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LETHAL AND SUBLETHAL EFFECTS OF PESTICIDES USED IN BRAZILIAN COMMERCIAL FLOWER GREENHOUSES ON TETRANYCHUS URTICAE (TETRANYCHIDAE) AND ITS NATURAL ENEMIES

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Abstract: The aim of this study was to evaluate, under laboratory conditions, the lethal and sublethal effects of eight commonly used pesticides on the phytophagous mite *Tetranychus urticae* Koch (Tetranychidae) and the predatory mites *Neoseiulus californicus* (McGregor) and *Phytoseiulus macropilis* (Banks) (Phytoseiidae), all associated with gerbera (*Gerbera jamesonii*) and chrysanthemum (*Chrysanthemum morifolium*) production in southern Brazil. A residual spray contact bioassay was conducted using a handheld sprayer, and mortality, reproductive performance, and egg viability were assessed. Pesticides were classified according to IOBC/WPRS (International Organization for Biological Control / West Palaearctic Regional Section) criteria, considering both lethal and sublethal (reproductive) effects. The results showed that chlorfenapyr was the most effective against *T. urticae* (98.36% mortality), whereas copper sulfate was the least effective (32.79%). For *N. californicus*, chlorfenapyr, pyridaben, and abamectin caused the highest mortalities (>97%), while spiromesifen was the least harmful (39.71%). In contrast, reproduction of *P. macropilis* was stimulated by copper sulfate, hexythiazox, and spiromesifen, although most compounds were classified as harmful to this predator. According to the IOBC/WPRS categories, 50% of the pesticides tested were harmless to *N. californicus*, while 87% were harmful to *P. macropilis*. These findings provide valuable insights into the compatibility of chemical and biological control strategies in ornamental crop systems, supporting integrated pest management (IPM) programs that prioritize the conservation of predatory mites in greenhouse production.

Keywords: IPM; *Neoseiulus californicus*; *Phytoseiulus macropilis*; ornamental flowers; pesticide selectivity

INTRODUCTION

Ornamental flower production, especially of chrysanthemum (*Chrysanthemum morifolium* Ramat.) and gerbera (*Gerbera jamesonii* Bolus & Hook), faces significant challenges from pests such as the two-spotted spider mite (*Tetranychus urticae* Koch, TSSM), which is particularly problematic under greenhouse conditions. Chemical control remains the predominant management strategy; however, intensive pesticide use has led to the development of resistant mite populations and the accumulation of chemical residues in flowers (Tamai et al. 1998; Buainain & Batalha 2007; Bernardi et al. 2013).

Among pests affecting ornamental crops, mites, thrips, whiteflies, aphids, and leafminer larvae are of major concern (Tamai et al. 1998). *Tetranychus urticae*, in particular, causes severe damage to gerbera and chrysanthemum under protected cultivation. Repeated use of acaricides has led to resistance to several active ingredients—including dimethoate, dicofol, cyhexatin, hexythiazox, clofentezine, abamectin, fenpyroximate, and chlorfenapyr—reported worldwide (Stumpf & Nauen 2002; Herron & Rophail 2003; Sato et al. 2005). Moreover, pesticide use is associated with environmental contamination (affecting soil, water and flowers), increased health risks for workers, higher production costs and disruption of natural enemy populations (Schwertner 2012). The intensive use of pesticides in floriculture also contributes to their dispersion into private gardens and public green spaces (Porseryd et al. 2024).

Predatory mites of the family Phytoseiidae are key biological control agents against mites, thrips and whiteflies and are widely used in integrated pest management (IPM) programs (Lindquist 1996; McMurtry et al. 2013). This family includes approximately 2,521 described species in 94 genera and three subfamilies (Demite et al. 2020). Among them, *Phytoseiulus macropilis* (Banks) and *Neoseiulus californicus* McGregor are commercially reared in Brazil and employed for biological control of TSSM in crops where pesticide use is reduced or avoided.

