Journal of Agricultural Science and Technology (JAST), 29(5)
In Press, Pre-Proof Version

Toxic Profiling of Sulfur Formulations against *Tetranychus urticae* and *Agonoscena pistaciae*

Fahimeh Azod[1], Azam Mikani[1], and Saeid Moharramipour[1]*

ABSTRACT

This study comprehensively evaluated the mortality effects of two sulfur-based formulations, wettable sulfur and Thiovit Jet, against adult females of the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), and fifth nymphs of the common pistachio psyllid, *Agonoscena pistaciae* Burckhardt & Lauterer (Hemiptera: Psyllidae), due to their economic importance as key pests and their documented resistance to conventional acaricides/insecticides, through various methods, including direct contact, fumigation, exposure of pests to the dry sulfur residues on the leaf surface, and ovicidal activities under controlled laboratory conditions. Based on preliminary tests, contact assays used 1000–5000 mg/L, while other tests used 1000–20000 mg/L to evaluate the potential effects of sulfur formulations under laboratory conditions. Contact assays showed 100% mortality for both formulations at 5000 mg/L after 72 h against both pests. Fumigation tests at 20000 mg/L caused 93–94% mortality in *T. urticae* and 88% in *A. pistaciae* for both formulations. The effects of dried sulfur residues on the leaf surface and ovicidal activity were negligible. Maximum mortality caused by dried sulfur residues on the leaf surface was ≤13.33% and egg hatching >75% across all treatments. These findings indicate that sulfur acts primarily through direct contact and fumigant modes of action, with limited activity of dried sulfur residues on the leaf surface and ovicidal activity. This efficacy profile supports the strategic use of sulfur formulations in integrated pest management (IPM) programs targeting mobile stages of these pests.

Keywords: Egg viability, Mortality assessment, Pest management strategies, Pesticide performance, Sulfur formulations.

INTRODUCTION

Tetranychus urticae Koch (Acari: Tetranychidae) is one of the most important pests in many cropping systems worldwide and the most polyphagous species. Its host plants (nearly 800 plant species) include vegetables, fruits, maize, cotton, and a wide range of ornamentals (Migeon *et al*.,

[1] Department of Entomology, Faculty of Agriculture, Tarbiat Modares University, Tehran, Islamic Republic of Iran.
*Corresponding author; e-mail: moharami@modares.ac.ir

2009). Adult and immature stages of *T. urticae* feed from the lower surface of leaves (Park and Lee, 2002). Leaf yellowing, bronzing, defoliation, and even plant death occur due to the direct effects of mite feeding (Helle and Sabelis, 1985; Mersino, 2002). Indirect effects of feeding may include decreased transpiration and photosynthesis, resulting in reduced yield (Brandenburg and Kennedy, 1987). High reproduction potential, short life cycle, and excessive use of chemical pesticides to control the *T. urticae* cause the emergence of resistance to many chemical pesticides after several applications and also the appearance of high levels of residual toxins in food products (Stumpf and Nauen, 2001; El Kady *et al*., 2007; Hamedi, 2022). Accordingly, attention has increasingly focused on alternative strategies for mite control. The common pistachio psyllid, *Agonoscena pistaciae* Burckhardt & Lauterer (Hemiptera: Psyllidae), is one of the most significant pests of pistachio trees due to its widespread distribution in all pistachio-producing regions of Iran (Roshani *et al.,* 2021). The widespread distribution causes severe problems in kernel development and leads to subsequent bud drop and defoliation, resulting in significant economic losses (Mehrnejad, 2001, 2002). For this reason, pistachio growers closely monitor psylla infestations and insist on spraying to reduce psyllid damage (Mehrnejad, 2010; Sheibani Tezerji, 2025). Every year, farmers apply chemical pesticides from the outset until harvest, raising economic concerns and endangering farmers' and consumers' health (Hassani *et al.,* 2009). Over the years, prolonged use of chemical pesticides has made pests resistant to many pesticides (Basirat, 2003; Alizadeh *et al*., 2014; Mostafavi *et al*., 2017) .Despite the extensive application of chemical pesticides in pistachio orchards in recent years, the pistachio psyllid remains a major and economically important pest in Iran. Furthermore, the use of non-standard and improper pesticides has resulted in ineffective pest control and the development of resistance in this key pest. Consequently, pistachio growers have emphasized the need for alternative and more effective pest management compounds. These challenges highlight the urgent need for safer and more sustainable pest management tools. Formulated sulfur may represent a suitable option for addressing these challenges. Considering the positive perception of pistachio growers regarding the effectiveness of sulfur as both an insecticide and an acaricide, along with its wide availability in Iran, the use of formulated sulfur could be regarded as a practical and promising alternative for pest management (Afrousheh and Hasheminasab, 2018). Sulfur has been used as a pesticide for a long time, with registrations in the United States dating back to the 1920s (US EPA, 1991). Today, elemental sulfur is the active ingredient in nearly 300 registered pesticide products (USDA, 2017). It is applied to a wide range of crops to control fungal diseases, mites, and insects (Forsyth, 1818; US EPA, 1991; 1994; Patra *et al*., 2020). It is also widely accepted in organic farming systems (Porcuna, 2002). Despite its benefits, sulfur in dust form has several drawbacks. Dusting sulfur is prone to drift, adheres poorly to plant surfaces, and can be easily removed by wind or rain. Moreover, sulfur dust may irritate the skin, eyes, and respiratory tract (US EPA, 1994). However, comprehensive comparative evaluations of sulfur formulations against *T. urticae* and *A. pistaciae* are lacking. Therefore, this study aimed to evaluate the insecticidal and acaricidal efficacy of two sulfur formulations: conventional wettable sulfur and Thiovit Jet, based on preliminary experiments, using contact and fumigation application methods and ovicidal effect against fifth nymphs of *A. pistaciae* and adult females of *T. urticae*. The tested concentrations were selected based on recommended field rates (1000–5000 mg/L for contact assays) and higher doses (up to 20000 mg/L) to explore potential sublethal or fumigant effects under extreme conditions.

