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Research Note

Acaricidal and Insecticidal Activities of Essential Oils against a Stored-Food Mite and Stored-Grain Insects

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ABSTRACT

Twenty plant-derived oils were evaluated for their acaricidal and insecticidal activities against *Sitotroga cerealella, Sitophilus oryzae, Sitophilus zeamais,* and *Tyrophagus putrescentiae* adults, by using the fumigant and filter paper diffusion methods. Responses varied with bioassay systems, insect or mite species, plant oils, and exposure time. Based on the 50% lethal dose (LD_{50}) values against *S. oryzae* and *S. zeamais* in the fumigant bioassay, *Anethum graveolens* oil (4.12 and 1.12 μg/cm^3, respectively) induced the highest mortality, followed by *Achillea millefolium* (21.92 and 14.91 μg/cm^3) and *Eucalyptus dives* (28.02 and 24.02 μg/cm^3) oils, respectively. The most toxic oil based on the 50% lethal concentration values against *T. putrescentiae* was *E. dives* (3.13 μg/cm^3), followed by *Melaleuca leucadendron* (3.93 μg/cm^3) and *Leptospermum pertersonii* (4.41 μg/cm^3). *Neroli birgard* oil (1.70 μg/cm^3) was the most toxic based on the LD_{50} values against *S. cerealella,* followed by *Citrus aurantium* (1.80 μg/cm^3) and *Artemisia vulgaris* (1.81 μg/cm^3). The insecticidal and acaricidal activities of the plant oils in the filter paper diffusion bioassay were similar to those in the fumigant bioassay. In comparison, *A. millefolium, A. graveolens,* and *E. dives* oils were more effective against *S. oryzae* and *S. zeamais* in the fumigant bioassay than in the contact bioassay. These results indicate that the insecticidal activity of the three plant oils against *S. oryzae* and *S. zeamais* may be due to their fumigant action. Acaricidal activities of the *A. millefolium, A. graveolens,* and *E. dives* oils against *T. putrescentiae* were 2.62, 1.11, and 122 times higher than that of benzyl benzoate in the contact bioassay. These results indicate that *A. millefolium, A. graveolens,* and *E. dives* oils have potential for development as agents to control stored-grain insects and mites.

Poor postharvest handling and grain storage practices remain major risks facing postharvest quality maintenance *(5, 18)*. The stored-grain situation is serious in the tropics and developing countries where storage pests cause ~40% post- and preharvest food grain losses *(5, 18)*. Postharvest handling and grain storage are key to the human food grains supply, as they influence stored-grain quality and affect food grain security *(5, 18)*. Despite the scientific technologies resulting in increased crop productivity, stored-grain pests have worsened food grain quality, with losses of 20 to 58% in developing countries *(19, 23)*. The extent of damage depends on pest control technologies, grain storage duration, and storage insect species *(19)*. In developing countries and in the tropics, coleopterans (beetles) and Angoumois moths are the major storage pests of grains and stored cereals, and *Sitophilus oryzae, Sitophilus zeamais, Sitotroga cerealella,* and *Tyrophagus putrescentiae* are the most destructive species *(7, 19)*. Control of stored-grain pests depends on continued use of synthetic pesticides *(9)*. However, repeated use of synthetic acaricides and insecticides has increased the risk of environmental pollution and resistance by stored-grain pests and pest resurgence, as well as increased the presence of acaricidal and insecticidal residues after treatment *(9)*. Thus, there is a demand for environmental technologies to control storage insect *(24)* and mite pests.

Essential oils derived from various plants have been used as natural acaricides and insecticides, eating-growth regulators, repellents, and inhibitors *(6, 10, 20)*. Plant-derived oils are important alternative sources to control populations of *S. oryzae, S. zeamais, S. cerealella,* and *T. putrescentiae* because their constituents are rich in bioactive chemicals *(6, 10, 17, 20)*. Studies have shown that low concentrations of plant-derived oils are effective in controlling coleopterans and gelechiid moths *(14, 15)*. In addition, it has been reported that the essential oils extracted from *Achillea millefolium* and *Anethum graveolens* possessed insecticidal activities against beetles, cockroaches, and mosquitoes *(2–4)*. However, few studies on plant-derived oils and their related compounds have been conducted to replace synthetic insecticides and acaricides for controlling storage insect and mite pests. Therefore, the aim of this study was to determine the insecticidal and acaricidal properties of 20 plant oils against *S. oryzae, S. zeamais, S. cerealella,* and *T. putrescentiae,* compared with those of a commercial acaricide.

