Toxicity of Five Plant Oils to Adult Tribolium castaneum (Coleoptera: Tenebrionidae) and Oryzaephilus surinamensis (Coleoptera: Silvanidae)

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Source: Florida Entomologist, 101(4) : 592-596

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.101.0420

Toxicity of five plant oils to adult *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Oryzaephilus surinamensis* (Coleoptera: Silvanidae)

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Abstract

Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) and *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae) cause extensive damage to many stored products, thereby reducing their nutritional and economic value. However, controlling these pests with insecticides can have an impact on the environment as well as on human health. Thus, it is important to identify more environmentally safe compounds, such as plant oils, that can be used as an alternative means of pest control. In this study, we investigated the toxicity of 5 plant oils isolated from lavender (*Lavandula angustifolia* Mill., Lamiaceae), onion (*Allium cepa* L., Amaryllidaceae), flax (*Linum usitatissimum* Mill., Linaceae), caraway (*Carum carvi* [Lindl.] H. Wolff, Apiaceae), and brown galingale (*Cyperus fuscus*, or saad L., Cyperaceae) for use on the stored-products insect pests *T. castaneum* and *O. surinamensis*. The efficacy of these oils was evaluated at concentrations of 1, 2, 3, and 4 µL per mL and at an exposure time of 24 h. Results indicated that *O. surinamensis* was more susceptible to plant oils than *T. castaneum*, which showed a greater resistance to these natural products. Results also revealed that caraway and lavender oils were the most toxic of all treatments rendered for *T. castaneum*, with 50% lethal concentration (LC_{50}) values of 1.2 and 2.4 µL per mL, respectively. The onion and lavender oils displayed the highest efficacy on *O. surinamensis* with insect mortality reaching 100% with onion oil and an LC_{50} value for lavender oil of 0.6 µL per mL. These results suggest that onion, lavender, and caraway oils are potentially promising and environmentally acceptable alternatives for the control of *T. castaneum* and *O. surinamensis*.

Key Words: biopesticides; lavender; onion; flaxseed; caraway; saad

Resumen

Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) y *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae) causan daños extensos a muchos productos almacenados, lo que reduce su valor nutricional y económico. Sin embargo, el control de estas plagas con insecticidas puede causar problemas ambientales y de salud. Por lo tanto, es necesario identificar compuestos más seguros para el medio ambiente, como los aceites vegetales, que se pueden usar como un medio alternativo de control de plagas. En este estudio, investigamos la toxicidad de 5 aceites vegetales aislados de lavanda (*Lavandula angustifolia* Mill., Lamiaceae), cebolla (*Allium cepa* L., Amaryllidaceae), lino (*Linum usitatissimum* Mill., Linaceae), alcaravea (*Carum carvi* [Lindl.] H. Wolff, Apiaceae) y galingale marrón (*Cyperus fuscus*, o saad L., Cyperaceae), para su uso contra las plagas de insectos de productos almacenados, *T. castaneum* y *O. surinamensis*. Se evaluó la eficacia de estos aceites a concentraciones de 1, 2, 3 y 4 µL para mL y con un tiempo de exposición de 24 horas. Los resultados indicaron que *O. surinamensis* es más susceptible a los aceites vegetales que *T. castaneum*, que mostró una mayor resistencia a estos productos naturales. Los resultados también revelaron que los aceites de alcaravea y lavanda fueron el tratamiento más tóxico para *T. castaneum*, con valores de concentración letal del 50% (CL_{50}) de 1.2 y 2.4 µL para mL, respectivamente. Los aceites de cebolla y lavanda mostraron la mayor eficacia en *O. surinamensis*, con una mortalidad de insectos que alcanzó el 100% con aceite de cebolla y un valor de CL_{50} para el aceite de lavanda de 0.6 µL para mL. Estos resultados sugieren que los aceites de cebolla, lavanda y alcaravea son alternativas potencialmente prometedoras y ambientalmente aceptables para el control de *T. castaneum* y *O. surinamensis*.

Palabras Clave: bioplaguicidas; lavanda; cebolla; semilla de lino; alcaravea; saad

Agricultural crops are the most important food source for millions of people worldwide. However, in most cases, grains are not used immediately after harvesting, but instead are stored for the next season or exported to other countries. The loss of grain yield during storage can be attributed to many factors, and among those, insect pests are the most important cause of loss because they reduce the quality of the stored grain (Jayakumar et al. 2017).

Unchecked growth of human population has led to numerous and very serious problems, including food shortage. Globally, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) and *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae) are the 2 most important stored-grain pests, damaging 10 to 40% of all stored agricultural crops (Al Qahtani et al. 2012). These beetles feed on grains, dried fruits, flour, sugar, candies, tobacco, and many other plant products intended for human consumption, as well as dried meat (Bilal et al. 2015).