MATERIALS AND METHODS

Chemicals and Formulations

1. Conventional wettable sulfur (WS): Conventional wettable sulfur was prepared in our laboratory based on preliminary formulation studies. Fine milling was employed to achieve a controlled particle size distribution (d_{90} = 10–12 µm). The composition (by weight) consisted of 80% sublimed sulfur, 6.5% bentonite, 7% diatomaceous earth, 5% lignin sulfonate, 0.5% sodium dodecyl sulfate, 0.5% polyethylene glycol, and 0.5% xanthan gum. This formulation showed excellent suspension stability, wetting, and redispersibility.
2. Commercial Formulation (Thiovit Jet® 80WG): The commercial product Thiovit Jet® 80WG (containing 800 g/kg elemental sulfur; Syngenta) was used as a ready-to-apply reference formulation for comparative analysis.

Rearing of Pests

Adults of the two-spotted spider mite and fifth nymphs of the common pistachio psyllid were used for the tests. Fifth nymphs were used because they were recognizable from the other nymphs and their mortality was low (Bemani *et al.,* 2018).

The mites were collected from unsprayed areas of cucumber in Shahreza, Isfahan province, Iran (32.077N, 51.835E) and maintained in the laboratory on potted bean plants (*Phaseolus vulgaris*

L.). The psyllids were obtained from pistachio orchards in Sarvestan, Fars province, Iran (29.165N, 53.269E), where no pesticides had been applied, and were maintained under controlled laboratory conditions; age-synchronized individuals were used for the experiments. All colonies were maintained at 28 ± 2°C, 60 ± 5% relative humidity, and a 16:8 h (light: dark) photoperiod.

Ovicidal Effects: Egg Hatching Rate at Different Concentrations

For *A. pistaciae*, petioles of healthy pistachio leaves were wrapped in moistened cotton and placed in small plastic cups (5 cm height and 3 cm diameter) with moistened soil to maintain humidity. These cups were then transferred into larger plastic containers (15 cm height and 40 cm diameter), containing a shallow layer of water, and the tops were covered with fine mesh to create a cage-like environment. For each replicate, 20 adults (10 males and 10 females; 1:1 sex ratio) were released onto the leaves in each arena. After 48 hours, the cups containing freshly laid eggs were transferred to new containers. The eggs were then treated with the sulfur formulations at specified concentrations, while the control group received distilled water. Egg hatching was assessed one week later using a stereomicroscope.