Phytoseiulus species are classified as Type I predators, following the functional system proposed by McMurtry et al. (2013), which includes highly specialized natural enemies of *Tetranychus* spp., whose reproductive performance strongly depends on prey availability. In contrast, *Neoseiulus* species are considered Type II predators, according to the same system, being primarily associated with *Tetranychus* but also capable of utilizing pollen and plant exudates as supplementary food sources. *Phytoseiulus macropilis* is one of the most studied predatory mites and is widely used for the control of *Tetranychus urticae* in protected crops in Brazil. Its survival, reproduction and behavior are influenced by environmental factors such as temperature, photoperiod and humidity (Sato et al. 2002; Ferla et al. 2011a, 2011b; Majolo & Ferla 2014). Typically, this mite inhabits the abaxial leaf surface near the central vein and exhibits rapid movement and negative phototropism (McMurtry & Croft 1997; Sato et al. 2002).

There is a positive correlation between *P. macropilis* and TSSM population densities, with increased oviposition and predation rates in response to higher prey densities (Ferla et al. 2011b). *Neoseiulus californicus* is a cosmopolitan predatory mite widely used in biological control programs across various crops. It is also considered relatively tolerant to many insecticides and fungicides (Escudero & Ferragut 2005; Greco et al. 2005; Liburd et al. 2007).

The aim of this study was to evaluate, under laboratory conditions, the lethal and sublethal effects of various pesticides on the predatory mites *N. californicus* and *P. macropilis*, as well as on the phytophagous mite *T. urticae*, all of which are associated with chrysanthemum and gerbera production in southern Brazil.

MATERIALS AND METHODS

The experiment was conducted at the Laboratory of Acarology, Universidade do Vale do Taquari – Univates, Lajeado, Rio Grande do Sul, Brazil, from March to August 2018.

Stock Colonies of TSSM

Tetranychus urticae (TSSM) colonies were established from specimens collected from chrysanthemum and gerbera plants grown in southern Brazil two months prior to the experiments. These mites were maintained on bean plants (*Phaseolus vulgaris* L.: Fabaceae)

in a climate-controlled chamber at 25 ± 1 °C, 65 ± 5% relative humidity and a 16:8 h light: dark photoperiod. Plants were replaced once yellowing occurred, indicating unsuitability for sustaining mite populations.

Stock Colonies of Predatory Mites

Neoseiulus californicus and *P. macropilis* colonies were established from individuals collected from the same environment as the TSSM. Both colonies were maintained under controlled conditions at 25 ± 1 °C, 70 ± 5% relative humidity, and a 16:8 h light: dark photoperiod. *Neoseiulus californicus* colonies were kept in plastic trays (30 × 15 × 6 cm) containing a 2-cm thick foam layer in the center and covered with polypropylene plastic. Strips of moist paper towel were placed around the plastic base to prevent mite escape (Peralta Quesada & Schausberger 2012). Distilled water was added to the bottom of the tray to maintain humidity in the cotton substrate. TSSM-infested bean leaves were provided as food three times a week. *Phytoseiulus macropilis* colonies were maintained on TSSM-infested bean plants in trays, with infested leaves replaced upon yellowing to ensure continuous food availability.

Experimental Design

Eight pesticides commonly used in gerbera and chrysanthemum production were tested, with Milli-Q® water used as the control. The products were diluted in Milli-Q® water at the manufacturer-recommended concentrations. When no specific recommendations for these crops were available, dosages commonly used by growers were adopted. The concentrations (g a.i./L or g a.i./kg) and dosages (mL/L or g/L) used were: Abamectin (18 g/L) – 0.25 mL·L^{-1}; Chlorfenapyr (240 g/L) – 0.50 mL·L^{-1}; Chlorpyrifos (480 g/L) – 0.50 mL·L^{-1}; Copper sulfate (985 g/kg) – 5 mL·L^{-1}; Fenpropathrin (300 g/L) – 0.30 mL·L^{-1}; Hexythiazox (500 g/kg) – 0.03 g·L^{-1}; Pyridaben (150 g/L) – 0.75 mL·L^{-1}; Spiromesifen (240 g/L) – 0.30 mL·L^{-1}.