MATERIALS AND METHODS

Chemicals and plant preparation. Benzyl benzoate (purity 97%) was supplied by Aldrich (Milwaukee, WI). Twenty plant

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TABLE 1. *List of 20 plants tested and yield of essential oils extracted by steam distillation*

Plant species	Family	Tissue sampled	Yield (%)[a]
Artemisia vulgaris	Compositae	Leaf, bud	0.193
Achillea millefolium	Compositae	All plant	0.592
Anethum graveolens	Apiaceae	Seed	3.872
Aconitum koreanum	Ranunculaceae	Seed	0.029
Cimicifuga heracleifolia	Ranunculaceae	Root	0.019
Citrus aurantium	Rutaceae	Peel	1.232
Citrus paradisi	Rutaceae	Peel	0.531
Chrysanthemum indicum	Compositae	Flower	0.099
Clematidis radix	Ranunculaceae	Root	0.039
Daucus carota	Apiaceae	Seed	0.723
Eucalyptus dives	Myrtaceae	Leaf	0.843
Ferula galbaniflua	Apiaceae	Stem	0.165
Leptospermum pertersonii	Myrtaceae	Leaf	0.966
Matricaria recutita	Compositae	Flower	0.759
Melaleuca leucadendron	Myrtaceae	Leaf	1.750
Neroli birgard	Rutaceae	Flower	0.942
Psidium cattleianum	Myrtaceae	Leaf	0.058
Paeonia suffruticosa	Ranunculaceae	Peel	0.074
Tagetes erecta	Compositae	Flower	1.473
Zanthoxylum piperitum	Rutaceae	Peel	0.591

[a] Yield (%) = (dried weight of essential oil/dried weight of sample) × 100.

species were purchased from a market in Chonju, South Korea (Table 1). Each sample (500 g) was oven dried at 41°C for 3 days and powdered using a mill. The oil of each sample was extracted by a steam distillation extraction apparatus, added to anhydrous magnesium sulfate, and then partially concentrated in a rotary evaporator at 40°C to increase the purity of essential oils, except for organic solvents. The essential oils were stored in a refrigerator at 4°C to prevent volatile compounds from evaporating. The yield of each sample extraction is shown in Table 1.

Storage insect pests. Cultures of *S. oryzae, S. zeamais,* and *S. cerealella* were supplied by the National Academy of Agricultural Science (Suwon, South Korea). *S. zeamais* and *S. oryzae* adults were reared on rice grains in plastic containers (31 by 30 by 29 cm), and the *S. cerealella* adults were reared on wheat kernels in plastic cages (44 by 45 by 44 cm). They were maintained at 25 ± 2°C, 64% ± 4% relative humidity, and a 16-h light/8-h dark photoperiod. None of the insects were exposed to any known insecticides during maintenance. The *T. putrescentiae* colony was reared on fry feed no. 1 and dried yeast (1:1, wt/wt) in plastic containers (14 by 12 by 7 cm), containing 31 g of a sterilized diet at 24 ± 1.5°C and 74% relative humidity in the dark *(18)*. The fry feed was supplied by the Korea Special Feed Meal Co., Ltd. (Chonju, South Korea). All storage insect pests were tested in the adult stage: *S. oryzae* (10 to 14 days old), *S. zeamais* (10 to 14 days old), *S. cerealella* (1 to 2 days old), and *T. putrescentiae* (7 to 10 days old).

Bioassay. Acaricidal and insecticidal activities of the 20 plant-derived oils against the four stored-product pests were evaluated by the filter paper diffusion and fumigant methods as described by Jeon and Lee *(12)*. Mixed sex adults were tested in each bioassay.