For *T. urticae*, 4 leaf discs (approximately 3–4 cm in diameter) were placed on moistened cotton in Petri dishes (9 cm diameter), with the abaxial surface facing upward, and transferred to each container as described above. One pair of adult male and female (1:1 sex ratio) mites was transferred on each leaf disc. After 48 hours, leaf discs containing eggs were treated with the formulations at the specified concentrations, and the control leaf discs were sprayed with distilled water. The percentage of egg hatching was recorded one-week post-treatment.

For both species, using a lab sprayer with a spray volume of 1.5 mL per disc and cup. All containers were maintained in an incubator at 28 ± 2°C, 60 ± 5% relative humidity, and a 16:8-hour (light: dark) photoperiod. A series of concentrations (1000, 5000, 10000, and 20000 mg/L) of each formulation was prepared. For each concentration and pest species, the egg hatching rate was determined using 20 freshly laid eggs per replicate, across five independent replicates. Eggs were considered unhatched if no embryonic development or larval/juvenile emergence was observed by the end of the observation period.

Assessment of exposure of pests to the dry sulfur residues on the leaf surface

For *T. urticae*, intact bean leaves were placed on moistened cotton pads inside plastic containers (10 cm diameter × 15 cm height), with the abaxial (lower) surface facing upward so mites could be positioned on them. The leaves were sprayed with the sulfur formulations at specified concentrations, while the control group was sprayed with distilled water. The treated leaves were allowed to air-dry for two hours. One-day-old adult female mites were transferred onto the leaves using a fine brush. The container lids were completely covered with fine mesh to allow ventilation while preventing escape.

For *A. pistaciae*, the same procedure was followed. Fifth nymphs of *A. pistaciae*, were carefully transferred to the treated pistachio leaves using a fine brush, and containers were similarly covered with mesh.

Based on preliminary range-finding tests, a series of concentrations (1000, 5000, 10000, 15000, and 20000 mg/L) was prepared for each formulation. All containers were maintained in an incubator at 28 ± 2°C, 60 ± 5% relative humidity, and a 16:8 h (light: dark) photoperiod. Test solutions were sprayed directly onto the leaves at 1.5 mL per leaf, with the nozzle positioned 30 cm from the target surface. Each treatment was replicated five times, with 20 mites or fifth-instar nymphs of *A. pistaciae* per replicate. Mortality was assessed at 24, 48, and 72 hours post-treatment; individuals showing no movement upon gentle prodding with a fine brush under a stereomicroscope were recorded as dead.

Assessment of Direct Contact Effect

For *T. urticae*, intact bean leaves were placed abaxially side up on moist cotton in plastic cylindrical containers (10 cm diameter × 15 cm height). Twenty-one-day-old adult female mites were transferred to each leaf. Test solutions were sprayed directly onto the leaves and surface-body individuals using a lab sprayer, with a spray volume of 1.5 mL per disc and cup; the spray distance was 30 cm from the nozzle to the target surface. Containers were sealed with mesh-covered lids to permit ventilation.

For *A. pistaciae*, the same procedure was followed. Twenty-fifth-instar nymphs of *A. pistaciae* were carefully transferred to the treated Pistacia leaves using a fine camel-hair brush (size 00) to avoid physical damage, and containers were similarly covered with mesh.

For each formulation, a series of concentrations (1000, 2000, 2500, 3500, and 5000 mg/L) was prepared. The entire experiment was conducted under controlled conditions identical to the rearing environment (28 ± 2 °C, 60 ± 5% RH, and a 16:8 h L:D photoperiod). Each treatment was replicated five times, with 20 individuals per replicate. Mortality was assessed at 24, 48, and 72 hours post-treatment using a stereomicroscope at 40× magnification.

Assessment of Fumigation Effect

For *T. urticae*, Cylindrical plastic containers (10 cm diameter × 15 cm height), lined with moist cotton, were prepared with untreated bean leaves and twenty female adults. Filter paper discs (2 cm diameter, Whatman No. 1) were impregnated with 10 mL of test solutions, air-dried for 1 minute, and affixed to the container lids. Controls received water-treated discs. A series of concentrations (3000, 5000, 10000, 15000, and 20000 mg/L) of each formulation was prepared.

For *A. pistaciae*, the same procedure was followed. Twenty-fifth nymphs of *A. pistaciae* were carefully transferred to the treated leaves using a fine brush. The same containers and concentrations were used as for *T. urticae*.

