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Diagnosis of acaricide resistance in *Oligonychus punicae* (Hirst) (Acari: Tetranychidae) in grapevines from the São Francisco Valley, Brazil

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ABSTRACT

The intensive use of acaricides, such as abamectin, in the São Francisco Valley region of Brazil has increased selection pressure on the red mite *Oligonychus punicae*, leading to frequent reports of field control failures. This study evaluated the hypothesis that repeated abamectin use for tetranychid mite control in grapevines has led to a high frequency of resistance in *O. punicae* populations. This study aimed to detect and document abamectin resistance in *O. punicae* populations infesting grapevines. To assess potential cross-resistance, toxicity assays were also conducted with bifenthrin and pyridaben—other acaricides registered for *Tetranychus urticae* control in Brazilian vineyards. Tested populations of *O. punicae* exposed to a diagnostic concentration of 9 mg L^{-1} abamectin were classified as resistant, with resistance ratios reaching up to 398-fold relative to the susceptible population. In contrast, the label-recommended concentrations of bifenthrin and pyridaben caused 100 % mortality in all tested populations, although resistance ratios varied from 1- to 25-fold. A significant positive correlation was observed between the LC_{90} values of abamectin and bifenthrin; however, the results suggest a pattern of multiple resistance rather than cross-resistance among the tested acaricides. Understanding the evolution of acaricide resistance in *O. punicae* is essential for developing effective pest control and resistance management strategies in viticulture.

1. Introduction

The red mite *Oligonychus punicae* (Hirst) (Trombidiformes: Tetranychidae) is a cosmopolitan species found in 35 countries, including Brazil, Mexico, the United States, and others in Asia and Oceania (Migeon and Dorkeld, 2025). It is a polyphagous pest commonly found on a wide range of cultivated and wild plant species. Among cultivated hosts, it is found on avocado (*Persea americana* Mill.) (González-Dávila et al., 2024), eucalyptus (*Eucalyptus urophylla* S.T. Blake) (Ferraz et al., 2020a), mango (*Mangifera indica* L.) (Melo et al., 2024a), and grapevine (*Vitis vinifera* L.) (Melo et al., 2024b). In grapevines, *O. punicae* is recognized as one of the most significant phytophagous mite species (Domingos et al., 2014; Melo et al., 2024b). The damage caused by *O. punicae* typically begins on the adaxial surface of the leaves near the central vein, leading to chlorosis, bronzing, necrosis, and leaf drop (Melo et al., 2024b).

Oligonychus punicae causes significant economic losses in grapevines and is commonly managed with acaricides, such as abamectin. Although no product is officially registered for the control of *O. punicae* in Brazil, several grape-importing countries have authorized the use of abamectin on this crop (Pertot et al., 2017; Melo et al., 2024b; MAPA, 2025). In Brazil, acaricides are often applied based on low infestation thresholds of 10 % (Botton et al., 2015), resulting in repeated use that fosters the selection and proliferation of resistant mite populations in the field (van Leeuwen et al., 2010; Ferreira et al., 2015; Monteiro et al., 2015). This overuse also compromises the survival of natural enemies, including predatory mites of the Phytoseiidae family (Silva et al., 2019). Resistant populations tend to disperse and colonize new agricultural regions, facilitating the spread of resistance alleles and compromising the long-term efficacy of control strategies (Hawkins et al., 2019).

Pesticide resistance refers to the emergence of a heritable trait within a target organism population that significantly reduces its susceptibility to a pesticide, rendering previously effective doses inadequate for control (IRAC, 2025). Acaricide resistance is well documented in the

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two-spotted spider mite, *Tetranychus urticae* (Koch) (Trombidiformes: Tetranychidae), which exhibits resistance to multiple compounds (Hawkins et al., 2019; Mota-Sanchez and Wise, 2025), including abamectin, in the São Francisco Valley region of Brazil (Ferreira et al., 2015; Monteiro et al., 2015). *Oligonychus punicae* also reaches high infestation levels in this region and is exposed to the same management practices as those applied to *T. urticae* (Domingos et al., 2014; Monteiro et al., 2015).