Age-synchronized mites were used for the evaluations. Gerbera leaf discs (2.8 cm diameter) were cut using a punch and sprayed with 0.5 mL of pesticide solution using a professional SW-775 airbrush (working pressure 10–45 psi) from a distance of 20 cm inside a laminar-flow hood. After spraying, the discs were dried on paper towels for approximately 1 hour, then placed on moist cotton inside 6.5 cm diameter Petri dishes. All experimental arenas were maintained in a climate-controlled chamber at 25 ± 1°C, 65 ± 5% relative humidity, and a 16:8 h light: dark photoperiod.

Separate tests were conducted for each species: *T. urticae* individuals (fiver mites per arena) were tested alone, while *N. californicus* and *P. macropilis* were tested separately in arenas containing 30 *T. urticae* individuals provided as prey. Five fertilized adult females of the respective predatory species, previously mated by keeping them with males of the same age and subsequently isolated, were introduced into each arena. Prey mites were replaced as they were consumed to maintain a constant food supply.

A completely randomized design with 15 replicates per treatment was adopted (adapted from Ferla et al. 2011b). Each replicate consisted of five fertilized females, totaling 75 females per treatment for each species tested. The arenas were examined daily to record mortality and other parameters. In total, the experiment comprised 3 species × 9 treatments × 15 replicates × 5 individuals per replicate, resulting in 2,025 individuals evaluated (675 per species).

Evaluation Criteria

Pesticide effects on female *T. urticae*, *N. californicus* and *P. macropilis* were assessed daily under a Leica S6E-LED 2500 stereomicroscope. Mortality, oviposition, and egg viability were recorded. Mites unresponsive to gentle brush contact were considered dead (Stark et al. 1997). Assays with control mortality exceeding 20% were excluded (Bakker et al. 1992). The assay lasted five days for TSSM and eight days for predators.

The corrected mortality of *T. urticae*, *N. californicus* and *P. macropilis* was calculated according to Abbott (1925) using the formula Mc = 100 × (Mo – Mt)(100 –Mt), where Mc = corrected mortality, Mo = observed mortality, Mt = control mortality. The effect on reproduction of *N. californicus* and *P. macropilis* was calculated by dividing the oviposition of females in each treatment by the average oviposition in the control. The formula is $E_r = R_{treatment} / R_{control}$. Mean oviposition per female (R) was obtained using the

ratio R = total viable eggs / number of live females at the end of the test.

The total adverse effect was calculated considering female mortality in the treatment, corrected according to control mortality, and the effect on reproduction (Overmeer & van Zon 1982, Hassan et al. 1985, Overmeer 1988, Bakker et al. 1992). The formula used to calculate the total effect was E = 100% – (100% – Mc) × Er, where E = total effect and Er = effect on reproduction (Overmeer & van Zon 1982).

Based on their total effects, acaricides were classified according to IOBC/WPRS criteria (International Organization for Biological and Integrated Control of Harmful Animals and Plants/ Regional Section of Western Palearctic) for extended laboratory testing as follows: Class 1 – harmless (E < 30% reduction), Class 2 – slightly harmful (30% ≤ E ≤ 79% reduction), Class 3 – moderately harmful (80% ≤ E ≤ 99% reduction) and Class 4 – harmful (E > 99% reduction) (Hassan et al. 1994).

Data on corrected mortality and egg viability for *T. urticae*, *N. californicus* and *P. macropilis* were analyzed separately. Prior to analysis, data were tested for normality using the Shapiro-Wilk test and for homogeneity of variances using Levene's test. When assumptions were not met, data were transformed using arcsine square root transformation. One-way ANOVA was conducted to compare the effects of treatments, followed by Tukey's honestly significant difference (HSD) test to separate means at a significance level of $p < 0.05$. Treatments with control mortality exceeding 20% were excluded from the analyses. All statistical analyses were performed using InfoStat version 0.1.0.0 (Di Rienzo et al. 2008).

