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Article

Mite incidence in Egyptian storage facilities and acaricidal activity of selected monoterpenes, phenylpropenes, and sesquiterpenes against *Suidasia medanensis* Oudemans (Astigmata: Suidasiidae), a formidable storage mite pest

Anar A. Bakr[1*], Mona M.G. Saad[2] and Samir A.M. Abdelgaleil[2]

1. *Department of Applied Entomology and Zoology, Faculty of Agriculture, El-Shatby, Alexandria University, Alexandria 21545, Egypt; E-mail: anarabdallh@alexu.edu.eg*
2. *Department of Pesticide Chemistry and Technology, Faculty of Agriculture, El-Shatby, Alexandria University, Alexandria 21545, Egypt; E-mails: mona.mgs72@gmail.com, samirabdelgaleil@gmail.com*

[*] Corresponding author

ABSTRACT

Mite pests cause significant postharvest losses to the world's food supply, where substandard storage conditions and lack of effective control enable mites to replicate. Therefore, the aim of this study was to assess mite infestation risk and determine the acaricidal efficacy of some monoterpenes, phenylpropenes, and sesquiterpenes against one of the most prevailing mite pests found in Egyptian storage facilities. A screening mite survey was conducted on bran and flour samples obtained from commercial stores and flour mills in Alexandria, Egypt between June and December 2019. Eight mite taxa belonging to five families were identified. *Tyrophagus putrescentiae* (Schrank) (Acaridae) and *Suidasia medanensis* Oudemans (Suidassidae) were the most dominant species, each representing ≃ 40% of the total mite count (142,988 individuals). *Cheyletus malaccensis* Oudemans (Cheyletidae) was the most abundant predatory mite recorded in both storage sites. The contact toxicity of eight compounds belonging to monoterpenes, phenylpropenes, and sesquiterpenes was evaluated against the adults of *S. medanensis*. *trans*-Cinnamaldehyde showed the highest acaricidal activity, followed by eugenol, cuminaldehyde, (*Z*,*E*)-nerolidol and farnesol with LC_{50} values of 0.007, 0.028, 0.036, 0.042 and 0.048 mg/cm^2, respectively, after 24 h of treatment. The toxicity of all compounds against the adults increased after 48 h, indicating that the effectiveness of compounds improved with increase of exposure time. On the other hand, the tested compounds showed different levels of repellent activity against *S. medanensis* adults after 1 and 6 h of treatment. The highest repellent effects were observed in the case of (*Z*,*E*)-nerolidol and farnesol displaying repellency of 92.0–96.3 and 81.4–92.1%, respectively, after 1 h of treatment. In contrary, (-)-citronellal and cuminaldehyde showed the lowest repellent effect. These results indicate that the tested compounds, particularly phenylpropenes and sesquiterpenes, could be effective candidates for the management of *S. medanensis* in storage products.

KEY WORDS: Contact toxicity; mite survey; repellency; stored product mites; terpenes.

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INTRODUCTION

Mite infestation impacts a wide range of stored agriculture and food products making commodities unacceptable to humans and livestock. Storage mites can cause grave economic losses by feeding

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directly on the product (Rajashekar *et al*. 2012; Dhooria 2016) and endanger the public health by contaminating stored food with allergens (Reichmuth *et al*. 2008; Stejskal and Hubert 2008). In addition, they may serve as vectors of infectious bacteria and toxigenic molds (Franzolin *et al*. 1999). The level of damage caused by mites is in direct relation with the number of species present in the commodity and the size of the population of each species (Iatrou *et al*. 2010).

There are numerous studies focusing on other important arthropod pests associated with stored products such as insects, however, data about mites is still insufficient. Reliable assessment of mite species distribution and infestation level through sampling in a given region is considered a key factor in planning an efficient management tactic. Application of synthetic acaricides is a common strategy for mite control in warehouses. Although effective and economic, such practices have resulted in mixed problems concerning human health and the environment (Collins 2006). The evolution of acaricide-resistant pest strains is an additional problem that was posed due to the continuous use of chemicals in stored-product protection (Szlendak *et al*. 2000; Van Leeuwen *et al*. 2010).