The intensive use of abamectin in the São Francisco Valley has increased selective pressure on *O. punicae*, leading to a growing number of field control failures. This study hypothesized that repeated application of abamectin for tetranychid mite control in grapevines has driven resistance development in *O. punicae* populations in the region. The primary objective was to assess the resistance of *O. punicae* to abamectin in grapevine crops in the São Francisco Valley. Additionally, toxicity tests were conducted with bifenthrin and pyridaben—other acaricides registered for the control of *T. urticae* in Brazilian vineyards—to evaluate the possible occurrence of cross-resistance in these populations.

2. Material and methods

2.1. Collection and maintenance of Oligonychus punicae populations

Specimens of *O. punicae* were collected from grapevine leaves in 12 commercial vineyards reporting abamectin control failures in the São Francisco Valley region. Sampling was conducted across four municipalities: Casa Nova, Bahia (09° 15′ 08″ S; 40° 54′ 19″ W); Juazeiro, Bahia (09° 08′ 59″ S; 40° 01′ 41″ W); Lagoa Grande, Pernambuco (09° 04′ 45″ S; 40° 08′ 04″ W); and Petrolina, Pernambuco (09° 12′ 43.9″ S; 40° 29′ 12.7″ W). All collection sites were georeferenced using a Global Positioning System (Fig. 1). An independent colony was established for each sampled site. Mites were reared under controlled laboratory conditions in Biochemical Oxygen Demand (B.O.D) incubators maintained at 28 ± 0.5 °C, 60 ± 10 % relative humidity, and a 12-h photoperiod. Each population was maintained in a separate incubator to avoid cross-contamination.

A mean of 1000 adult females were transferred onto 14-cm diameter grapevine leaf discs, placed adaxial side up to match the species' preferred feeding site. The leaf discs were positioned on polyethylene foam pads of equal diameter and 1-cm thickness and placed in 18-cm