Currently, the intensive use of chemicals for the control of stored-products pests has resulted in serious problems, including pest resistance to insecticides, environmental contamination, the presence of

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unacceptable pesticide residues in foods, and lethal effects on non-target organisms (White & Leesch 1995; Jovanovic et al. 2007; Lu et al. 2011). Botanical insecticides have long been used as alternatives to synthetic insecticides for insect pest management because botanicals pose little threat to the environment or to human health (Isman 2006; Ahmad et al. 2013). Many previous studies have demonstrated the effectiveness of plant oils to control stored-products insects. Magd El-Din (2001) evaluated the efficacy of 3 essential oils to control 3 stored-product insects, among which caraway seed oil demonstrated high toxicity to both insect eggs and adults. Plant oils comprise complex mixtures of monoterpenes, sesquiterpenes, and aromatic compounds (Nattudri et al. 2017), and may act as contact insecticides, antifeedants, repellents, or fumigants (Jayakumar et al. 2017).

Essential oils are interesting natural plant products thatpossess various biological activities, among other qualities. These materials rapidly degrade under ambient air temperature and moisture, and are readily broken down by detoxification enzymes. These features are important for their use as biopesticides, because a rapid breakdown means less persistence in the environment (i.e., lower residual effects), and reduced risks to non-target organisms. Although natural enemies are sensitive to direct contact with such materials, predators and parasitoids that attack the product 1 to 2 d after treatment application are not affected by the toxins (Isman 2006).

In this study, we evaluated the effectiveness of 5 types of plant oils on *T. castaneum* and *O. surinamensis*. These plant oils were selected based on prior knowledge regarding their effective toxicity to control similar pests (Magd-El-Din 2001; Al-Jabr 2006; Lopez et al. 2008; Germinara et al. 2017). These oils also are relatively inexpensive and readily available in most countries.

Materials and Methods

PLANT OILS

Pure plant oils were obtained from Diar Almadina Company in Jeddah, Saudi Arabia (Table 1). We evaluated 4 concentrations of these oils (1, 2, 3, and 4 µL per mL) diluted in acetone, that was used as a solvent because of its rapid evaporation.

INSECT REARING TECHNIQUE

Tribolium castaneum and *O. surinamensis* were collected from infested products obtained from a local market in Albaha City, Saudi Arabia, and reared under laboratory conditions at 27 °C, 70 ± 5% relative humidity, and 12:12 h (L:D) photoperiod. Yeast and flour (5:100 g) were used as food for the insects that were maintained in jars covered with muslin cloth fastened with rubber bands. One- to 3-wk-old adults were collected and used for bioassays (Madkour et al. 2013).

CONTACT TOXICITY BIOASSAY

As a bioassay, we used the thin film technique described by Iwuala et al. (1981). One mL of each concentration of the plant oils was evenly spread over the bottom of a Petri dish. Petri dishes used for control treatments were treated with 1 mL of acetone. Mature adults were exposed to a thin film of plant oils for 24 h, when mortality was recorded following adjustment with Abbott's (1925) formula. Four replicates of 10 adults were used for each concentration treatment.

STATISTICAL ANALYSIS

The data were analyzed using 1-way analysis of variance (ANOVA), followed by Tukey's honest significant difference (HSD) test. Differences were considered significant at $P < 0.05$. The LC_{50} values (oil concentration high enough to kill 50% of the insects) were calculated using Probit analysis (Finney 1964).

Results

The insecticidal activity of lavender, onion, flaxseed, caraway, and saad oils tested on *T. castaneum* are listed in Table 2 and depicted in Figures 1 to 5, respectively. The data indicated that caraway oil was the most toxic of the oils evaluated, causing a mortality rate of 50% at the lowest concentration (1 µL per mL) and 95% mortality at the highest concentration (4 µL per mL), with LC_{50} value of 1.2 µL per mL. For insects treated with lavender oil for 24 h, mortality was 30% at a concentration of 1 µL per mL and 70% at 4 µL per mL. Onion oil was less potent than the 2 aforementioned oils, causing only 5% mortality at a concentration of 1 µL per mL and 90% mortality at 4 µL per mL. Flaxseed and saad oils showed similarly low toxic effects, with LC_{50} values of 4.5 and 4.24 µL per mL, respectively. Results clearly indicated that insect mortality increased with increasing oil concentration. Thus, plant oils can be ranked as follows according to their toxicity to control *T. casteneum*: caraway > lavender > onion > saad > flaxseed.

Insecticidal activity of the 5 plant oils examined on *O. surinamensis* are listed in Table 3, and those of lavender, flaxseed, caraway, and saad oils are depicted in Figures 6 to 9, respectively. Onion oil caused 100% insect mortality at all concentrations that were examined. The LC_{50} value was 0.6 µL per mL for lavender oil, which caused 65% mortality at a concentration of 1 µL per mL and 90% mortality at 4 µL per mL, after a 24 h exposure. Insects treated with saad oil exhibited 60% mortality at a concentration of 1 µL per mL and 90% mortality at 4 µL per mL, with an LC_{50} value of 0.77 µL per mL. Caraway oil caused 100% insect mortality at the highest concentration, with an LC_{50} value 0.81 µL per mL. Flaxseed oil caused 55% and 95% mortality in insects treated at 1 and 4 µL per mL, respectively, and produced an LC_{50} value of 1 µL per mL. Based on these results, plant oils were ranked in the following order according to their toxicity for *O. surinamensis*: onion > lavender > saad > caraway > flaxseed.