To evaluate the fumigant toxicities of the samples against *S. oryzae, S. zeamais,* and *S. cerealella,* pieces of filter paper were impregnated with acetone solutions of 20 concentrations (1 to 300 μg/cm^3) of each sample. Filter paper treated with acetone (100 μl) was used as a negative control. After drying in a hood for 11 min, the filter paper was placed in the lid of a petri dish. Thirty stored-product insects were then placed in the petri dish; then, the dish was covered with 55 mesh cloth to avoid direct contact with the sample, and the lid was replaced. *S. oryzae, S. zeamais,* and *S. cerealella* adults in the treated petri dishes were kept under the same conditions as those used for rearing. All treatments were replicated three times, and mortalities were recorded after a 24-h treatment against *S. cerealella* and a 48-h treatment against *S. oryzae* and *S. zeamais*. The fumigant bioassay of the essential oils against *T. putrescentiae* was modified from the method described by Yang and Lee *(26)*. Nine concentrations (2 to 20 μg/cm^3) of each sample were dissolved and applied to a paper disk (8 mm in diameter; Advantec, Tokyo, Japan). We applied the same dose of acetone as a negative control, and benzyl benzoate was used as a positive control and applied to the paper disks. After air drying in a hood for 11 min, each piece was placed in the cap of a microtube (2 ml). Thirty adult mites were placed in the microtubes and the tubes were then sealed with a lid by using a stereomicroscope. Mortality rates were determined after 24 h by using a binocular microscope. The death of mites was established when they did not move when pierced with a pin.

To measure the contact toxicities of the essential oils against *S. zeamais* and *S. oryzae* adults by using a filter paper diffusion method, 20 concentrations (8 to 300 μg/cm^2) of each sample were dissolved in acetone (purity 99.5%; Duksan, Chonju, Korea) and applied to filter paper, with an acetone negative control. Each piece of filter paper was placed in the bottom of a petri dish (5.5 by 1.5 cm) after solvent evaporation in a hood for 11 min. Thirty stored-product insects were placed in the petri dish, and the lid was replaced. The filter paper diffusion method was used to assess contact toxicities of the samples against *T. putrescentiae,* as described by Yang and Lee *(26)*. Ten concentrations (0.06 to 15 μg/cm^2) of test samples were applied to filter paper. Acetone was applied as a control at the same volume. After drying for 11 min in a fume hood, each disk was placed in a petri dish (5 by 1.5 cm), 30 mites were placed in a petri dish, and the lid was sealed. Experiments were conducted at 24 ± 1°C and 74% relative humidity in the dark. All treatments were replicated three times.

Statistical analysis. Mortality percentages of the 50% lethal concentration values were determined and transformed to arcsine square root values for analysis of variance *(22)*. The effects of each treatment were determined to be significantly different at $P < 0.05$.

RESULTS AND DISCUSSION

The insecticidal and acaricidal toxicities of the plant-derived oils against the adult stored-food mite *T. putrescentiae* and adult stored-grain insects *S. cerealella, S. oryzae,* and *S. zeamais* exposed to the fumigants are shown in Table 2. Significant differences in plant-derived oil toxicities were observed for the three insect species. Based on the 50% lethal dose (LD_{50}) values against *S. oryzae,* the essential oil of *Anethum graveolens* (4.12 μg/cm^3) demonstrated the highest mortality, followed by *Achillea millefolium* (21.92 μg/cm^3), *Eucalyptus dives* (28.02 μg/cm^3), *Artemisia vulgaris* (29.04 μg/cm^3), *Matricaria recutita* (111 μg/cm^3), *Daucus carota* (125 μg/cm^3), and *Zanthoxylum piperitum* (194 μg/cm^3) within 48 h after treatment. The LD_{50} value of *A. graveolens* oil against *S. zeamais* was 1.12 μg/cm^3,

TABLE 2. *Acaricidal and insecticidal activities of 20 plant essential oils against four stored-food and -grain pests (three insects and one mite) by using the fumigant method*

Plant species	LD_{50} ± SE (μg/cm^3)			
	S. oryzae[a]	*S. zeamais*[a]	*T. putrescentiae*[b]	*S. cerealella*[b]
A. vulgaris	29.04 ± 2.98	26.01 ± 1.67	—[c]	1.81 ± 0.07
A. millefolium	21.92 ± 3.12	14.91 ± 2.21	7.85 ± 0.23	4.80 ± 0.17
A. graveolens	4.12 ± 0.51	1.12 ± 0.12	11.08 ± 0.72	5.20 ± 0.54
A. koreanum	—	—	—	—
C. heracleifolia	—	—	—	—
C. aurantium	—	—	—	1.80 ± 0.06
C. paradisi	—	—	—	20.3 ± 1.18
C. indicum	—	—	—	—
C. radix	—	—	—	—
D. carota	125 ± 14	117 ± 15	—	2.10 ± 0.12
E. dives	28.02 ± 2.33	24.02 ± 3.51	3.13 ± 0.22	2.60 ± 0.14
F. galbaniflua	—	—	—	7.20 ± 0.58
L. pertersonii	—	—	4.41 ± 0.36	—
M. recutita	111 ± 11	93 ± 10	—	—
M. leucadendron	—	—	3.93 ± 0.37	2.61 ± 0.25
N. birgard	—	—	8.36 ± 0.71	1.70 ± 0.05
P. cattleianum	—	—	—	—
P. suffruticosa	—	—	—	—
T. erecta	—	—	—	—
Z. piperitum	194 ± 19	159 ± 16	15.65 ± 1.89	23.8 ± 3.11