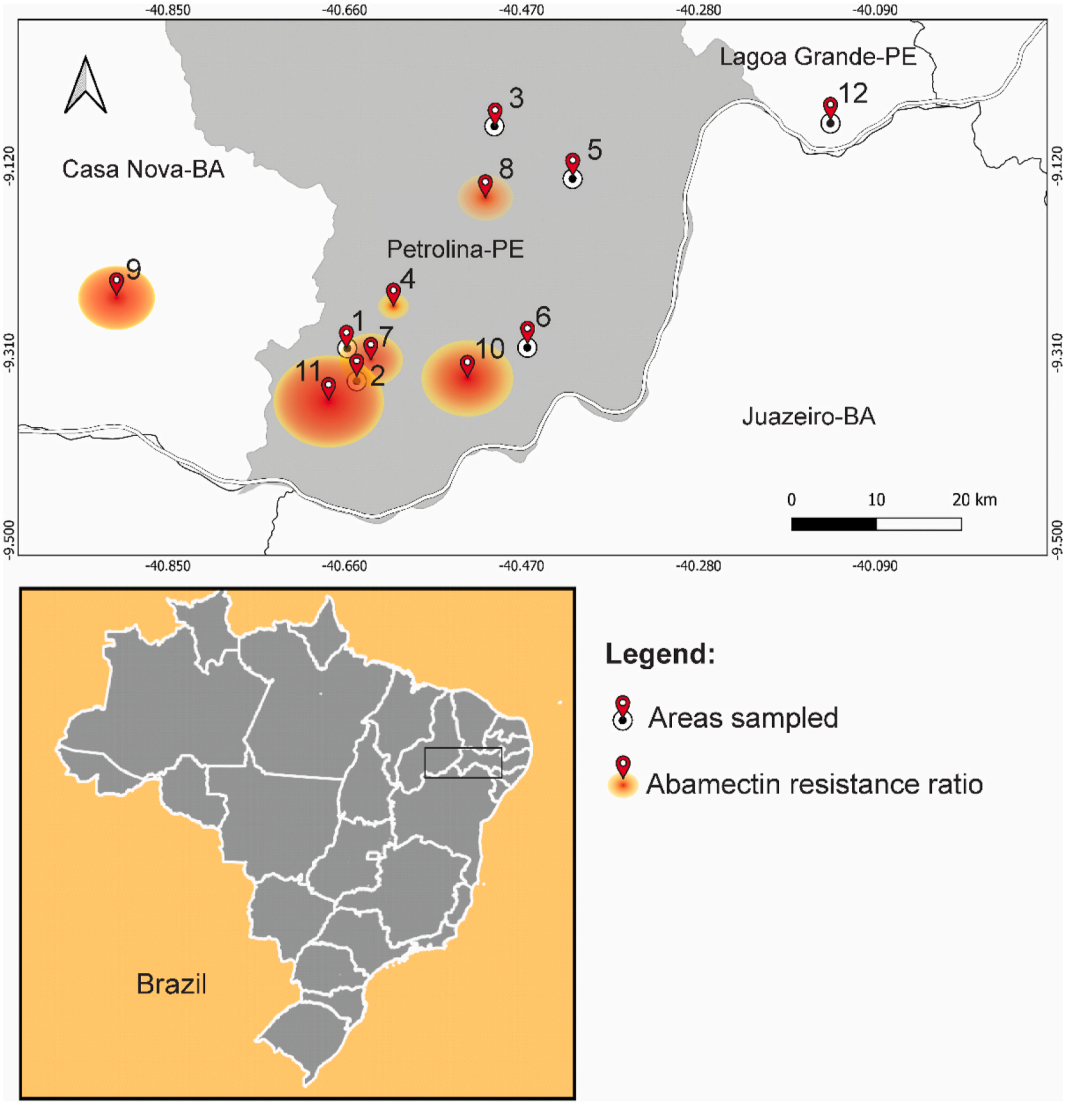

Fig. 1. Geographical distribution of *Oligonychus punicae* populations collected from vineyards in the São Francisco Valley. Black circles indicate monitored vineyard sites, whereas red gradient dots represent resistance levels to abamectin across six vineyards. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

diameter polyethylene trays. Cotton wool daily moistened with distilled water was arranged around the discs to prevent mite escape. Additionally, a population of *O. punicae* was collected from *M. indica* plants in Recife, Pernambuco, Brazil (08° 00′ 58″ S; 34° 56′ 40″ W), from an area with no history of acaricide use. This population, maintained on grapevine leaves and replaced every week, served as the reference susceptible strain. Prior to colony establishment, some individuals were slide-mounted in Hoyer's medium and examined under a phase-contrast microscope (Olympus® BX41) for species confirmation, following morphological descriptions and identification keys from the literature (Baker and Tuttle, 1994; Bolland et al., 1998; Migeon and Dorkeld, 2025).

2.2. Bioassays

Toxicity bioassays were conducted using the following acaricides and label-recommended doses: abamectin (Vertimec 84 SC, Syngenta Proteção de Cultivos Ltda., São Paulo, Brazil) – (100–250 mL ha^{-1}), bifenthrin (Talstar 100 EC, FMC Química do Brasil Ltda., Campinas, Brazil) – (250–500 mL ha^{-1}), and pyridaben (Sanmite EW, Iharabras S. A. Indústrias Químicas, Sorocaba, Brazil) – (75 mL ha^{-1}). All three compounds are recommended for the control of *T. urticae* in grapevines, according to Agrofit (MAPA, 2025). The bioassays were performed following Method No. 4 from the series of standardized protocols recommended by the Insecticide Resistance Action Committee (IRAC, 2009) for susceptibility testing.

2.3. Diagnosis of acaricide resistance in Oligonychus punicae populations

Resistance to abamectin in *O. punicae* was assessed using preliminary diagnostic concentrations of 1 mg L^{-1} and 9 mg L^{-1}, derived from LC_{50} and LC_{95} values previously determined for *T. urticae* in vineyards of the same region (Monteiro et al., 2015). These concentrations are also close to the label-recommended dose for *T. urticae* control and were selected due to the absence of established susceptibility baselines for *O. punicae*. *Oligonychus punicae* and *T. urticae* are phylogenetically closely related species that cohabit the same host plant and are controlled using the same acaricides. Among these, six populations (4, 7, 8, 9, 10, and 11) were randomly selected for additional testing with bifenthrin and pyridaben at label-recommended concentrations for grapevine (MAPA, 2025). Each population was tested using both the 9-mg L^{-1} abamectin diagnostic concentration and the label-recommended doses of bifenthrin and pyridaben, with distilled water serving as the control treatment.