Mortality was assessed at 24, 48, and 72 h as described above, with five replicates per concentration. Containers were sealed with parafilm to minimize gas leakage and maintained under controlled conditions (28 ± 2 °C, 60 ± 5% RH, 16:8 L:D).

Statistical Analysis

Data were corrected with Abbott's formula (Abbott, 1925) for control mortality >5%, subjected to one-way ANOVA, and means separated using Tukey's HSD test ($\alpha = 0.05$). All analyses were conducted in SPSS V. 26.

RESULTS

Evaluation of Ovicidal Effects: Egg Hatching Rate at Different Concentrations

For *T. urticae*, one-way ANOVA revealed a significant treatment effect for wettable sulfur ($F = 12.50$; df = 4,20; $p < 0.05$). Tukey's HSD test showed that only the highest concentration (20000 mg/L) significantly reduced egg hatchability (76.67 ± 1.00%) compared with the control (90.00 ± 0.00%). No significant effects were detected at lower concentrations. Thiovit Jet did not significantly affect *T. urticae* egg hatching at any tested concentration ($F = 1.71$; df = 4,20; $p > 0.05$).

For *A. pistaciae*, neither wettable sulfur ($F = 1.96$; $df = 4,20$; $p > 0.05$) nor Thiovit Jet ($F = 1.41$; $df = 4,20$; $p > 0.05$) significantly influenced egg hatching across all tested concentrations. Egg hatching remained high (>80%) across all treatments (Table 1).

Assessment of exposure of pests to the dry sulfur residues on the leaf surface

For *T. urticae*, no mortality was observed at 24 h for any treatment. At 48 h, wettable sulfur ($F = 26.01$; $df = 4,20$; $p < 0.001$) showed a weak mortality (5.10 ± 0.10 %) only at the highest concentration (20000 mg/L). After 72 h, mortality increased at both 15000 and 20000 mg/L, reaching 9.80 ± 0.20% at 20000 mg/L. Thiovit Jet exhibited minimal effect against *T. urticae*, with only 6.89 ± 0. 00 % mortality at 20000 mg/L after 72 h ($F = 13.90$; $df = 4,20$; $p < 0.001$), indicating very low efficacy under these conditions.

For *A. pistaciae*, no mortality occurred at 24 h. At 48 h, wettable sulfur ($F = 18.78$; $df = 4,20$; $p < 0.001$) caused weak mortality (6.51 ± 1.51%) only at the highest concentration (20000 mg/L). By 72 h, mortality increased at 15000 and 20000 mg/L, with the highest concentration (20000 mg/L) resulting in 11.51 ± 1.80 % mortality. Thiovit Jet showed negligible toxicity on *A. pistaciae* nymphs, producing only 13.33 ± 0. 00 % mortality at 20000 mg/L after 72 h ($F = 64.00$; $df = 4,20$; $p < 0.0001$) (Table 2).

Assessment of Direct Contact-Induced Mortality

For *T. urticae*, at 24 hours, wettable sulfur ($F = 90.65$; $df = 4,20$; $p < 0.0001$) and Thiovit Jet ($F = 36.00$; $df = 4,20$; $p < 0.0001$) caused significant mortality, with efficacy increasing with concentration. Mortality rates for wettable sulfur ranged from 10.00% at 1000 mg/L to 80% at 5000 mg/L, while Thiovit Jet achieved 16.67% at 1000 mg/L and 80.00% at 5000 mg/L. By 48 hours, the concentration effect was more pronounced for both wettable sulfur ($F = 234.56$; $df = 4,20$; $p < 0.0001$) and Thiovit Jet ($F = 75.72$; $df = 4,20$; $p < 0.0001$). Thiovit Jet reached 48. 00% mortality at 2000 mg/L, and both products showed over 89% efficacy at 5000 mg/L. At 72 hours, both acaricides achieved complete (100%) mortality at 5000 mg/L (wettable sulfur: $F = 135.31$; $df = 4,20$; $p < 0.0001$; Thiovit Jet: $F = 187.00$; $df = 4,20$; $p < 0.0001$).