[a] Exposed for 48 h.
[b] Exposed for 24 h.
[c] —, no activity.

followed by *A. millefolium* (14.91 μg/cm^3), *E. dives* (24.02 μg/cm^3), *A. vulgaris* (26.01 μg/cm^3), *M. recutita* (93 μg/cm^3), *D. carota* (117 μg/cm^3), and *Z. piperitum* (159 μg/cm^3) within 48 h after treatment. These results indicate that the *A. graveolens* oil was the most effective for controlling *S. oryzae* and *S. zeamais,* due to the low concentration required to produce potent activity. However, weak or no activity was observed against *S. oryzae* and *S. zeamais* from the other plant-derived oils over a 48-h period at 300 μg/cm^3. No mortalities were observed in the untreated controls.

The most toxic oil against *T. putrescentiae* based on the 24-h 50% lethal concentration values obtained after the fumigant toxicity bioassay was *E. dives* (3.13 μg/cm^3), followed by *Melaleuca leucadendron* (3.93 μg/cm^3), *Leptospermum pertersonii* (4.41 μg/cm^3), *A. millefolium* (7.85 μg/cm^3), *Neroli birgard* (8.36 μg/cm^3), *A. graveolens* (11.08 μg/cm^3), and *Z. piperitum* (15.65 μg/cm^3) (Table 2). *N. birgard* (1.70 μg/cm^3) was the most toxic oil identified from the fumigant toxicity bioassay based on the 24-h LD_{50} values against *S. cerealella,* followed by *Citrus aurantium* (1.80 μg/cm^3), *A. vulgaris* (1.81 μg/cm^3), *D. carota* (2.10 μg/cm^3), *E. dives* (2.60 μg/cm^3), *M. leucadendron* (2.61 μg/cm^3), *A. millefolium* (4.80 μg/cm^3), *A. graveolens* (5.20 μg/cm^3), *Ferula galbaniflua* (7.20 μg/cm^3), and *Z. piperitum* (23.8 μg/cm^3). However, the other plant-derived oils showed relatively little activity against *T. putrescentiae* and *S. cerealella* when applied in the fumigant toxicity bioassay at 20 and 300 μg/cm^3, respectively. No mortality was observed in the untreated controls. Thus, *T. putrescentiae* and *S. cerealella* adults were more susceptible to the plant oils than *S. oryzae* and *S. zeamais* adults in the fumigant toxicity bioassay. A clear dose-response relationship was observed against *S. cerealella* and *T. putrescentiae* adults.

Experiments were conducted to evaluate whether the acaricidal and insecticidal toxicities of the plant-derived oils against *S. oryzae, S. zeamais,* and *T. putrescentiae* adults were attributable to direct contact action (Table 3). The *A. graveolens* oil (12.91 μg/cm^2) produced the highest mortality based on the 48-h LD_{50} values against *S. oryzae,* followed by *E. dives* (112 μg/cm^2), *M. recutita* (184 μg/cm^2), *A. vulgaris* (189 μg/cm^2), *D. carota* (193 μg/cm^2), *Z. piperitum* (262 μg/cm^2), and *A. millefolium* (297 μg/cm^2). The LD_{50} value of *A. graveolens* oil against *S. zeamais* was 9.92 μg/cm^2, followed by *E. dives* (105 μg/cm^2), *M. recutita* (152 μg/cm^2), *A. vulgaris* (166 μg/cm^2), *D. carota* (172 μg/cm^2), *Z. piperitum* (231 μg/cm^2), and *A. millefolium* (287 μg/cm^2) within 48 h after treatment. These results indicate that *A. graveolens* oil was the most effective for controlling *S. oryzae* and *S. zeamais,* owing to the low concentration required to produce potent toxicity. The most toxic oil against *T. putrescentiae* based on the 24-h 50% lethal concentration values obtained from the direct contact toxicity bioassay was *E. dives* (0.09 μg/cm^2), followed by *L. pertersonii* (0.15 μg/cm^2), *A. millefolium* (4.15 μg/cm^2), *N. birgard* (6.05 μg/cm^2), *A. graveolens* (9.37 μg/cm^2), *M. leucadendron* (12.58 μg/cm^2), and *Z. piperitum* (13.94 μg/cm^2). *T. putrescentiae* adults were more susceptible to the plant-derived oils than *S. oryzae* and *S. zeamais* adults in the direct contact toxicity bioassay.