Each experimental unit consisted of a 9-cm diameter Petri dish containing filter paper of the same size, with 10 replicates per treatment. Acaricide application was performed by immersing 5-cm diameter grapevine leaf discs in the test solution for 5 s. Control discs were dipped in distilled water. After treatment, the discs were air-dried at room temperature for 30 min and placed on the filter paper inside the Petri dishes. The edges of the dishes were sealed with water-agar to prevent mite escape. Ten adult *O. punicae* females were transferred to each experimental unit, totaling 300 mites per treatment. The units were maintained in B.O.D.-type incubators under the same environmental conditions as that of the colonies. Mortality was assessed 48 h post-treatment by counting live and dead mites in each replicate. Mites that failed to move at least one body length after being gently touched with a fine brush were recorded as dead. Percent mortality was corrected using Abbott's formula (Abbott, 1925). Populations exhibiting less than 80 % mortality when exposed to the diagnostic concentration of abamectin (9 mg L^{-1}) or the label-recommended field dose were classified as resistant.

2.4. Acaricide toxicity bioassays on Oligonychus punicae populations

Preliminary tests were conducted to establish an "all-or-nothing" mortality response using a series of acaricide concentrations diluted by a factor of 10 (for example, 0.0001; 0.001; 0.01; 0.1; 1; 10; and 100 mg L^{-1}). Three replicates were performed for each concentration, totaling 21 experimental units. Based on the results, seven to eight concentrations diluted by a factor of two were selected within a range that produced approximately 0 % ("nothing") to 100 % ("all") mortality. Each bioassay was repeated at least three times under identical conditions until a Probit model fit was achieved ($P > 0.05$), allowing parallelism and equality between two or more dose-response curves. Procedures for acaricide application, preparation of experimental arenas, mite confinement, and mortality evaluation were as previously described.

2.5. Statistical analysis

Mortality data were analyzed using Probit analysis (Finney, 1971), with mortality at each concentration corrected using Abbott's formula (Abbott, 1925). Concentration-response curves were generated using POLO-Plus 2.0 software (LeOra Software, 2005; Petaluma, USA). Resistance ratios (RR_{50}) for resistant populations were calculated with 95 % confidence intervals according to the method described by Robertson and Preisler (1992). Pearson correlation analyses were performed using log-transformed LC_{50} and LC_{90} values to assess association between bifenthrin and abamectin, pyridaben and abamectin, and bifenthrin and pyridaben across the evaluated populations. Statistical analyses were performed using the GGally package in R software (version 4.0.5 for Windows; R Core Team, 2025).

3. Results

3.1. Diagnosis of acaricide resistance in Oligonychus punicae populations

The diagnostic concentrations of abamectin (1 mg L^{-1} and 9 mg L^{-1}) resulted in lower-than-expected mortality across all tested populations (<50 % at 1 mg L^{-1}; <80 % at 9 mg L^{-1}), confirming the presence of resistance to this acaricide. In contrast, the label-recommended concentrations of bifenthrin and pyridaben achieved 100 % mortality in the six tested populations (Fig. 2).

3.2. Acaricide toxicity bioassays on Oligonychus punicae populations

Toxicity assays with abamectin yielded LC_{50} values ranging from 0.0001 mg L^{-1} (population 4) to 1.5533 mg L^{-1} (population 10), and LC_{90} values from 0.0256 mg L^{-1} (population 4) to 372 mg L^{-1} (population 10). Resistance ratios (RR_{50}) based on LC_{50} values ranged from 0- to 398-fold compared to the susceptible reference population. For bifenthrin, LC_{50} values ranged from 0.0132 mg L^{-1} (population 9) to 0.0345 mg L^{-1} (population 4); and LC_{90} values from 0.0618 mg L^{-1} (population 7) to 0.6980 mg L^{-1} (population 9). Resistance ratios based on LC_{50} values ranged from 2- to 4-fold. For pyridaben, LC_{50} values varied from 0.00007 mg L^{-1} (population 8) to 0.0037 mg L^{-1} (population 9); and LC_{90} values from 0.0011 mg L^{-1} (population 8) to 0.0344 mg L^{-1} (population 10). Resistance ratios for LC_{50} values ranged from 1- to 25-fold relative to the susceptible population (Table 1).