Among the various secondary plant metabolites, essential oils and their constituents have drawn attention in previous years as a promising alternative to conventional acaricides (Macchioni *et al*. 2002; Assis *et al*. 2011; Insung *et al*. 2016). Plant secondary metabolites showed acaricidal properties against *Tyrophagus putrescentiae* (Acaridae) and *Dermatophagoides* spp. (Pyroglyphidae), the most common mite species of stored products and house dust worldwide (Sánchez-Ramos and Castañera 2000; Kim *et al*. 2004; Jeong *et al*. 2009). Conversely, little is known about the acaricidal efficacy of these plant secondary metabolites against other pestilential storage mite pests. Although mites are important arthropod pests of stored products, information about their occurrence and control using alternative methods in Egypt is very limited. Therefore, the main purpose of this study is screening mite species that are currently associated with some selected stored products in two types of storage facilities in Alexandria, Egypt. In addition, the acaricidal activity of some monoterpenoids, phenylpropenes, and sesquiterpenes against adults of *Suidasia medanensis* Oudemans (Suidassidae), one of the most prevailing mite species found in our screening survey, was also evaluated.

MATERIALS AND METHODS

Mite rearing

A stock culture of *S. medanensis* was originally collected from infested flour samples obtained from flour mills in Alexandria, Egypt. The mites were reared in plastic flasks under laboratory conditions as described by Bakr (2018). Individuals were fed on a mixture of bran, flour, and yeast (40:10:1) at 25 ± 1 °C, 80 ± 5% RH and kept in complete darkness. Mite cultures had been maintained in the laboratory for about two years without exposure to pesticides. Adults of mixed sex and age were used in toxicity and repellency tests (Palyvos *et al*. 2006; Stara *et al*. 2014).

Test chemicals

Four monoterpenes [(−)-citronellal (95%), cuminaldehyde (98%), (1*R*,2*S*,5*R*)-menthol (98%) and thymol (98%)], two phenylpropenes [*trans*-cinnamaldehyde (99%) and eugenol (99%)] and two sesquiterpenes [farnesol (95%) and (Z,E)–nerolidol (98%)] were purchased from Sigma–Aldrich Chemical Co., Steinheim, Germany.

Mite survey procedure

A total of 48 samples of flour and wheat bran were collected from commercial stores and flour mills in Alexandria Governorate, Egypt between June and December 2019. Samples (100 g) were taken into plastic bags at biweekly intervals and directly transferred to the laboratory for subsequent experiments. The Berlese-Tullgren funnel was used for mite collection. Collected mites were preserved in 70% ethanol in glass jars. After vigorous shaking, one ml alcohol portions were taken from each jar for mite counting. Counted mites were then multiplied by the alcohol volume in each jar to assess the total number of mites per 100 g (Çobanoğlu 2009). For identification, mites were mounted in Hoyer's medium then examined using light microscopy (Zeiss, Germany) following the identification keys of Hughes (1976), and Krantz (1978).

Contact toxicity bioassay

The acaricidal activity of four monoterpenes, two phenylpropenes as well as two sesquiterpenes was tested against *S. medanensis* adults via contact toxicity method. Stock solutions of these compounds were prepared in hexane, which did not display any toxicity in preliminary trials. A volume of 250 µl of compound solution was applied using a micropipette into a small glass vial (2 cm diameter × 3 cm height) to give final concentrations of 0.002, 0.004, 0.008, 0.01, 0.02, 0.04, 0.08, 0.1, 0.2 and 0.4 mg/cm^2. After solvent evaporation (5 min.), a group containing 10 adults of *S. medanensis* was transferred into each vial. Control vials received 250 µl of hexane. All treatments including controls were replicated three times. The vials were then covered by a nylon mesh. Treated and control vials were held at the same optimum rearing conditions described earlier. To assess adult mortality, mite individuals were considered to be dead if they did not exhibit movement under a physical stimulus. Mite mortality was recorded after 24 and 48 hours of exposure and corrected using Abbott's formula (Abbott, 1925).

Repellency test

To investigate the repellent effect of the compounds, a choice test was set up following the method of De Geyter *et al*. (2011) with some modifications. Glass slides (2 × 7 cm) were smeared using a camel hair brush on one half of the slide with 250 µl tested solution, and on the other half with 250 µl hexane. The compounds were tested at concentrations of 0.02, 0.04, 0.06, 0.08 and 0.1 mg/cm^2. Slides were left to dry and then placed individually in glass dishes (7.5 cm diameter × 1.5 cm height). Subsequently, twenty adults of *S. medanensis* were put on the treated half of slide then the Petri dish was covered by a nylon mesh. For each concentration, three replicates were performed. The number of mites on each half (compound-treated half versus control half) were recorded after one- and six-hour intervals. Repellency (%) was calculated using the formula of Steltenkamp *et al*. (1992):

$$\text{Repellency (\%)} = 100 - [(NT) / (NT + NC) \times 100]$$

where NT is the number of mites on the treated surface, and NC is the number of mites on the hexane-treated control surface.