In this study, the acaricidal and insecticidal toxicities varied with bioassay system, plant-derived oil, pest species, and exposure time. Potent acaricidal and insecticidal

TABLE 3. *Acaricidal and insecticidal activities of 20 plant essential oils against three stored-food and -grain pests (two insects and one mite) by using the filter paper diffusion method*

Plant species	LD_{50} ± SE (μg/cm^2)		
	S. oryzae[a]	*S. zeamais*[a]	*T. putrescentiae*[b]
A. vulgaris	189 ± 12	166 ± 13	—[c]
A. millefolium	297 ± 12	287 ± 14	4.15 ± 0.15
A. graveolens	12.91 ± 2.21	9.92 ± 1.82	9.37 ± 0.93
A. koreanum	—	—	—
C. heracleifolia	—	—	—
C. aurantium	—	—	—
C. paradisi	—	—	—
C. indicum	—	—	—
C. radix	—	—	—
D. carota	193 ± 25	172 ± 21	—
E. dives	112 ± 10	105 ± 9	0.09 ± 0.01
F. galbaniflua	—	—	—
L. pertersonii	—	—	0.15 ± 0.05
M. recutita	184 ± 16	152 ± 14	—
M. leucadendron	—	—	12.58 ± 1.35
N. birgard		—	6.05 ± 0.52
P. cattleianum	—	—	—
P. suffruticosa	—	—	—
T. erecta	—	—	—
Z. piperitum	262 ± 24	231 ± 27	13.94 ± 2.41

[a] Exposed for 48 h.
[b] Exposed for 24 h.
[c] —, no activity.

activities against *S. cerealella, S. oryzae, S. zeamais,* and *T. putrescentiae* adults were observed in plants belonging to the families Apiaceae, Compositae, Myrtaceae, and Rutaceae. Jacobson *(11)* reported that the most promising plant insect-control agents are in the families Annonaceae, Asteraceae, Canellaceae, Meliaceae, Labiatae, and Rutaceae. Plant-derived acaricides and insecticides affect a limited range of storage-grain insects, act in various ways on many pests, and have little or no harmful effects on the environment and nontarget organisms *(1, 8).*

Three plant-derived oils were selected according to their strong toxicity based on direct contact toxicity and fumigant toxicity bioassays against *S. cerealella, S. oryzae, S. zeamais,* and *T. putrescentiae* adults and compared with that of benzyl benzoate, the positive control (Table 4). The fumigant toxicity of *A. millefolium, A. graveolens,* and *E. dives* oils was ~3.13 to 19.25 times more toxic than the contact toxicity based on the LD_{50} values against *S. oryzae* and *S. zeamais*. However, for *T. putrescentiae,* the contact toxicity of *A. millefolium, A. graveolens,* and *E. dives* oils was ~1.18 to 34.78 times more toxic than the fumigant toxicity. Lee et al. *(16)* reported that the acaricidal toxicities of piperazine derivatives against *T. putrescentiae* were greater in a contact toxicity bioassay than those in a fumigant toxicity bioassay. Moreover, Kang et al. *(13)* reported that bisabolangelone exhibits strong acaricidal toxicities against *Dermatophagoides farinae* and *Dermatophagoides pteronyssinus,* as analyzed using the fumigant toxicity bioassay. The acaricidal toxicity of bisabolangelone in a contact toxicity bioassay was less than that of positive

TABLE 4. *Acaricidal and insecticidal activities of selected plant oils against four stored-food and -grain pests (three insects and one mite) by using the filter paper diffusion and fumigant methods*