No significant correlation was observed between the LC_{50} values of abamectin and bifenthrin ($r_p = 0.295$; $P = 0.520$; $N = 6$). However, a significant positive correlation was found between their LC_{90} values ($r_p = 0.820$; $P = 0.024$; $N = 6$). No significant correlations were detected between the LC_{50} values of abamectin and pyridaben ($r_p = 0.510$; $P = 0.243$; $N = 6$), or those between bifenthrin and pyridaben ($r_p = 0.682$; $P = 0.092$; $N = 6$). Similarly, no significant correlations were detected between the LC_{90} values of abamectin and pyridaben ($r_p = 0.501$; $P = 0.252$; $N = 6$), or those between bifenthrin and pyridaben ($r_p = 0.577$; $P = 0.175$; $N = 6$).

4. Discussion

Oligonychus punicae is a tetranychid mite increasingly prevalent in

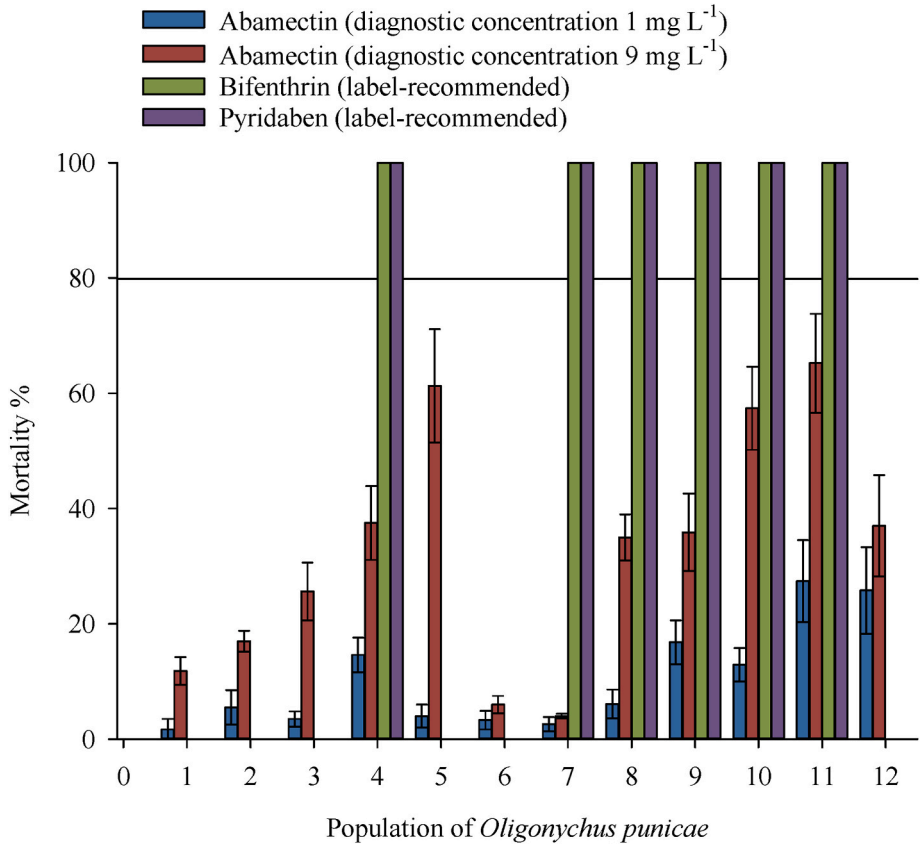

Fig. 2. Percentage mortality of *Oligonychus punicae* populations from vineyards in the São Francisco Valley after exposure to diagnostic concentrations of abamectin (1 mg L^{-1} and 9 mg L^{-1}), and to manufacturer-recommended concentrations of bifenthrin and pyridaben, used for the control of *Tetranychus urticae*.