Statistical analysis

Mite survey and repellency data was analyzed by a one-way analysis of variance (ANOVA). Mean separations were performed by Tukey's Test and differences at $P = 0.05$ were considered significant. The data were checked for normality and homoscedasticity, and transformed when needed. Values of LC_{50} were obtained by subjecting mortality data to probit analysis (Finney 1971). All data analysis was done by using SPSS 21.0 Software (SPSS, Chicago, IL, USA).

RESULTS

Abundance of mite species in commercial stores and flour mills

An assortment of astigmatic, prostigmatic, and mesostigmatic mite species was isolated from bran and flour samples present in both commercial stores and flour mills at Alexandria (Table 1). Acaridae was the most prevailing family found in all samples followed by the family Suidasiidae corresponding to 53.7% and 41.2%, respectively, of the total number of collected mites.

Tyrophagus putrescentiae and *S. medanensis* were the most abundant species in Alexandria storage facilities, representing equal percentages (≃ 40% each) of the total mite count. Two predator mite species were identified during the course of our faunistic survey. The predator *C. malaccensis* Oudemans ranked fifth among the most frequent species found in both storage sites while the predator *Blattisocius keegani* Fox showed low mite incidence only in commercial stores. In addition, the obtained results showed that commercial stores were more heavily infested with mite taxa and individuals than flour mills where the infestation percentages were 65.9% and 34.2%, respectively. Furthermore, the total infestation level was more pronounced in bran samples than in flour in both storage facilities.

Table 1. Dominance of mites encountered on bran and flour in two storage sites in Alexandria, Egypt during 2019.

Mite species	Family	Commercial stores		Flour mills		Total No. of mites	%
		Bran	Flour	Bran	Flour		
***Acarus siro* L.**	Acaridae	-	921	-	646	1567	1.1
***Aleuroglyphus ovatus* (Troupeau)**		9862	1690	6633	-	18,185	12.7
Tyrophagus putrescentiae		42,105	180	1485 0	-	57,135	39.9
Suidasia medanensis	Suidassidae	11,590	20,263	9773	15,599	57,225	40.0
***S. nesbitti* Hughes**		-	978	-	732	1710	1.2
***Dermatophagoides farinae* Hughes**	Pyroglyphidae	3086	734	-	202	4022	2.8
Cheyletus malaccensis	Cheyletidae	578	819	306	83	2786	1.9
Blattisocius keegani	Blattisociidae	358	-	-	-	358	0.2
Total No. of mites		86,579	25,285	31,56	17,262	142,988	
%		48.0	17.9	22.1	12.1		

Counts were done/100 g of product sample. 12 samples were taken/product/storage site. Least significant difference test (LSD) value for mite species is 422.67**, for product types is 211.34** and for storage sites is 211.34*.

Table 2. Contact toxicity of monoterpenes, phenylpropenes, and sesquiterpenes against *Suidasia medanensis* after 24h of exposure.

Compound	LC_{50}[a] (mg/cm^2)	95% confidence interval (CI) (mg/cm^2)		Slope[b] ± SE	Intercept[c] ± SE	(χ^2)[d]	RT[e]
		Lower	Upper				
***trans*-Cinnamaldehyde**	0.007	0.004	0.011	0.85 ± 0.11	1.82 ± 0.21	3.56	1.0
(-)-Citronellal	0.075	0.066	0.086	2.53 ± 0.44	2.86 ± 0.53	0.02	0.09
Cuminaldehyde	0.036	0.030	0.042	2.15 ± 0.29	3.11 ± 0.41	1.65	0.19
Eugenol	0.028	0.022	0.035	1.61 ± 0.21	2.49 ± 0.33	2.07	0.25
Farnesol	0.048	0.003	0.065	3.20 ± 0.46	4.22 ± 0.56	4.29	0.14
(1*R*,2*S*,5*R*)-Menthol	0.096	0.082	0.18	2.14 ± 0.81	2.18 ± 0.90	1.15	0.08
(*Z*,*E*)-Nerolidol	0.042	0.041	0.053	3.41 ± 0.46	4.51 ± 0.56	0.09	0.17
Thymol	0.102	0.086	0.140	2.19 ± 0.46	2.17 ± 0.53	4.00	0.07

a-Lethal concentration for 50% of tested population, b-Slope of the concentration-mortality regression line ± standard error, c-Intercept of the regression line ± standard error, d-Chi-square value, e-Relative toxicity = LC_{50} value of *trans*-Cinnamaldehyde/LC_{50} value of each compound. df = 3.

