17.966 (15.12-2078)	58.627 (47.482-79.45)	2.495±0.28	4.24	4.11
Bifenazate.	26.684 (22.42-30.42)	41.587 (37.31-45.75)	96.629 (84.68-115.16)	3.5±0.322	7.294	1.78
Cyflumetofen	1.594 (1.224-1.939)	3.434 (2.934-4.01)	14.754 (11.17-22.01)	2.024±0.209	5.708	21.52
Neem oil	2864 (2066-3654)	6882.447 (5654-8222)	36400 (27568-53333)	1.772±0.17	0.502	0.011
Peppermint oil	13300 (9469-16949)	32122.418 (26593-38220)	171570 (126060-268890)	1.761±0.19	7.217	0.002
Clove oil	20482 (7507-27820)	46906.038 (28481-84513)	226440 (184670-1356000)	1.874±0.2	7.363	0.0016

TI: Toxicity index; X^2: Chi-square; CL: Confidence Limit

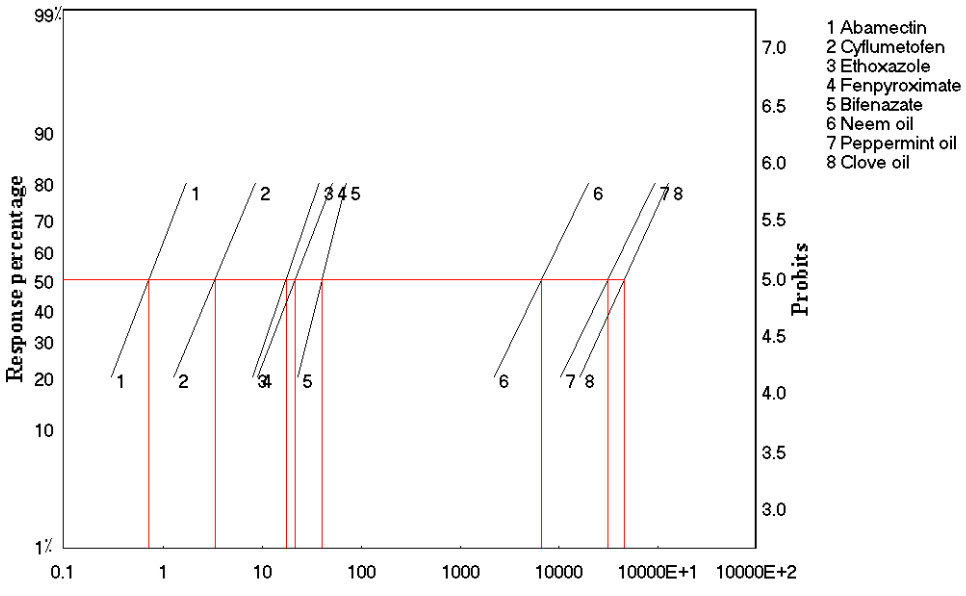

Figure 3. Toxicity lines of the tested pesticides and essential oils against larvae of *T. urticae* **after 24 hours of exposure.**

Larvicidal toxicity of the tested treatments against *T. urticae* after 48 hours

After 48 hours of exposure, the larval response to the tested pesticides and oils (Table 5 and Fig. 4) confirmed several patterns observed at 24 hours, with some shifts in toxicity ranking and improved efficacy in specific treatments due to prolonged exposure. Abamectin remained the most potent treatment, with a remarkably low

LC_{50} of 0.625 ppm, slightly lower than the 24-hour value (0.739 ppm). This consistency across time intervals confirms its fast and sustained toxicity against immature stages. Although the slope (1.778 ± 0.256) is slightly less steep than at 24 h, it still indicates a strong dose-response relationship. The narrow 95% confidence limits and low chi-square value (χ^2 = 0.616) further emphasize data reliability. Cyflumetofen exhibited substantial toxicity (LC_{50} = 2.705 ppm), improving from the previous 3.434 ppm after 24 hours. This compound demonstrates both fast action and enhanced efficacy with time. Its slope (1.997 ± 0.207) also remained consistent, confirming a reliable effect. Ethoxazole also performed better at 48 hours (LC_{50} = 14.445 ppm) compared to 17.966 ppm at 24 hours. However, the confidence intervals for LC_{50} seem inconsistent or possibly misreported (21.91–16.82), which should be double-checked. Still, the improved toxicity and strong slope (2.584 ± 0.281) indicate high effectiveness over time. Fenpyroximate demonstrated increased toxicity at 48 h with an LC_{50} of 17.111 ppm (down from 22.281 ppm at 24 h). The slope (2.291 ± 0.274) and low χ^2 value indicate good model fit and consistent response. It ranks as moderately effective. Bifenazate, traditionally more adulticidal than larvicidal, maintained a relatively high LC_{50} (38.394 ppm), only slightly better than the 24 h value (41.587 ppm). However, it still exhibited the steepest slope (3.75 ± 0.316), reflecting a very sharp dose-response, which may be helpful when higher doses are applied.