Table 1
Toxicity of abamectin, bifenthrin, and pyridaben to *Oligonychus punicae* populations from the São Francisco Valley, identified as resistant to abamectin.

Active ingredient	Population	N[a]	χ^2 (DF)[b]	p[c]	Slope ± SE[d]	LC_{50} (95 % CI)[e]	LC_{90} (95 % CI)[f]	RR_{50} (95 % CI)[g]
Abamectin	Susceptible	312	9.65 (5)	0.08	0.73 ± 0.06	0.0039 (0.0015–0.0071)	0.0173 (0.009–0.075)	–
	4	232	4.15 (4)	0.38	0.56 ± 0.08	0.0001 (0.0001–0.0003)	0.0256 (0.006–0.296)	0 (0.01–0.2)
	7	249	3.26 (4)	0.51	1.47 ± 0.27	0.0139 (0.0076–0.0217)	0.1031 (0.062–0.220)	4 (1.0–14.5)[h]
	8	281	7.76 (4)	0.10	0.84 ± 0.11	0.0107 (0.0032–0.0241)	0.3491 (0.126–2.688)	3 (0.4–16.1)[h]
	9	269	14.01 (4)	0.01	0.48 ± 0.05	0.0503 (0.0031–0.3051)	21.995 (2.772–1791)	13 (0.4–203.4)[h]
	10	306	3.99 (5)	0.55	0.53 ± 0.08	1.5533 (0.7509–3.6592)	372.93 (83.85–4508)	398 (105.7–2439.5)[h]
	11	270	3.05 (4)	0.54	1.08 ± 0.12	0.0107 (0.0078–0.0150)	0.1620 (0.091–0.358)	3 (1.1–10.0)[h]
Bifenthrin	Susceptible	224	1.11 (3)	0.77	4.02 ± 0.82	0.0071 (0.0050–0.0091)	0.0148 (0.011–0.022)	–
	4	223	1.32 (4)	0.85	1.75 ± 0.28	0.0345 (0.0224–0.0469)	0.1848 (0.135–0.287)	5 (2.5–9.4)[h]
	7	292	5.01 (5)	0.41	3.39 ± 0.34	0.0259 (0.0226–0.0294)	0.0618 (0.051–0.078)	4 (2.5–5.9)[h]
	8	267	6.81 (4)	0.14	1.08 ± 0.18	0.0175 (0.0047–0.0424)	0.2675 (0.098–2.376)	2 (0.5–8.5)
	9	274	7.64 (4)	0.10	0.74 ± 0.12	0.0132 (0.0044–0.0365)	0.6980 (0.158–35.77)	2 (0.5–7.3)
	10	251	6.00 (4)	0.19	0.90 ± 0.14	0.0167 (0.0032–0.0527)	0.4403 (0.130–3.824)	2 (0.3–10.5)
	11	310	3.55 (4)	0.47	3.25 ± 0.42	0.0172 (0.0146–0.0200)	0.0425 (0.034–0.056)	2 (1.6–4.0)
Pyridaben	Susceptible	655	11.2 (3)	0.01	1.05 ± 0.07	0.00015 (0.00005–0.00035)	0.0047 (0.0009–0.0130)	–
	4	222	7.10 (3)	0.07	0.99 ± 0.14	0.0024 (0.0005–0.0066)	0.0464 (0.014–0.799)	16 (1.43–132.0)[h]
	7	255	2.59 (4)	0.62	0.81 ± 0.10	0.0003 (0.0001–0.0005)	0.0111 (0.005–0.030)	2 (0.29–10.0)
	8	270	0.74 (4)	0.94	1.09 ± 0.16	0.00007 (0.00004–0.0001)	0.0011(0.0006–0.002)	1 (0.11–2.0)
	9	270	2.91 (4)	0.57	1.57 ± 0.24	0.0037 (0.0022–0.0053)	0.0242 (0.016–0.039)	25 (6.29–106.0)[h]
	10	263	3.12 (4)	0.53	1.05 ± 0.16	0.0021 (0.0010–0.0035)	0.0344 (0.020–0.072)	14 (2.86–70.0)[h]
	11	315	3.78 (5)	0.58	1.18 ± 0.15	0.0012 (0.0008–0.0016)	0.0148 (0.009–0.029)	8 (2.29–32.0)[h]