RESULTS

Effect on TSSM

The mortality of *T. urticae* increased significantly over time for all pesticide treatments, especially after 72 hours (Table 1). Chlorfenapyr exhibited the highest early effect at 24 h and reached 98.53% mortality by 72 h. At the end of the trial, copper sulfate caused the lowest mortality (32.79%), while other pesticides exceeded 50%, notably

Table 1. Mean number of live female *Tetranychus urticae* per arena (mean ± SE: standard error), corrected mortality (%), and egg viability (%) at 24, 48, 72, 96, and 120 h after pesticide application under laboratory conditions (25 ± 1°C, 70 ± 5% RH, 16:8 h light:dark photoperiod). Each arena contained five females, with 15 replicates per treatment. Means followed by the same letters in each column (different products at the same time) do not differ significantly according to Tukey's test, $P < 0.05$

Treatment	24 h		48h		72h		96h		120h		Viability
	N ± SE	%	N ± SE	%	N ± SE	%	N ± SE	%	N ± SE	%	N ± SE
Abamectin	3.53 ± 0.38bc	27.40	3.00 ± 0.26c	36.62	1.93 ± 0.36bc	57.35	1.47 ± 0.39abc	64.52	1.13 ± 0.32abc	72.13	55.93 ± 14.39
Chlorfenapyr	0.33 ± 0.16a	93.15	0.13 ± 0.09b	97.18	0.07 ± 0.07a	98.53	0.07 ± 0.07a	98.39	0.07 ± 0.07a	98.36	23.33 ± 7.44
Chlorpyrifos	4.07 ± 0.27cd	16.44	3.60 ± 0.31cd	23.94	2.93 ± 0.30cd	35.29	2.47 ± 0.31cd	40.32	1.93 ± 0.34cd	52.46	83.56 ± 8.93
Copper sulfate	4.67 ± 0.16d	4.11	4.00 ± 0.26cd	15.49	3.67 ± 0.32de	19.12	3.00 ± 0.39de	27.42	2.73 ± 0.38de	32.79	85.66 ± 7.07
Fenpropathrin	3.87 ± 0.29cd	20.55	3.40 ± 0.34c	28.17	2.47 ± 0.29bcd	45.59	1.40 ± 0.29abc	66.13	1.00 ± 0.29abc	75.41	65.93 ± 12.48
Hexythiazox	4.60 ± 0.13cd	5.48	4.07 ± 0.21cd	14.08	3.13 ± 0.31cd	30.88	2.13 ± 0.35cd	48.39	1.80 ± 0.35bcd	55.74	68.22 ± 11.47
Pyridaben	2.47 ± 0.26b	49.32	1.40 ± 0.34b	70.42	1.13 ± 0.32ab	75.00	0.67 ± 0.25ab	83.87	0.47 ± 0.19ab	88.52	13.33 ± 9.09
Spiromesifen	4.13 ± 0.35cd	15.07	3.33 ± 0.41c	29.58	2.47 ± 0.45bcd	45.59	2.07 ± 0.45bcd	50.00	1.87 ± 0.46cd	54.10	35.96 ± 1.52
Water	4.87 ± 0.13d	0.00	4.73 ± 0.15d	0.00	4.53 ± 0.19e	0.00	4.13 ± 0.19e	0.00	4.07 ± 0.21e	0.00	100 ± 0.00

chlorfenapyr (98.36%), pyridaben (88.52%), fenpropathrin (75.41%) and abamectin (72.13%).

Egg viability was most strongly reduced by pyridaben (13.33%), followed by chlorfenapyr (23.33%) and spiromesifen (35.96%). In the remaining treatments, viability remained above 50%, with copper sulfate (85.66%) and chlorpyrifos (83.56%) showing the smallest effect.