Acaricidal activity of terpenes and phenylpropenes against S. medanensis

The contact toxicity of the tested compounds against the adults of *S. medanensis* after 24h of exposure expressed as LC_{50} values is shown in Table 2. The tested compounds showed variable levels of contact toxicity against the mite species. *trans*-Cinnamaldehyde was significantly the most potent toxicant against the adults with LC_{50} value of 0.007 mg/cm^2. Eugenol, cuminaldehyde, (*Z*,*E*)-nerolidol and farnesol were also highly toxic to the mite displaying LC_{50} values of 0.028, 0.036, 0.042 and 0.048 mg/cm^2, respectively. In contrary, thymol and (1*R*,2*S*,5*R*)-menthol induced the lowest contact toxicity. The results also revealed that the toxicity improved with increasing the exposure time as all tested compounds caused higher contact toxicity after 48h exposure (Table 3) than after 24h. Afterwards, the activity of the less toxic compounds, (-)-citronellal, (1*R*,2*S*,5*R*)-menthol and thymol, after 24h was strongly improved after 48h. Among the tested compounds, *trans*-cinnamaldehyde was also the most effective compound after 48h of exposure, while thymol was the least toxic one. Also, phenylpropenes were the most toxic to the mite adults, followed by sesquiterpenes and monoterpenes.

Table 3. Contact toxicity of monoterpenes, phenylpropenes, and sesquiterpenes against *Suidasia medanensis* after 48h of exposure.

Compound	LC_{50}[a] (mg/cm^2)	95% confidence interval (CI) (mg/cm^2)		Slope[b] ± SE	Intercept[c] ± SE	(χ^2)[d]	RT[e]
		Lower	Upper				
***trans*-Cinnamaldehyde**	0.005	0.000	0.012	1.11 ± 0.12	2.58 ± 0.24	4.17	1.0
(-)-Citronellal	0.045	0.038	0.050	3.31 ± 0.47	4.45 ± 0.57	2.31	0.11
Cuminaldehyde	0.028	0.008	0.041	1.78 ± 0.25	2.76 ± 0.33	6.82	0.18
Eugenol	0.021	0.018	0.025	1.72 ± 0.23	2.87 ± 0.37	0.70	0.24
Farnesol	0.036	-	-	1.75 ± 0.38	2.53 ± 0.55	2.44	0.14
(1*R*,2*S*,5*R*)-Menthol	0.057	0.040	0.119	0.83 ± 0.28	1.03 ± 0.39	0.68	0.09
(*Z*,*E*)-Nerolidol	0.041	0.002	0.055	3.78 ± 0.50	5.26 ± 0.61	4.84	0.12
Thymol	0.064	0.058	0.071	3.10 ± 0.45	3.70 ± 0.53	1.75	0.08

a-Lethal concentration for 50% of tested population, b-Slope of the concentration- mortality regression line ± standard error, c-Intercept of the regression line ± standard error, d-Chi-square value, e-Relative toxicity = LC_{50} value of *trans*-Cinnamaldehyde/LC_{50} value of each compound. df = 3.

Repellency of terpenes and phenylpropenes on S. medanensis

The repellency of the different concentrations of tested compounds on the adults of *S. medanensis* after 1 and 6 h of treatment is summarized in Table 4. The results clearly indicate that the repellent activity improved with increasing the compound concentration but there was no clear effect of exposure time on the repellent effect of compounds. Among the tested compounds, (*Z*,*E*)-nerolidol showed the highest repellent effect with repellency ranging between 92.0 and 96.3% after 1h of treatment. Also, farnesol exhibited potent repellent effect at the tested concentrations displaying repellency ranging between 81.4 and 92.1%. (-)-Citronellal and cuminaldehyde were the less active compounds at all of the tested concentrations with repellency of 13.0 and 15.2% at 0.1 mg/cm^2, respectively. The other compounds caused high repellency action only at the highest two concentrations (0.08 and 0.1 mg/cm^2). Comparing the repellent effects of compounds after 1 and 6h of treatment revealed that there were slight changes (increase or decrease) in the repellent activities. It was also clear that sesquiterpenes possessed higher repellent effects than monoterpenes and phenylpropenes.