[a] The number of mites tested.
[b] Qui-square and degree of freedom.
[c] *p*-value.
[d] Slope and standard error.
[e] Mean lethal concentration (mg a. i./L) and confidence interval at 95 %.
[f] Mean lethal concentration (mg a. i./L) and confidence interval at 95 %.
[g] Resistance ratio: ratio (95 % CI) of the LC50 between resistant and susceptible populations, calculated using the Robertson and Preisler (1992) method.
[h] Resistance ratio significant at 5 % when confidential limits do not bracket the value of 1.0.

vineyards of the São Francisco Valley, where it coexists with *T. urticae*, a species traditionally controlled with abamectin. This study provides the first documented evidence of field-evolved resistance to abamectin in *O. punicae*, despite the absence of any acaricide registered for its control in Brazil, across all crops (MAPA, 2025). The near-exclusive use of avermectins for controlling pests such as *T. urticae* has exerted selective pressure on *O. punicae*, contributing to its emergence as an important pest in the region. Each of the evaluated *O. punicae* populations exhibited varying degrees of resistance to abamectin, with clear evidence of potential control failure. The diagnostic concentration of 9 mg L^{-1} resulted in less than 70 % mortality, even in the most susceptible population, and resistance ratios reached up to 398-fold compared to the susceptible reference. The species' biological traits—high reproductive potential, haplodiploid sexual reproduction, and a short life cycle—further facilitate the rapid development of resistance, even after limited acaricide exposure (Ferraz et al., 2020b).

Abamectin is an acaricide belonging to the avermectin class, derived from the soil microorganism *Streptomyces avermitilis* Burg. It primarily targets glutamate-gated chloride channels, and, to a lesser extent, gamma-aminobutyric acid-gated chloride channels (Sparks and Nauen, 2015). Several mechanisms underlying abamectin resistance have been identified, including target-site insensitivity, sex-linked inheritance, and enhanced oxidative metabolism, indicating a complex genetic basis for resistance (Dermauw et al., 2012; Ferreira et al., 2015; Xu et al., 2018; Xue et al., 2021). Resistance to abamectin in *T. urticae* populations appears to be unstable, with the frequency of resistant individuals declining during periods without selection pressure, supporting the efficacy of resistance management strategies (Nicastro et al., 2010; Dağlı, 2016). Although these studies focus on *T. urticae* populations, similar resistance mechanisms may also occur in mites of the genus *Oligonychus*, due to their biological similarities. In this context, rotating the modes of action is essential, based on the premise that no cross-resistance exists between them.

Studies show that abamectin remains the most widely used acaricide worldwide for controlling mites of the genus *Oligonychus*, including *O. punicae* (Hoddle and Morse, 2012; Cantú-Díaz et al., 2016; Reyes, 2024; Torres et al., 2024). However, other acaricides such as ethion, fenpropathrin, azadirachtin, bifenazate, etoxazole, fenpyroximate, and spirodiclofen are reported to control mites of this genus. (Das et al., 2017; Santos et al., 2022; Cua-Basulto et al., 2021). In this study, *O. punicae* populations exhibited high susceptibility to bifenthrin and pyridaben, as indicated by very low LC_{50} values. These findings corroborate results from label dose evaluations demonstrating the efficacy of formulated products in controlling this mite in grapevine areas of the São Francisco Valley. However, abamectin-resistant populations showed low resistance to bifenthrin and moderate resistance to pyridaben, with ratios ranging from 1- to 20-fold, relative to susceptible populations. Considering that the resistance ratios were calculated based on LC_{50} values and no significant correlation was observed, these cases likely represent low-level multiple resistance. Although pyridaben and bifenthrin have been used in Brazil for over 15 years, the selection pressure has not been strong enough to increase the frequency of resistant individuals to these acaricides.