Among the essential oils, Neem oil had the best larvicidal effect (LC50 = 4256.442 ppm), significantly better than its 24-hour value (6882.447 ppm). This indicates that time enhances the efficacy of botanical compounds, possibly due to slower penetration or physiological delays in the mites. Peppermint and Clove oils also showed improved toxicity at 48 h. However, the LC_{50} values (31,330.72 ppm and 35,532.807 ppm, respectively) are still several orders of magnitude higher than synthetic insecticides, confirming their limited practical larvicidal effect under laboratory conditions.

Table 5. Toxicity of selected acaricides and essential oils against larval stage of *T. urticae* after 48 hours of exposure under laboratory conditions

Treatment	LC_{25} (ppm) (95% CL)	LC_{50} (ppm) (95% CL)	LC_{90} (ppm) (95% CL)	Slop ± SE	X^2	TI
Fenpyroximate	8.686 (6.114-10.99)	17.111 (14.08-20.05)	62.057 (49.22-87.59)	2.291±0.274	1.701	3.65
Abamectin	0.261 (0.17-0.34)	0.625 (0.511-0.76)	3.286 (2.225-6.39)	1.778±0.256	0.616	100
Ethoxazole	7.919 (5.75-9.89)	14.445 (21.91-16.82)	45.253 (37.82-30.79)	2.584±0.281	4.423	4.33
Bifenazate.	25.374 (21.59-28.74)	38.394 (34.561-42.07)	84.34 (75.37-97.27)	3.75±0.316	7.216	1.63
Cyflumetofen	1.243 (0.92-1.55)	2.705 (2.28-3.16)	11.86 (9.142-17.19)	1.997±0.207	7.077	23.11
Neem oil	1931 (1260-2552)	4256.442 (3382-5113)	19094 (14464-29217)	1.966±0.247	0.967	0.015
Peppermint oil	10228 (5858-14237)	31330.72 (24508-40404)	262870 (151340-720200)	1.387±0.218	2.137	0.002
Clove oil	15457 (11463-19241)	35532.807 (29862-41938)	172770 (128820-263460)	1.866±0.194	5.476	0.0018

TI: Toxicity index; X^2: Chi-square; CL: Confidence Limit

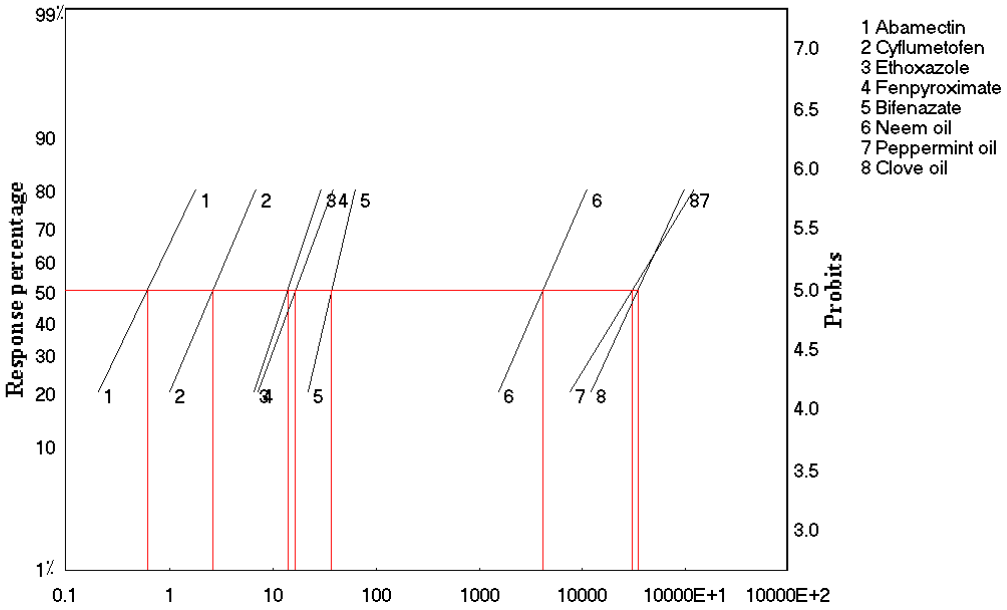

Figure 4. Toxicity regression lines of the tested pesticides and essential oils against larvae of *T. urticae* after 48 hours of exposure.