DISCUSSION

The results of our study confirmed that flour and wheat bran stored in Egyptian facilities were subjected to serious infestation by mite taxa, in particular *T. putrescentiae* and *S. medanensis*. The toxicity and repellency of some plant-derived extracts were also confirmed against *S. medanensis* which is one of the most harmful pests of the selected materials. Flour and wheat bran are the main components used in making bread, which is a staple food of Egyptian citizens. The preservation and storage of these products are critical steps in their production process and subsequent utilization to maintain food security.

Table 4. Repellency of monoterpenes, phenylpropenes, and sesquiterpenes on *Suidasia medanensis* after 1 and 6h of exposure.

Compound	Concentration (mg/cm^2)	Repellency (% ± SD)	
		1h	6h
***trans*-Cinnamaldehyde**	0.02	15.7 ± 3.57no	11.7 ± 1.22mno
	0.04	15.7 ± 3.57no	31.6 ± 4.49jk
	0.06	31.2 ± 1.02kl	33.5 ± 4.12ijk
	0.08	53.3 ± 1.43i	59.9 ± 0.96g
	0.1	72.7 ± 2.62fgh	63.8 ± 4.29fg
(-)-Citronellal	0.02	3.2 ± 1.70qr	1.2 ± 0.31p
	0.04	4.3 ± 0.89pqr	4.1 ± 0.96op
	0.06	2.3 ± 0.76r	4.0 ± 0.99op
	0.08	10.5 ± 2.94opq	9.8 ± 1.33nop
	0.1	13.0 ± 0.45nopq	14.3 ± 1.77mn
Cuminaldehyde	0.02	10.5 ± 2.41opq	14.1 ± 1.82mno
	0.04	14.3 ± 1.99nop	14.6 ± 0.71mn
	0.06	14.6 ± 1.33nop	17.9 ± 2.22lmn
	0.08	16.0 ± 3.60no	16.5 ± 3.19lmn
	0.1	15.2 ± 1.78no	21.3 ± 2.73lm
Eugenol	0.02	22.8 ± 3.49lmn	39.6 ± 2.71hij
	0.04	42.59 ± 2.21i	43.6 ± 1.70hi
	0.06	78.9 ± 5.28efg	86.0 ± 2.0bcd
	0.08	80.9 ± 1.53defg	90.1 ± 2.03abc
	0.1	83.4 ± 2.20bcde	87.6 ± 2.60bcd
Farnesol	0.02	81.4 ± 4.27defg	68.0 ± 2.41fg
	0.04	82.64 ± 1.34cdef	84.2 ± 2.55cd
	0.06	90.2 ± 2.73abcd	92.2 ± 3.27abc
	0.08	92.1 ± 1.85abc	90.2 ± 3.52abc
	0.1	90.7 ± 1.15abcd	91.6 ± 6.01abc
(1*R*,2*S*,5*R*)-Menthol	0.02	21.0 ± 2.46lmn	15.3 ± 0.99mn
	0.04	18.9 ± 1.85lmno	25.7 ± 3.61kl
	0.06	41.2 ± 1.79jk	62.1 ± 2.92fg
	0.08	64.3 ± 4.88h	70.5 ± 5.10ef
	0.1	73.0 ± 3.62fgh	71.7 ± 0.76ef
(*Z*,*E*)-Nerolidol	0.02	92.0 ± 3.22abc	92.2 ± 4.78abc
	0.04	92.3 ± 5.68abc	92.2 ± 3.0abc
	0.06	93.7 ± 4.02a	93.1 ± 1.91abc
	0.08	93.3 ± 5.77ab	100 ± 0.0a
	0.1	96.3 ± 5.48a	95.6 ± 5.09ab
Thymol	0.02	27.2 ± 3.18lm	45.0 ± 3.42h
	0.04	64.5 ± 3.51h	67.0 ± 3.69fg
	0.06	71.7 ± 2.37gh	79.1 ± 3.26de
	0.08	82.1 ± 2.83cdef	79.9 ± 5.15de
	0.1	86.9 ± 4.14abcde	87.8 ± 4.04bcd
Significance		$F(39, 80) = 361.4$, $P = 0.05$	$F(39, 80) = 359.6$, $P = 0.05$

Means within columns followed by the same letter(s) are not significantly different at P = 0.05 by Tukey's test.

During the course of our survey, eight mite taxa were recorded, mostly belonging to the Astigmata (six taxa). Among these, *T. putrescentiae* and *S. medanensis* were found to be the most prevalent species collected in our study, although the former preferred to settle on bran more than on flour and vice versa for the later. Given the improved conditions of mite development, it is probable that wheat bran may provide a better nutritional value for *T. putrescentiae* than offered by flour and conversely for *S. medanensis*. *Tyrophagus putrescentiae* has been found as a dominant pest in an extremely wide variety of commodities containing high fat and protein content (Hughes 1976; Palyvos *et al*. 2008). In addition, our results are in agreement with Bakr (2000), Assis *et al*. (2011) and Zannou *et al*. (2013), who reported that *S. medanensis* was the predominant species commonly associated with stored products in tropical and subtropical regions.