For *A. pistaciae*, significant concentration-dependent mortality was detected at 24 hours for both wettable sulfur ($F = 40.07$; $df = 4,20$; $p < 0.0001$) and Thiovit Jet ($F = 40.61$; $df = 4,20$; $p < 0.0001$), with mortality increasing from 10.00% at 1000 mg/L to 73.33 % for both at 5000 mg/L. The efficacy increased over time, with highly significant effects at 48 hours (wettable sulfur: $F= 49.93$; $df = 4,20$; $p < 0.0001$; Thiovit Jet: $F = 62.79$; $df = 4,20$; $p < 0.0001$) and 72 hours (wettable sulfur: $F= 171.38$; $df = 4,20$; $p < 0.0001$; Thiovit Jet: $F = 113.86$; $df = 4,20$; $p < 0.0001$). At 72 hours, wettable sulfur caused 100% mortality at 5000 mg/L, while Thiovit Jet reached 94.00% mortality at the same concentration and time (Table 3).

Assessment of Fumigation -Induced Mortality

For *T. urticae*, significant concentration-dependent mortality was established at 24 hours for both wettable sulfur ($F= 117.42$; $df = 4,20$; $p < 0.0001$) and Thiovit Jet ($F = 67.74$; $df = 4,20$; $p < 0.0001$). The effect intensified over time, with wettable sulfur achieving 84.00% mortality at 20000 mg/L by 48 hours (wettable sulfur: $F= 193.60$; $df = 4,20$; $p < 0.0001$) and with Thiovit Jet achieving 81.00% mortality at 20000 mg/L by 48 hours (Thiovit Jet: $F= 92.71$; $df = 4,20$; $p < 0.0001$). At 72 hours, the highest concentration (20000 mg/L) caused 93.00% and 94.00% mortality for wettable sulfur and Thiovit Jet, respectively (wettable sulfur: $F = 196.23$; $df = 4,20$; $p < 0.0001$; Thiovit Jet: $F = 97.78$; $df = 4,20$; $p < 0.0001$) (Table 4).

For *T. urticae*, analysis of variance revealed a highly significant effect of concentration on mortality at all time points for both, wettable sulfur (24h: $F = 44.32$; $df = 4,20$; $p < 0.0001$; 48h: $F = 85.72$; $df = 4,20$; $p < 0.0001$; 72h: $F = 71.50$; $df = 4,20$; $p < 0.0001$) and Thiovit Jet (24h: $F = 39.98$; $df = 4,20$; $p < 0.0001$; 48h: $F = 57.39$; $df = 4,20$; $p < 0.0001$; 72h: $F = 59.70$; $df = 4,20$; $p < 0.0001$). At 72 hours post-treatment, the highest concentration (20000 mg/L) resulted in 88.33% mortality for wettable sulfur and 88.00% for Thiovit Jet (Table 4).

DISCUSSION

This study provides a comprehensive evaluation of the contact, fumigation, and leaf-surface exposure, as well as ovicidal toxicity, of two sulfur-based formulations, wettable sulfur and Thiovit Jet, against two major pests: *T. urticae and A. pistaciae*. The results reveal a clear dichotomy in efficacy by route of exposure, highlighting the importance of application method in sulfur's mode of action against these arthropods.

Both sulfur formulations showed potent contact toxicity from 1000 mg/L, with mortality strongly correlated to concentration and time. The fumigation toxicity results were particularly striking, showcasing a powerful alternative mode of action. Both sulfur formulations were highly volatile, with *T. urticae* proving significantly more susceptible than *A. pistaciae*. The greater susceptibility of *T. urticae* might be hypothetically linked to the penetration of gaseous sulfur compounds into the tracheal system, potentially leading to rapid toxicity. Conversely, the comparatively delayed and reduced effect observed in *A. pistaciae* could speculatively be attributed to its thicker integument or dissimilar respiratory morphology, which might confer partial protection. However, these proposed mechanisms remain speculative and require empirical validation through targeted experimental studies. In stark contrast to the high contact and fumigation efficacy, both exposure to dried sulfur residues on the leaf surface and ovicidal toxicity were minimal. Exposure to the dried sulfur residues assays showed mortality only at the concentration (20000 mg/L) after 72 hours, reaching a maximum of only 9.80% for *T. urticae* and 13.33% for *A. pistaciae*. Similarly, ovicidal effects were weak; this limited activity via body contact and direct egg contact underscores that sulfur's primary lethal action is not systemic or stomach-based but rather topical or via vapor action. These findings align with the work of Auger *et al.* (2003), who reported that wettable sulfur formulation at concentrations of 12 and 25 g a.i. L^{-1} using a contact spray method against *T. urticae* under laboratory conditions; the results indicated that the ovicidal efficacy of wettable sulfur is temperature- and RH-dependent, starting at 27.5 °C/75% RH and maximizing at 35 °C/90% RH. However, as these conditions were not included in our study, we did not observe any ovicidal effect.