The toxicity index (TI) values presented in Tables 2-5 provide a comparative measure of the relative toxicity of the tested pesticides and essential oils against *T. urticae* adult females and larvae after 24 and 48 hours. Abamectin consistently exhibited the highest toxicity (TI = 100) across all time points and life stages, indicating its superior efficacy to all other treatments. Cyflumetofen ranked second, showing high toxicity with TI values exceeding 21 in both adults and larvae. Fenpyroximate and Ethoxazole display moderate toxicity, with slightly higher effects on larvae than adults, especially in the case of Ethoxazole, which reached a TI of 4.33 at 48 hours. Bifenazate demonstrated relatively lower toxicity (TI < 2) across all stages. On the other hand, the essential oils (neem, peppermint, and clove) showed minimal toxicity, with TI values below 0.02, indicating a significantly weaker impact compared to chemical pesticides. These results highlight the higher potency of conventional acaricides while suggesting the potential of essential oils as eco-friendly alternatives, albeit with lower effectiveness under laboratory conditions.

Discussion

The results of the toxicological evaluation of selected acaricides and essential oils against *T. urticae* provided insightful data on the relative potency of these treatments under laboratory conditions, 24 and 48 hours of exposure.

At the 24-hour time point, Abamectin demonstrated the highest efficacy, with the lowest LC_{50} value of 0.85 ppm. This result confirms the potent acaricidal activity of Abamectin, which has been extensively documented in the literature (Lasota and Dybas, 1991). The steep slope value (2.042 ± 0.221) indicates a consistent mortality response across different concentrations, suggesting that *T. urticae* females exhibit high susceptibility to this compound. Its neurotoxic mode of action, which involves the activation of chloride channels, leads to paralysis and death of the mite (Lasota and Dybas, 1991), explaining its strong performance in this assay. Cyflumetofen, a mitochondrial complex II inhibitor, also showed promising efficacy, with an LC_{50} value of 3.9 ppm. This aligns with previous studies (Van Pottelberge *et al.*, 2009; Allam *et al.*, 2022), highlighting its role in energy depletion and its potential in resistance management programs. Fenpyroximate, while less potent with an LC_{50} of 26.786 ppm, exhibited a steep dose-response curve, indicating a strong toxic effect at higher concentrations. Ethoxazole and Bifenazate, on the other hand, exhibited lower toxicity, with LC_{50} values of 33.324 and 55.174 ppm, respectively. The lower toxicity of Ethoxazole, known for its role in inhibiting chitin synthesis, might be attributed to its reduced effectiveness against adult stages, which require more direct modes of action (Kwon *et al.,* 2013).

In contrast, essential oils displayed significantly lower acaricidal activity than synthetic acaricides. Neem oil, with an LC_{50} of 8269.193 ppm, showed some promise, but its slower acting nature, as noted by the shallower slope, limits its immediate effectiveness. Peppermint and clove oils, with much higher LC_{50} values, demonstrate the limitations of essential oils under these laboratory conditions. While these oils contain potent monoterpenes, such as menthol and eugenol, which have been reported to exhibit fumigant and contact toxicity (Park *et al.*, 2011; Pavela, 2015), their slow modes of action and poor penetration may have contributed to their reduced efficacy in this study.

At the 48-hour time point, all treatments exhibited enhanced efficacy compared to the 24-hour results. Abamectin maintained its position as the most effective treatment, with a slight decrease in LC_{50}, further confirming its fast and sustained action. The improvement in LC_{50} values for synthetic acaricides such as Cyflumetofen, Fenpyroximate, and Ethoxazole suggests that these compounds may have cumulative effects that increase their potency over time. This finding aligns with the mode of action of these compounds, such as the inhibition of mitochondrial respiration by Fenpyroximate (Van Pottelberge *et al*., 2009) and chitin synthesis inhibition by Ethoxazole (Kwon *et al.*, 2013), which may require a longer exposure period to reach full efficacy.