Moreover, the predator *C. malaccensis* was isolated in our survey from the two examined substrates in both storage sites. This species is a free-living predator that is widespread in different foods associated especially with astigmatic mites, on which it feeds (Zaher *et al*. 1986; Cebolla *et al*. 2009; Zannou *et al*. 2013). Although this mite has been used to control storage mite pests, it sometimes fails to solely eliminate high mite infestation (Žd'árková 1998). Recently, Bakr and Selim (2019) reported that the combination of *C. malaccensis* and spinosad, a chemical product based on bacteria, significantly enhanced the control efficiency against astigmatic storage mites.

Additionally, our results confirmed that the mite fauna in flour mills was less abundant, both in terms of the number of species and individuals, than in commercial stores, and that may be due to the application of contact insecticides or fumigants and the implementation of preventative hygiene tactics. Still, the sizable mite numbers in both investigated sites have highlighted the need for the development of more efficient alternatives in controlling storage mites.

The results of contact toxicity of monoterpenes, phenylpropenes, and sesquiterpenes against *S. medanensis* indicated that the tested compounds possess promising acaricidal activity. To the best of our knowledge, this is the first report on the acaricidal activity of these compounds against *S. medanensis*. However, some of the tested compounds have been shown to possess acaricidal activity against other mite species. For example, cuminaldehyde, (1*R*,2*S*,5*R*)-menthol, thymol and (-)-citronellal have been described to have contact and fumigant toxicities against *Tetranychus urticae* with cuminaldehyde (LC_{50} = 0.31 mg/L air) being the most effective as fumigant toxicant and (1*R*,2*S*,5*R*)-menthol (LC_{50} = 128.5 mg/L) being the most effective contact toxicant (Badawy *et al*. 2010; Abdelgaleil *et al*. 2019).

In the current study, *trans*-cinnamaldehyde was the most potent compound against *S. medanensis*. This finding is supported by earlier studies in which this compound showed strong acaricidal activity against other mite species. Kim *et al*. (2004) found *trans*-cinnamaldehyde to be a potent toxicant against *T. putrescentiae* with LD_{50} of 1.12 mg/cm^2, this compound was more toxic than the reference acaricides, benzyl benzoate, DEET and dibutyl phthalate. Moreover, it has been also reported that *trans*-cinnamaldehyde was highly effective to kill *Psoroptes cuniculi* (Shen *et al*. 2012). Eugenol displayed strong contact toxicity against *S. medanensis* in our study. Similarly, eugenol has been reported to possess potent acaricidal activity against *T. putrescentiae* and *Suidasia pontifica* with LC_{50} values of 0.23 and 0.57 µl/L, respectively (Assis *et al*. 2011). Kim *et al*. (2003) also evaluated the toxicity of eugenol using impregnated fabric disc against *T. putrescentiae* and found that the compound was highly effective with LC_{50} value of 12.11 mg/cm^2. In addition, eugenol showed great acaricidal activity via contact bioassay against *Dermatophagoides pteronyssinus* and *D. farinae* with LC_{50} values of 3.92 µg/cm^2 and 4.94 µg/cm^2, respectively (Sung and Lee 2005). Although menthol and thymol showed the lowest toxicity against *S. medanensis* in the current study, both compounds have been described to show acaricidal activity against *T. putrescentiae* displaying LD_{50} values of 0.96 and 11.70 mg/cm^2 (Lee *et al*. 2006; Park *et al*. 2014). Furthermore, thymol had a high acaricidal activity against *Varroa destructor* as its LC_{50} value was 4.65 µg/Petri dish at 24 h (Natalia *et al*. 2009).