Effect on Neoseiulus californicus

Chlorfenapyr caused the highest mortality (82.67%) after 24 hours (Table 2), whereas other pesticides initially caused less than 50% mortality. After 72 hours, pyridaben induced 90.67% mortality, and chlorfenapyr reached 100%. Abamectin significantly increased mortality after 120 hours. At the end of the experiment, the highest mortalities were recorded for chlorfenapyr (100%), pyridaben (98.53%) and abamectin (97.06%). Intermediate values were observed for fenpropathrin (66.18%) and chlorpyrifos (57.35%), whereas spiromesifen showed the lowest mortality (39.71%).

Reproduction of *N. californicus* was positively affected by abamectin, chlorpyrifos, fenpropathrin, copper sulfate, hexythiazox, and spiromesifen, whereas pyridaben caused a strong reduction in oviposition (Table 3). Total adverse effects were highest for chlorfenapyr, abamectin, and pyridaben, and lowest for chlorpyrifos, copper sulfate, and spiromesifen. According to the IOBC/WPRS classification, 50% of pesticides were harmless.

Effect on Phytoseiulus macropilis

Within 24 hours, fenpropathrin caused total mortality of *P. macropilis*, followed by chlorpyrifos (98.67%) and pyridaben (93.33%) (Table 4). Mortality increased significantly for all treatments by 96 hours, with chlorfenapyr, chlorpyrifos, and pyridaben causing total mortality. Abamectin also reached 100% mortality by 120 hours. Copper sulfate showed the lowest mortality (72.58%), followed by hexythiazox and spiromesifen, both reaching 95.16% (Table 4). These three pesticides positively influenced *P. macropilis* reproduction (Table 5). Most tested products (87%) were classified as harmful, with only copper sulfate considered harmless, despite corrected mortality exceeding 70%. Notably, copper sulfate significantly increased oviposition in this species.

DISCUSSION

This study provides important insights into the efficacy and selectivity of widely used pesticides against TSSM and its main natural enemies, *N. californicus* and *P. macropilis*. A critical pattern emerged: products highly effective against TSSM often exhibited substantial toxicity to predatory mites, hindering their integration into Integrated Pest Management (IPM) programs for ornamental crops.

Although the experiment generated data across multiple time points (five reviews), the analyses were conducted independently for each evaluation time. We acknowledge that this approach does not explicitly account for temporal autocorrelation among repeated observations and may increase the risk of type I error when multiple tests are performed. The decision not to apply survival analysis or repeated-measures models was based on the primary objective of the study, which was to compare treatment effects at predefined and biologically relevant time intervals, rather than to model temporal trajectories or time-to-event responses. In addition, the limited number of evaluation times and the short experimental duration reduced the suitability and interpretability of more complex temporal models. To mitigate potential overinterpretation, the results were evaluated by emphasizing consistent patterns across consecutive time points rather than isolated significant differences. Nevertheless, this analytical limitation should be considered when interpreting the results, and future studies with longer monitoring periods and finer temporal resolution should incorporate statistical approaches that explicitly account for temporal dependence.

Among all products tested, chlorfenapyr was the most effective against TSSM, causing nearly complete adult mortality and drastically reducing egg viability. However, it was also highly toxic to both *N. californicus* and *P. macropilis*, placing it in IOBC/WPRS class 4 (harmful). These findings corroborate field reports of chlorfenapyr resistance in Brazilian TSSM populations (Nicastro et al. 2013) and confirm its strong ovicidal activity (Vásquez & Ceballos 2009). Despite its efficacy, the high non-

Table 2. Mean number of live female *Neoseiulus californicus* per arena (mean ± SE: standard error) and corrected mortality (%) at 24, 48, 72, 96, 120, 144, 168, and 192 h after pesticide application under laboratory conditions (25 ± 1°C, 70 ± 5% RH, 16:8 h light:dark photoperiod). Each arena contained five females, with 15 replicates per treatment.