While synthetic acaricides showed substantial improvements, the essential oils, particularly Neem oil, also demonstrated an increase in efficacy with prolonged exposure. The reduced LC_{50} of Neem oil at 48 hours suggests that its physiological effects, including antifeedant and hormonal disruption (Isman, 2006), may become more pronounced with time. However, despite this improvement, the LC_{50} values for Neem oil and the other essential oils (Peppermint and Clove) are still much higher than those of the synthetic acaricides, reflecting their limited practical application for immediate mite control.

Regarding larvicidal activity, abamectin again proved to be the most potent compound, with the lowest LC_{50} values at 24 and 48 hours. The results from the larval bioassay further highlight the effectiveness of abamectin across both life stages, which is consistent with its neurotoxic mode of action. Cyflumetofen and ethoxazole also showed strong larvicidal effects, indicating that these compounds can effectively target both adult and immature stages of *T. urticae*. Fenpyroximate, while moderately effective against adults, showed weaker activity against larvae, suggesting that its mechanism of action may be less effective in younger stages of the mite.

CONCLUSION

In conclusion, synthetic acaricides like abamectin and cyflumetofen exhibited superior toxicity to both adult and larval stages of T. urticae. However, essential oils, although showing improved efficacy over time, remain less effective in comparison. This reinforces the potential of synthetic acaricides for rapid and effective mite control. At the same time, essential oils could still play a role in integrated pest management (IPM) programs, particularly in reducing the environmental impact and toxicity to non-target organisms. Future studies should focus on optimizing the application conditions and exploring combinations of these treatments to enhance their efficacy and sustainability in pest management.

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التقييم المعملي لفعالية خمس مبيدات اكاروسية من مجموعات كيميائية مختلفة وثلاثة زيوت عطرية ضد العنكبوت الأحمر ذو البقعتين *Tetranychus urticae* Koch

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الملخص العربي

هدفت هذه الدراسة إلى تقييم فعالية سمية خمس من المبيدات الأكاروسية (أبامكتين، سيفلوميتوفين، فينبايروكسيمايت، إيثوكسازول، وبيفينازيت) وثلاثة زيوت عطرية (زيت النيم، النعناع، والقرنفل) ضد إناث ويرقات العنكبوت الأحمر ذو البقعتين *Tetranychus urticae* تحت الظروف المعملية. أظهرت نتائج التعرض للمبيدات الكيميائية بعد ٢٤ و٤٨ ساعة ظهور سمية حادة أعلى مقارنة بالزيوت العطرية. أظهر أبامكتين أعلى درجة من السمية بشكل مستمر عبر جميع الأطوار الحياتية والفترات الزمنية المختلفة، حيث سجّل أقل قيم (LC_{50} 0.85 جزء في المليون بعد ٢٤ ساعة، ٠,٦٥٤ جزء في المليون بعد ٤٨ ساعة للإناث البالغة، و٠,٧٣٩ و٠,٦٢٥ جزء في المليون لليرقات على التوالي)، مما يشير إلى فعالية أكاروسية سريعة وقوية. جاء كل من سيفلوميتوفين وفينبايروكسيمايت في المرتبة التالية، حيث أظهرا منحنيات استجابة حادة وتركيزات فعالة متزايدة بمرور الوقت. كانت الزيوت العطرية أقل فعالية بشكل ملحوظ، وكان زيت النيم هو الأكثر فاعلية بينها، رغم أن قيم LC_{50} تجاوزت ٥٠٠٠ ميكرولتر/لتر. أظهرت جميع المعاملات زيادة في السمية بمرور الوقت، خاصة مع المستخلصات النباتية. تشير هذه النتائج إلى أن المبيدات الكيميائية أكثر ملاءمة للمكافحة السريعة للعنكبوت الأحمر، في حين يمكن أن تسهم الزيوت العطرية في استراتيجيات الإدارة المتكاملة للآفات على المدى الطويل بفضل انخفاض سميتها وملاءمتها البيئية. وتوفر هذه الدراسة المقارنة أساسًا لاختيار العوامل المناسبة وفقًا للطور المستهدف وسرعة التأثير المطلوبة في برامج إدارة *T. urticae*.

الكلمات المفتاحية: العنكبوت الأحمر(Tetranychus urticae) ، المبيدات الحشرية، الزيوت الأساسية، اختبار بيولوجي في المختبر، إدارة الآفات المتكاملة.