Besides their strong contact toxicity, the tested compounds revealed pronounced repellent activity against *S. medanensis*, particularly (*Z*,*E*)-nerolidol, farnesol, thymol and (1*R*,2*S*,5*R*)-menthol (Table 4). There were no reported studies on the repellency of the tested compounds against this mite. The strong repellency of (*Z*,*E*)-nerolidol observed in this study is supported by earlier study in which (*Z*,*E*)-nerolidol revealed high repellency (83.2 ± 0.59%) against *T. urticae* (Araújo *et al*. 2012). Our results indicated that thymol showed higher repellent effect than eugenol, *trans*-cinnamaldehyde, (1*R*,2*S*,5*R*)-menthol and (-)-citronellal, respectively, against *S. medanensis* (Table 4). Furthermore, eugenol and *trans*-cinnamaldehyde revealed equal repellent effect (Table 4). Similar findings were concluded by Tak and Isman (2017) on the repellent activity of these compounds against *T. urticae*. The repellency (%) of thymol, eugenol, *trans*-cinnamaldehyde, (1*R*,2*S*,5*R*)-menthol and (-)-citronellal were 93.3, 86.7, 86.7, 60.0 and 60.0%, respectively, at concentration of 10 mg/ml against *T. urticae*. The strong repellency of thymol observed in this study is also supported by a study of Tabari *et al*. (2017) who found that this compound induced > 90% repellency on *Ixodes ricinus* at concentrations ranged between 0.25 and 5%. In addition, some of the tested compounds, such as *trans*-cinnamaldehyde, eugenol and (-)-citronellal have been shown to possess repellent effect against *Tribolium castaneum* (Saad *et al*. 2019). Also, eugenol and (-)-citronellal revealed significant repellent against *Callosobruchus maculatus* and *Sitophilus zeamais* (Reis *et al*. 2016). Furthermore, (1*R*,2*S*,5*R*)-menthol was found to be strongly repellent (82–100% at 0.353 $\mu g/cm^2$) against *C. maculatus*, *Rhyzopertha dominica*, *S. oryzae* and *T. castaneum* (Aggarwal *et al*. 2001). Few reports indicated that repellents work by modifying the pest behavior leading to the pest avoiding contact with such compound (Nerio *et al*. 2010)

Investigation the relationship between chemical structure and acaricidal activity of tested compounds revealed that phenylpropenes, *trans*-cinnamaldehyde in addition to eugenol, were more potent than sesquiterpenes, farnesol, and (*Z*,*E*)-nerolidol, while monoterpenes were the less effective compounds except cuminaldehyde. Similarly, Lee *et al*. (2006) demonstrated that eugenol (phenylpropene) had higher acaricidal activity than thymol (monoterpene) against *T. putrescentiae*. Among phenylpropenes, *trans*-cinnamaldehyde (an aldehyde) showed higher toxicity than eugenol (an alcohol). Similar finding was observed on the contact toxicity of both compounds against *S. oryzae* (Saad *et al*. 2018). In the case of monoterpenes, cuminaldehyde (a cyclic aldehyde) displayed higher toxicity than (-)-citronellal (an acyclic aldehyde) and alcohols [(1*R*,2*S*,5*R*)-menthol and thymol. These observations raise the possibility that the toxicity is augmented due to the presence of a carbonyl group. Zhang *et al*. (2016) noticed that the structure of compound and the forms of its functional groups can greatly affect its biological efficacy. Moreover, they reported that the presence of the carbonyl group in many terpenes that were investigated has increased the toxicity of these compounds against *Drosophila melanogaster*.

The mode of action of monoterpenes, phenylpropenes, and sesquiterpenes on mites is not completely studied. Therefore, the exact acaricidal mode of action of these compounds remains unspecified. Nevertheless, the toxicity of some monoterpenes and phenylpropenes on insects has been reported to be related to the inhibition of AChE activity and GABA receptors (Enan 2001; Garcia *et al*. 2005). Monoterpenes, (1*R*,2*S*,5*R*)-menthol, thymol, cuminaldehyde and (-)-citronellal, showed inhibitory effect on the activity of AChE isolated from *T. urticae* (Badawy *et al*. 2010; Abdelgaleil *et al*. 2019). Furthermore, Isman (1999) and Kim *et al*. (2003) suggested that the acaricidal activity of phenylpropenes was related to the interaction with octopaminergic receptors. Additional studies are needed to recognize the precise mode of action of these compounds on mites.

Based on our results, the monoterpenes, phenylpropenes, and sesquiterpenes may present a useful approach as safe acaricides in control of *S. medanensis*. Taking into account some advantages of these compounds, such as low mammalian toxicity and less persistence in environment (George *et al*. 2014), the use of these compounds in integrated control of mites is highly recommended. However, further studies are required on the formulations and the acaricidal modes of action of these compounds.