Treatment	24 h		48 h		72 h		96 h		120 h		144 h		168 h		192 h	
	N ± SE	%	N ± SE	%	N ±SE	%	N ± SE	%	N ± SE	%	N ± SE	%	N ± SE	%	N ± SE	%
Abamectin	2.80 ± 0.33b	44.00	2.47 ± 0.34b	50.67	1.53 ± 0.32b	69.33	0.87 ± 0.31a	82.43	0.53 ± 0.24a	89.19	0.40 ± 0.21a	91.78	0.27 ± 0.15a	94.20	0.13 ± 0.09a	97.06
Chlorfenapyr	0.87 ± 0.17a	82.67	0.20 ± 0.11a	96.00	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100
Chlorpyrifos	4.27 ± 0.28c	14.67	3.93 ± 0.28c	21.33	3.60 ± 0.27c	28.00	3.47 ± 0.27b	29.73	3.13 ± 0.27b	36.49	2.87 ± 0.29b	41.10	2.47 ± 0.27b	46.38	1.93 ± 0.25bc	57.35
Copper sulfate	4.87 ± 0.09c	2.67	4.73 ± 0.15cd	5.33	4.33 ±0.21cd	13.33	3.73 ± 0.32b	24.32	3.27 ± 0.36b	33.78	2.80 ± 0.37b	42.47	2.67 ± 0.36b	42.03	2.60 ± 0.34c	42.65
Fenpropathrin	4.53 ± 0.17c	9.33	3.93 ± 0.23c	21.33	3.40 ± 0.29c	32.00	3.20 ± 0.31b	35.14	2.87 ± 0.24b	41.89	2.67 ± 0.29b	45.21	2.53 ± 0.29b	44.93	1.53 ± 0.34b	66.18
Hexythiazox	4.47 ± 0.17c	10.67	3.93 ± 0.21c	21.33	3.53 ± 0.27c	29.33	3.33 ± 0.32b	32.43	3.00 ± 0.32b	39.19	2.80 ± 0.28b	42.47	2.73 ± 0.28b	40.58	2.40 ± 0.29bc	47.06
Pyridaben	2.93 ± 0.44b	41.33	1.07 ± 0.25a	78.67	0.47 ± 0.17a	90.67	0.33 ± 0.13a	93.24	0.20 ± 0.11a	95.95	0.13 ± 0.09a	97.26	0.07 ± 0.07a	98.55	0.07 ± 0.07a	98.53
Spiromesifen	4.47 ± 0.19c	10.67	4.13 ± 0.19cd	17.33	3.93 ± 0.18c	21.33	3.73 ± 0.18b	24.32	3.53 ± 0.19b	28.38	3.27 ± 0.21b	32.88	2.93 ± 0.18b	36.23	2.73 ± 0.21c	39.71
Water	5.00 ± 0.00c	0.00	5.00 ± 0.00d	0.00i	5.00 ± 0.00d	0.00	4.93 ± 0.07c	1.33	4.93 ± 0.07c	1.33	4.87 ± 0.09c	2.67	4.60 ± 0.16c	8.00	4.53 ± 0.17d	9.33

Means followed by the same letters in each column (different products at the same time) do not differ significantly according to Tukey´s test, $P < 0.05$

Table 3. Biological and reproductive effects of *Neoseiulus californicus* 192 hours after the beginning of exposure under laboratory conditions at 25 ± 1 °C, 70 ± 5% RH, and 16:8 h light: dark photoperiod.

Treatment	Dosage (g or mL)	C_m(%)	E_r	E%	Class[a]
Abamectin	0.25 mL L^{-1}	97.06	4.75	86.04	3
Chlorfenapyr	0.50 mL L^{-1}	100	0.00	100	4
Chlorpyrifos	0.50 mL L^{-1}	57.35	2.02	13.70	1
Copper sulfate	5 mL L^{-1}	42.65	1.44	17.53	1
Fenpropathrin	0.30 mL L^{-1}	66.18	1.73	41.43	2
Hexythiazox	0.03g L^{-1}	47.60	1.38	26.84	1
Pyridaben	0.75mL L^{-1}	98.53	0.81	98.81	3
Spiromesifen	0.30 mL L^{-1}	39.71	1.44	13.33	1

C_m, corrected mortality; E_r, effect on reproduction; E%, total effect. [a] Classification according to the IOBC/WPRS: class 1 = harmless (E 30% reduction), class 2 = slightly harmful (30% < E < 79% reduction), class 3 = moderately harmful (80% < E < 99% reduction), and class 4 = harmful (E > 99% reduction).

target toxicity limits its suitability in IPM strategies focused on predator conservation.