Plant species	Pest species	Bioassay method	LD_{50} ± SE	95% confidence limit	RT (%)[a]
A. millefolium	*S. oryzae*[b]	Filter paper (μg/cm^2)	297 ± 12	281.47–312.53	—
		Fumigant (μg/cm^3)	21.92 ± 3.12	21.65–22.19	—
	S. zeamais[b]	Filter paper (μg/cm^2)	287 ± 14	272.47–302.53	—
		Fumigant (μg/cm^3)	14.91 ± 2.21	14.64–15.18	—
	T. putrescentiae[c]	Filter paper (μg/cm^2)	4.15 ± 0.15	3.87–4.42	2.65
		Fumigant (μg/cm^3)	7.85 ± 0.23	7.58–8.12	2.01
	S. cerealella[c]	Fumigant (μg/cm^3)	4.80 ± 0.17	4.51–5.07	—
A. graveolens	*S. oryzae*[b]	Filter paper (μg/cm^2)	12.91 ± 2.21	12.63–13.19	—
		Fumigant (μg/cm^3)	4.12 ± 0.51	3.85–4.40	—
	S. zeamais[b]	Filter paper (μg/cm^2)	9.92 ± 1.82	9.68–10.20	—
		Fumigant (μg/cm^3)	1.12 ± 0.12	0.84–1.41	—
	T. putrescentiae[c]	Filter paper (μg/cm^2)	9.37 ± 0.93	9.09–9.65	1.11
		Fumigant (μg/cm^3)	11.08 ± 0.72	10.80–11.36	1.42
	S. cerealella[c]	Fumigant (μg/cm^3)	5.20 ± 0.54	4.91–5.49	—
E. dives	*S. oryzae*[b]	Filter paper (μg/cm^2)	112 ± 10	96.47–127.53	—
		Fumigant (μg/cm^3)	28.02 ± 2.33	25.50–30.54	—
	S. zeamais[b]	Filter paper (μg/cm^2)	105 ± 9	89.47–120.53	—
		Fumigant (μg/cm^3)	24.02 ± 3.51	22.49–25.55	—
	T. putrescentiae[c]	Filter paper (μg/cm^2)	0.09 ± 0.01	0.08–0.10	122
		Fumigant (μg/cm^3)	3.13 ± 0.22	3.11–3.15	5.04
	S. cerealella[c]	Fumigant (μg/cm^3)	2.60 ± 0.14	2.31–2.89	—
Benzyl benzoate	*T. putrescentiae*[c]	Filter paper (μg/cm^2)	11.01 ± 0.10	10.52–11.54	1.00
		Fumigant (μg/cm^3)	15.78 ± 0.06	15.54–15.97	1.00

[a] Relative toxicity = LD_{50} value of benzyl benzoate/LD_{50} value of each oil against *T. putrescentiae*. —, not applicable.
[b] Exposed for 48 h.
[c] Exposed for 24 h.

controls. Therefore, *A. millefolium, A. graveolens,* and *E. dives* oils were more effective against *S. oryzae* and *S. zeamais* in the fumigant toxicity bioassay than that in the contact toxicity bioassay. Our results indicate that the insecticidal activity of these three plant oils may be largely due to fumigant action, as they may be toxic when penetrating the insect body via the respiratory system. The insecticidal and acaricidal constituents of plant-derived oils are mainly monoterpenoids *(21)*. Due to their high volatility, fumigant action, which is the action of a compound in the gaseous phase, may be important for toxicity against stored-grain insects. The acaricidal activities of *A. millefolium, A. graveolens,* and *E. dives* oils against *T. putrescentiae* were 2.62, 1.11, and 122 times higher than that of benzyl benzoate in the contact toxicity bioassay and 2.01, 1.42, and 5.04 times higher than that of benzyl benzoate in the fumigant toxicity bioassay. The susceptibility to essential oils is influenced by various biochemical factors (glutathione *S*-transferase, hydrolase, and mixed function oxidase activities), biological factors (insect size, sex, and weight), and bioassay system *(25)*.

In conclusion, the present work indicated that the essential oils extracted from *A. millefolium, A. graveolens,* and *E. dives* have potential insecticidal and acaricidal activities against *S. cerealella, S. oryzae, S. zeamais,* and *T. putrescentiae* adults. Furthermore, it suggests that these oils could be developed as natural insecticidal and acaricidal agents.

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