The differential efficacy—high via direct spray on the pest body/fumigation and low via exposure to dried sulfur residues on the leaf surface —implies sulfur should target direct spray on nymphs/adults, not eggs. Optimal timing with pest emergence is critical for success. One concern with sulfur is its potential to cause phytotoxicity. Sulfur phytotoxicity occurs when high temperatures and high humidity happen at the same time. The risk increases substantially when temperatures exceed 32 °C and relative humidity exceeds 70% (Emmett *et al*., 2003; Sanders *et al*., 2025).

Furthermore, the significance of sulfur in resistance management should not be overlooked. From an epidemiological perspective, pesticides with multiple sites of action are the most recalcitrant to evolutionary forces (Gressel, 2020). Elemental sulfur acts as a strong oxidant, causing glutathione oxidation, glutathione disulfide (GSSG) accumulation, and increased reactive oxygen species (ROS), which induce oxidative stress and disrupt multiple cellular functions. This multi-site mode of action, involving both mitochondrial inhibition and oxidative stress, significantly reduces the likelihood of resistance development compared to single-target-site pesticides (Wang *et al.,* 2022).

A limitation of our study is the use of eggs collected over a 48-hour period, which introduces variability in egg age. Future studies should use more tightly synchronized egg cohorts, such as 12-hour or 24-hour oviposition windows, and assess post-hatching larval survival to provide a more comprehensive evaluation of sublethal effects.

CONCLUSIONS

Wettable sulfur and Thiovit Jet were highly effective as contact and fumigant agents against both pests, but showed minimal ovicidal activity, with toxicity strongly dependent on concentration and time. These findings confirm that application method critically influences sulfur efficacy, supporting its strategic use in pest control. Future research should evaluate these formulations under field conditions, optimize application timing, and integrate sulfur with other compatible IPM tactics; vapor monitoring and age-specific ovicidal assays are also recommended to better understand the mechanisms.

Acknowledgements

This research was supported by a grant from Tarbiat Modares University (grant number 9930462003).

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Table 1. Egg hatching rate of *Tetranychus urticae* and *Agonoscena pistaciae* exposed to serial concentrations of sulfur formulations.

Pest species	Treatment	Concentration (mg/L)	Egg hatching (%) (Mean ± SE)
T. urticae	wettable sulfur	1000	88.33 ± 1.67a
		5000	86.67 ± 1.17a
		10000	83.33 ± 1.67ab
		20000	76.67 ± 1.00b
	control	–	90.00 ± 0 a
	Thiovit Jet	1000	86.67 ± 1.67a
		5000	83.33 ± 1.67a
		10000	80.00 ± 2.90a
		20000	78.33 ± 7.26a
	control	–	90.00 ± 0 a
A. pistaciae	wettable sulfur	1000	83.33 ± 1.20a
		5000	81.67 ± 6.00a
		1000	78.33 ± 3.31a
		20000	77.67 ± 1.90a
	control	–	90.00 ± 2.89a
	Thiovit Jet	1000	86.33 ± 3.33a
		5000	78.33 ± 7.26a
		10000	76.41 ± 4.41a
		20000	75.00 ± 5.00a
	Control	–	86.67 ± 1.67a

Notes: Means within a column for each pest and treatment sharing the same letter are not significantly different (Tukey's HSD, $p < 0.05$).

Table 2. Effects of exposure to dried residue sulfur formulations on leaf surface against *Tetranychus urticae* and *Agonoscena pistaciae* at various concentrations and exposure times.