Abamectin, another commonly used acaricide in ornamental crops, showed moderate efficacy against TSSM but considerable toxicity to predatory mites, especially *P. macropilis*. These results align with reports of resistance and cross-resistance in TSSM populations, particularly in strawberry fields (Sato et al. 2009). While abamectin reduced TSSM egg viability, its detrimental effects on beneficial mites highlight the need for caution when biocontrol agents are applied.

Pyridaben ranked second in efficacy against TSSM adults but also caused notable mortality in *P. macropilis* and moderate effects in *N. californicus*. Its strong contact and ovicidal action, as previously reported by Albuquerque et al. (2003), reinforces the observed impact. In that study, however, pyridaben did not consistently outperform other acaricides across all post-treatment intervals, with mortality of *T. urticae* females ranging from approximately 93% to 63% depending on the application interval. This indicates that although pyridaben is effective in suppressing TSSM populations, its performance can vary over time. Moreover, repeated use in IPM programs may disrupt biological control by impairing predator survival and reproduction.

Conversely, chlorpyrifos, copper sulfate, hexythiazox and spiromesifen were less toxic to *N. californicus* throughout the evaluated post-treatment period (24–192 h), with the first three also enhancing predator reproduction. Notably, copper sulfate was the only compound classified as harmless to both predatory species, although its efficacy against TSSM was limited. These findings are consistent with previous studies reporting moderate to low toxicity of copper sulfate to phytoseiids (Reis et al. 1998, 2006), supporting its suitability for IPM programs when predator conservation is required.

Hexythiazox and spiromesifen caused minimal impacts on *N. californicus*, and although their efficacy against TSSM was moderate, they may be useful in rotation schemes to manage resistance while preserving predator populations. Nevertheless, spiromesifen was highly toxic to *P. macropilis* and should be avoided in areas where this predator is released.

The differential susceptibility between predators is also noteworthy. *Phytoseiulus macropilis* was more sensitive to nearly all tested compounds, confirming its higher vulnerability compared to *N. californicus*. This aligns with earlier studies (Cloyd et al. 2006; Silva et al. 2012) and suggests that use of *P. macropilis* in IPM programs requires greater attention to pesticide compatibility.

Altogether, the results demonstrate that many pesticides used in ornamental crop protection disproportionately harm predatory mites relative to TSSM. This underscores a central challenge in IPM implementation: balancing chemical efficacy with ecological sustainability. While laboratory conditions can sometimes amplify toxicity, field

Table 4. Mean number of live female *Phytoseiulus macropilis* per arena (mean ± SE: standard error) and corrected mortality (%) at 24, 48, 72, 96, 120, 144, 168, and 192 h after pesticide application under laboratory conditions (25 ± 1°C, 70 ± 5% RH, 16:8 h light:dark photoperiod). Each arena contained five females, with 15 replicates per treatment.