Evaluation of label doses of bifenthrin and pyridaben—two compounds also recommended for controlling *T. urticae*—resulted in 100 % mortality in resistant populations of *O. punicae*, indicating their potential utility for managing multiple pest species. Although no clear cross-resistance has been reported between abamectin and these compounds, a strong positive correlation between abamectin and bifenthrin at high concentrations (LC_{90}) suggests possible cross-resistance. More tolerant individuals (at the upper end of the dose–response curve) may exhibit elevated expression of esterases and/or cytochrome P450-dependent monooxygenases, which metabolize these acaricides due to their carboxylester residues (Stumpf and Nauen, 2002; Bhatt et al., 2021). Cross-resistance between abamectin and pyrethroids has also been documented in thrips (Zhao et al., 1995). However, resistance levels have generally remained low and have not compromised pyrethroid efficacy, even under high abamectin selection pressure, as observed in the São Francisco Valley. Resistance to pyridaben and bifenthrin in *T. urticae* has been recently linked to mutations in their respective target sites (van Leeuwen et al., 2010; De Beer et al., 2022; De Rouck et al., 2023). Additionally, UDP-glycosyltransferases have been implicated in bifenthrin resistance (De Beer et al., 2022). In contrast, a mutation in the PSST gene of the mitochondrial electron transport chain complex I has been associated with pyridaben resistance (Bajda et al., 2017), as well as with detoxifying enzymes that confer resistance to abamectin (van Leeuwen and Tirry, 2007; Tsagkarakou et al., 2009; Sparks and Nauen, 2015).

Although this study did not investigate the physiological or molecular mechanisms underlying resistance, our findings are consistent with previous reports of abamectin resistance mediated by metabolic detoxification and target-site insensitivity in *T. urticae*. Given the biological similarities between *T. urticae* and *O. punicae*, it is plausible that comparable mechanisms may be involved. Future studies incorporating synergist assays, enzymatic activity profiling, and molecular markers are warranted to validate these hypotheses.

The results of this study demonstrated that selection pressure from abamectin and bifenthrin acaricides used in grapevine cultivation in the São Francisco Valley may have contributed to the development of multiple resistance in *O. punicae* populations. Most abamectin-resistant populations were concentrated in the western part of the study area, where the highest resistance ratios were observed (Fig. 1), consistent with findings by Monteiro et al. (2015) for *T. urticae* populations in the same area. This spatial pattern may be associated with the predominant east-to-west wind direction in the region (Windfinder, 2025), which likely facilitates mite dispersal.

Resistance to acaricides directly impacts crop protection by reducing the effectiveness of chemical control, thereby favoring pest outbreaks—especially in hot and dry regions, where these organisms reproduce rapidly. Resistant populations increase control costs, as growers must apply treatments more frequently and at higher doses. Consequently, intensified applications may negatively affect natural enemies, particularly mites from the Phytoseiidae family and other predators, further hindering integrated pest management.

The elevated resistance rate, coupled with the species' rapid biological adaptation and wind-mediated dispersal, underscore the urgent need for alternative control strategies. These strategies should include integrated approaches, such as resistance management, including the constant monitoring of resistance frequency in field populations, in order to track the evolution of resistance in *O. punicae* populations. This measure will provide information that helps keep resistance levels below the economic damage threshold. The rotation of acaricides with a low likelihood of cross-resistance, such as pyridaben, is an alternative to delay or reverse the evolution of abamectin resistance. Resistance management, in combination with other management plans and cultural practices—such as the installation of windbreaks that account for mite dispersal between adjacent areas—helps maintain the susceptibility of *O. punicae* to avermectins in the field. Additionally, the registration of new products for controlling *O. punicae* could enhance pest management efforts in Brazilian grapevine crops.

CRediT authorship contribution statement

André S. Melo: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Maria Luiza T. Matheus:** Writing – review & editing, Resources, Methodology. **José E.M. Oliveira:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition. **José W.S. Melo:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation. **Herbert A. A. Siqueira:** Writing – review & editing, Validation, Supervision, Investigation, Formal analysis, Data curation, Conceptualization.

Manoel G.C. Gondim: Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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