			%mortality (Mean ± SE)		
Pest species	Treatment	Concentration (mg/L)	24 h	48 h	72 h
T. urticae	wettable sulfur	1000	0	0 b	0 b
		5000	0	0 b	0 b
		10000	0	0 b	0 b
		15000	0	0 b	6.78 ± 1.78a
		20000	0	5.10 ± 0.10a	9.80 ± 0.20a
	Thiovit Jet	1000	0	0 b	0 b
		5000	0	0 b	0 b
		10000	0	0 b	0 b
		15000	0	0 b	0 b
		20000	0	0 b	6.89 ± 0 a
A. pistaciae	wettable sulfur	1000	0	0 b	0 b
		5000	0	0 b	0 b
		10000	0	0 b	0 b
		15000	0	0 b	6.51 ± 1.50a
		20000	0	6.50 ± 1.50a	11.51 ± 1.80a
	Thiovit Jet	1000	0	0 b	0 b
		5000	0	0 b	0 b
		10000	0	0 b	0 b
		15000	0	0 b	0 b
		20000	0	0 b	13.33 ± 0 a

Notes: Means within a column for each pest and treatment sharing the same letter are not significantly different (Tukey's HSD, *p* < 0.05).

Table 3. Contact effect of different types of sulfur formulations on *Tetranychus urticae* and *Agonoscena pistaciae* at various concentrations and exposure times.

			%mortality (Mean ± SE)		
Pest species	Treatment	Concentration (mg/L)	24 h	48 h	72 h
T. urticae	wettable sulfur	1000	10.00 ± 2.87e	20.00 ± 2.87e	30.00 ± 2.89d
		2000	33.33 ± 1.67d	40.00 ± 2.89d	49.50 ± 2.13c
		2500	45.00 ± 2.87c	66.67 ± 1.67c	71.71 ± 4.41b
		3500	65.00 ± 2.74b	73.67 ± 1.67b	85.00 ± 0 a
		5000	80.00 ± 2.69a	89.00 ± 0.00a	100 ± 0 a
	Thiovit Jet	1000	16.67± 1.67d	31.57 ± 4.40d	35.00 ± 2.77d
		2000	35.00 ± 2.89d	48.00 ± 5.00c	60.00 ± 2.63c
		2500	46.66 ± 6.01c	66.00 ± 2.89c	75.30 ± 1.67b
		3500	60.00± 0.00b	75.00 ± 0.00b	87.00 ± 0.00a
		5000	80.00 ± 5.77a	89.00 ± 0.00a	100 ± 0 a
A. pistaciae	wettable sulfur	1000	10.00 ± 2.36d	20.00 ± 2.89d	30.00 ± 2.82e
		2000	18.33 ± 3.33c	35.00 ± 0.00cd	43.33 ± 1.66d
		2500	25.33 ± 1.60c	51.67 ± 4.41bc	53.33 ± 1.07c
		3500	46.67 ± 4.41b	50.00 ± 2.81b	75.00 ± 2.89b
		5000	73.33 ± 4.40a	83.33 ± 4.40a	100 ± 0 a
	Thiovit Jet	1000	19.33 ± 1.61e	24.00 ± 0.00c	32.00 ± 2.80d
		2000	31.47 ± 1.67dc	38.31 ± 1.67c	48.32 ± 1.17c
		2500	38.33 ± 3.33bc	55.00 ± 2.81b	65.00 ± 2.19b
		3500	51.67 ± 4.41b	63.30 ± 1.07b	76.13 ± 3.03b
		5000	73.33 ± 1.67a	79.17 ± 4.04a	94.00 ± 0 a

Notes: Means within a column for each pest and treatment sharing the same letter are not significantly different (Tukey's HSD, *p* < 0.05).

Table 4. Fumigant effects of different types of sulfur formulations on *Tetranychus urticae* and *Agonoscena pistaciae* at various concentrations and exposure times.