Treatment	24 h		48 h		72 h		96 h		120 h		144 h		168 h		192 h	
	N ± SE	%	N ± SE	%	N ± SE	%	N ± SE	%	N ± SE	%	N ± SE	%	N ± SE	%	N ± SE	%
Abamectin	1.53 ± 0.29b	69.33	0.87 ± 0.27ab	82.67	0.27 ± 0.15a	94.44	0.13 ± 0.09a	97.18	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100
Chlorfenapyr	2.13 ± 0.31b	57.33	0.20 ± 0.11a	96.00	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100
Chlorpyrifos	0.07 ± 0.07a	98.67	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100
Copper sulfate	4.60 ± 0.13cd	8.00	4.20 ± 0.20d	16.00	3.73 ± 0.23c	22.22	3.33 ± 0.27c	29.58	2.80 ± 0.28c	40.85	2.20 ± 0.31b	51.47	1.60 ± 0.24b	63.08	1.13 ± 0.24b	72.58
Fenpropathrin	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100
Hexythiazox	2.27 ± 0.33b	54.67	1.60 ± 0.27b	68.00	1.20 ± 0.24b	75.00	0.60 ± 0.19ab	87.32	0.53 ± 0.19ab	88.73	0.33 ± 0.13a	92.65	0.20 ± 0.11a	95.38	0.20 ± 0.11a	95.16
Pyridaben	0.33 ± 0.16a	93.33	0.07 ± 0.07a	98.67	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100	0.00 ± 0.00a	100
Spiromesifen	3.93 ± 0.23c	21.33	2.93 ± 0.42c	41.33	1.20 ± 0.31b	75.00	0.80 ± 0.22b	83.10	0.60 ± 0.19b	87.32	0.53 ± 0.19a	88.23	0.33 ± 0.16a	92.31	0.20 ± 0.11a	95.16
Water	5.00 ± 0.00d	0.00	5.00 ± 0.00d	0.00	4.80 ± 0.11d	4.00	4.73 ± 0.12d	5.33	4.73 ± 0.12d	5.33	4.53 ± 0.13c	9.33	4.33 ± 0.16c	13.33	4.13 ± 0.17c	17.33

Means followed by the same letters in each column (different products at the same time) do not differ significantly according to Tukey´s test, $P < 0.05$

Table 5. Biological and reproductive effects of *Phytoseiulus macropilis* 192 hours after the beginning of exposure under laboratory conditions at 25 ± 1 °C, 70 ± 5% RH, and 16:8 h light: dark photoperiod.

Treatment	Dosage (g or mL)	C_m(%)	E_r	E%	Class[a]
Abamectin	0.25 mL L^{-1}	100	0.00	100	4
Chlorfenapyr	0.50 mL L^{-1}	100	0.00	100	4
Chlorpyrifos	0.50 mL L^{-1}	100	0.00	100	4
Copper sulfate	5 mL L^{-1}	72.58	4.36	-19.57	1
Fenpropathrin	0.30 mL L^{-1}	100	0.00	100	4
Hexythiazox	0.03g L^{-1}	95.16	3.57	82.72	3
Pyridaben	0.75mL L^{-1}	100	0.00	100	4
Spiromesifen	0.30 mL L^{-1}	95.16	2.20	89.35	3

C_m, corrected mortality; E_r, effect on reproduction; E%, total effect. [a] Classification according to the IOBC/WPRS: class 1 = harmless (E 30% reduction), class 2 = slightly harmful (30% < E < 79% reduction), class 3 = moderately harmful (80% < E < 99% reduction), and class 4 = harmful (E > 99% reduction).

studies remain essential to validate these findings under commercial production scenarios.

Although resistance development in pest mites is well documented, far less is known about its occurrence in predatory species. Some studies suggest that *N. californicus* may develop tolerance under selection pressure (Yorulmaz-Salman & Ay 2014a, 2014b), but the long-term ecological fitness of such strains is uncertain. These knowledge gaps highlight the need for further research into predator resilience, cross-resistance mechanisms, and acaricide rotation protocols tailored to ornamental systems.

Although laboratory studies provide fundamental insights into pesticide effects, extrapolation to field conditions remains limited. Therefore, field validation is essential to confirm compatibility with biological control in commercial settings. Integrating selective acaricides with strategic releases of predatory mites is key for sustainable management of ornamental crops. IPM programs should prioritize compounds with minimal non-target impact while ensuring effective TSSM control, supported by ongoing resistance monitoring and ecological research.

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