STORAGE MITES IN ALEXANDRIA AND ACARICIDAL ACTIVITY OF SOME TERPENS ON *S. MEDANENSIS*

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18

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بروز کنه‌ها در انبارهای مصر و فعالیت کنه‌کشی مونوترپن‌ها، فنیل‌پروپن‌ها و سسکوی‌ترپن‌های منتخب در برابر *Suidasia medanensis* Oudemans (Astigmata: Suidasiidae) کنهٔ آفت انباری مهیب

أنار عبدالله بکر*، منی جبریل سعد و سمیر محمدعبدالجلیل

۱. گروه حشره‌شناسی و جانورشناسی، دانشکدهٔ کشاورزی، الشاطبی، دانشگاه اسکندریه، اسکندریه ۲۱۵٤۵، مصر؛ رایانامه: anarabdallh@alexu.edu.eg

۲. گروه شیمی و فناوری آفت‌کش‌ها، دانشکدهٔ کشاورزی، الشاطبی، دانشگاه اسکندریه، اسکندریه ۲۱۵٤۵، مصر؛ رایانامه‌ها: mona.mgs72@gmail.com ، samirabdelgaleil@gmail.com

* نویسندهٔ مسئول

چکیده

کنه‌های آفت موجب تلفات زیادی پس از برداشت به منابع غذایی جهان می‌شوند، جایی که شرایط ذخیره‌سازی نامرغوب و نبود کنترل موثر کنه‌ها را قادر به تکثیر می‌کند. بنابراین، هدف از این مطالعه ارزیابی خطر آلودگی کنه‌ها و تعیین اثر کنه‌کشی برخی مونوترپن‌ها، فنیل‌پروپن‌ها و سسکوی‌ترپن‌ها در برابر یکی از شایع‌ترین آفات کنه‌های موجود در انبارهای مصر بود. کنه‌ها از نمونه‌های سبوس و آرد به‌دست‌آمده از فروشگاه‌های تجاری و کارخانه‌های آرد در اسکندریه، مصر بین ژوئن تا دسامبر ۲۰۱۹ غربالگری شدند. هشت گونه کنه متعلق به پنج خانواده شناسایی شدند. کنه‌های *Tyrophagus putrescentiae* (Schrank) (Acaridae) و *Suidasia medanensis* Oudemans (Suidassidae) غالب‌ترین گونه‌ها بودند که هر کدام ٤٠٪≃ از کل تعداد کنه‌ها (۱٤۲۹۸۸ نمونه) را تشکیل می دادند. گونهٔ *Cheyletus malaccensis* Oudemans (Cheyletidae) فراوان‌ترین کنهٔ شکارگر ثبت شده در هر دو انبار بود. سمیت تماس هشت ترکیب متعلق به مونوترپن‌ها، فنیل-پروپن‌ها و سسکوی‌ترپن‌ها در برابر کنه‌های کامل *S. medanensis* مورد بررسی قرار گرفت. ترانس‌سینامالدئید بیشترین فعالیت کنه‌کشی را نشان داد و پس از آن اوژنول، کومینالدئید، (Z,E)-نرولیدول و فارنزول با مقادیر LC50 به ترتیب ۰/۰۰۷، ۰/۰۲۸، ۰/۰۳٦، ۰/۰٤۲ و ۰/۰٤۸ میلی گرم بر سانتی‌متر مربع پس از تیمار ۲٤ ساعت قرار گرفتند. سمیت تمام ترکیبات علیه کنه‌های کامل پس از ٤۸ ساعت افزایش یافت که نشان می‌دهد با افزایش زمان در معرض قرار گرفتن، اثربخشی ترکیبات بهبود می‌یابد. از سوی دیگر، ترکیبات آزمایش شده سطوح مختلفی از اثرهای دورکنندگی را علیه کنه‌های کامل *S. medanensis* در تیمارهای ۱ و ٦ ساعت نشان دادند. بیشترین اثرهای دورکنندگی در مورد (Z,E)–نرولیدول و فارنزول مشاهده شد که به ترتیب دورکنندگی ۹۲/۰–۹٦/۳ و ۸۱/٤–۹۲/۱٪ را در تیمار ۱ ساعت نشان دادند. در مقابل، (–)-سیترونلال و کومینالدئید کمترین اثر دورکنندگی را نشان دادند. این نتایج نشان می‌دهد که ترکیبات آزمایش شده، به ویژه فنیل‌پروپن‌ها و سسکوی‌ترپن‌ها، می‌توانند نامزدهای موثری برای مدیریت *S. medanensis* در محصولات انباری باشند.

واژگان کلیدی: سمیت تماسی؛ بررسی کنه‌ها؛ دورکنندگی؛ کنه‌های انباری؛ ترپن‌ها.

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