			%mortality (Mean ± SE)		
Pest species	Treatment	Concentration (mg/L)	24 h	48 h	72 h
A.pistaciae	wettable sulfur	3000	20.00 ± 2.71d	28.13 ± 1.61d	30.00 ± 2.12d
		5000	28.33 ± 1.67d	40.00 ± 2.89c	46.67 ± 4.40c
		10000	43.30 ± 1.00c	65.00 ± 2.89b	68.33 ± 1.41b
		15000	56.00 ± 5.72ab	70.07 ± 1.67b	76.33 ± 4.41b
		20000	69.00 ± 1.81a	78.33 ± 1.07a	88.33 ± 1.67a
	Thiovit Jet	3000	21.67 ± 1.67a	30.00 ± 2.41b	36.67 ± 1.67c
		5000	30.00 ± 2.89d	41.67 ± 3.30b	45.00 ± 1.89c
		10000	41.00 ± 5.77c	68.31 ± 1.40a	66.67 ± 6.07b
		15000	58.00 ± 2.09ab	70.00 ± 2.01a	73.00 ± 1.89b
		20000	73.33 ± 3.33a	79.00 ± 1.81a	88.00 ± 0.00a
T.urticae	wettable sulfur	3000	26.67 ± 7.64d	30.00 ± 2.81d	40.00 ± 2.89c
		5000	33.33 ± 1.60bc	40.00 ± 2.81c	55.00 ± 2.89b
		10000	50.00 ± 2.05c	65.00 ± 2.01b	77.00 ± 0.00a
		15000	65.00 ± 2.79b	78.33 ± 1.67a	86.00 ± 0.00a
		20000	78.00 ± 2.88a	84.00 ± 0.00a	93.00 ± 0.00a
	Thiovit Jet	3000	26.67 ± 4.41d	31.64 ± 4.40c	35.00 ± 2.80c
		5000	33.33 ± 1.67d	40.00 ± 5.00b	43.31 ± 4.41b
		10000	48.33 ± 4.04c	68.00 ± 2.89a	74.00 ± 0 a
		15000	66.67 ± 3.33b	72.33 ± 1.67a	81.00 ± 0 a
		20000	73.67 ± 3.33a	81.00 ± 0.00a	94.00 ± 0 a

Notes: Means within a column for each pest and treatment sharing the same letter are not significantly different (Tukey's HSD, *p* < 0.05).

سمیت‌شناسی فرمولاسیون‌های گوگردی روی کنه تارتن دو لکه‌ای *Tetranychus urticae* و پسیل معمولی پسته *Agonoscena pistaciae*

فهیمه آزود، اعظم میکانی، و سعید محرمی پور

چکیده

این مطالعه به‌طور جامع اثرات کشندگی دو فرمولاسیون گوگردی، گوگرد وتابل وتیویت جت، را روی ماده‌های بالغ کنه تارتن دولکه‌ای، *Tetranychus urticae* Koch (Acari: Tetranychidae)، و پوره‌های سن پنجم پسیل معمولی پسته، *Agonoscena pistaciae* Burckhardt & Lauterer (Hemiptera: Psyllidae)، به‌دلیل اهمیت اقتصادی آن‌ها به‌عنوان آفات کلیدی و مقاومت اثبات‌شده به کنه‌کش‌ها و حشره‌کش‌های رایج، با استفاده از روش‌های مختلف از جمله تماسی، تدخینی، قرارگیری آفات در معرض باقیمانده‌های خشک گوگرد روی سطح برگ و تخم‌کشی در شرایط کنترل‌شده آزمایشگاهی ارزیابی شدند. بر اساس آزمون‌های مقدماتی، سنجش‌های تماسی از ۱۰۰۰ تا ۵۰۰۰ میلی‌گرم در لیتر و سایر آزمون‌ها از ۱۰۰۰ تا ۲۰۰۰۰ میلی‌گرم در لیتر برای ارزیابی اثرات بالقوه فرمولاسیون‌های گوگرد استفاده شدند. آزمون‌های تماسی در غلظت ۵۰۰۰ میلی‌گرم در لیتر پس از ۷۲ ساعت باعث ۱۰۰ درصد مرگ‌ومیر در هر دو گونه شدند. آزمون‌های تدخینی در غلظت ۲۰۰۰۰ میلی‌گرم در لیتر، ۹۳ تا ۹۴ درصد برای *T . urticae* و ۸۸ درصد برای *A. pistaciae* در هر دو فرمولاسیون مرگ و میر ایجاد کردند. اثرات باقیمانده‌های خشک گوگرد روی سطح برگ و تخم‌کشی ناچیز بودند. به‌طوری حداکثر مرگ‌ومیر ناشی از باقیمانده‌های خشک گوگرد روی سطح برگ کمتر از 13/33 درصد و تفریخ تخم بیش از 75 درصد در تمام تیمارها بود. این نتایج تأیید می‌کند که گوگرد عمدتاً از طریق مسیرهای تماسی و تدخینی عمل می‌کند. اما اثرات باقی‌مانده خشک گوگرد روی سطح برگ و تخم‌کشی محدودی دارد. این ویژگی، استفاده استراتژیک از فرمولاسیون‌های گوگردی را در برنامه‌های مدیریت تلفیقی آفات (IPM) با هدف قرار دادن مراحل متحرک این آفات تأیید می‌کند.