Discussion

The results of this study demonstrated that the toxicity of the 5 selected plant oils varied depending on the oil concentration and target

Table 1. Plant oils used in bioassays and source of essential oil.

Common name	Scientific name	Plant family	Plant part
Lavender	*Lavandula angustifolia*	Lamiaceae	Flowers
Onion	*Allium cepa*	Amaryllidaceae	Bulbs
Flaxseed	*Linum usitatissimum*	Linaceae	Seeds
Caraway	*Carum carvi*	Umbelliferae	Seeds
Saad (Brown galingale)	*Cyperus fuscus*	Cyperaceae	Seeds

Table 2. Mortality of *Tribolium castaneum* adults exposed to different concentrations of plant oils.

Plant oil	Concentration (µL per mL)	SD	Mortality (%) (mean ± SE)	Slope function (S ± SE)	LC_{50} (µL per mL)
Lavender	1	11.54	30 ± 5.77 a	1.50 ± 0.13	0.60
	2	5.77	45 ± 2.88 a		
	3	5.77	45 ± 2.88 ab		
	4	0.00	70 ± 0.00 c		
Onion	1	5.77	5 ± 2.88 a	4.5 ± 0.05	—
	2	5.77	15 ± 2.89 b		
	3	17.32	45 ± 8.66 c		
	4	11.54	90 ± 5.77 d		
Flaxseed	1	0.00	10 ± 0.00 a	2.03 ± 0.11	1.00
	2	5.77	25± 2.88 b		
	3	0.00	25 ± 2.88 b		
	4	5.77	55 ± 2.88 c		
Caraway	1	11.55	50 ± 5.77 a	2.56 ± 0.09	0.81
	2	0.00	60 ± 0.00 a		
	3	9.67	80 ± 4.84 b		
	4	5.77	95 ± 2.88 c		
Saad	1	11.55	10 ± 5.77 a	2.23 ± 0.09	0.77
	2	0.00	20 ± 0.00 b		
	3	5.77	25 ± 2.88 c		
	4	23.09	60 ± 11.54 d		

Means within each plant oil followed by different letters are significantly different (P < 0.05; 1-way ANOVA and Tukey's HSD test).

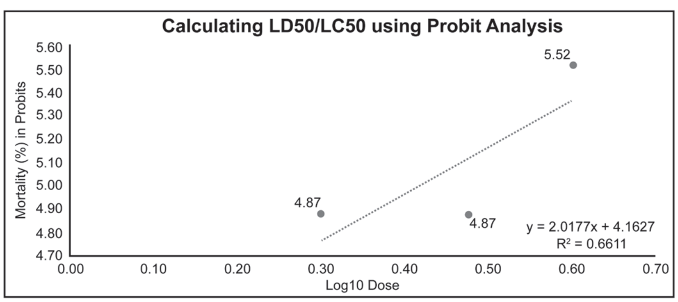

Fig. 1. Log concentration-mortality regression line for the activity of lavender oil on *Tribolium castaneum*.

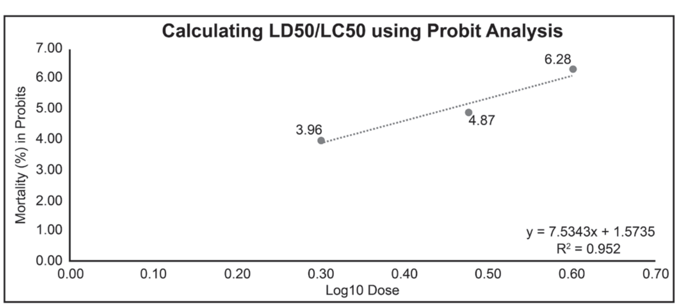

Fig. 2. Log concentration-mortality regression line for the activity of onion oil on *Tribolium castaneum*.

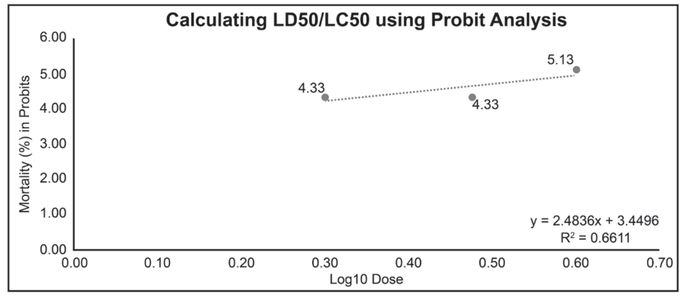

Fig. 3. Log concentration-mortality regression line for the activity of flaxseed oil on *Tribolium castaneum*.

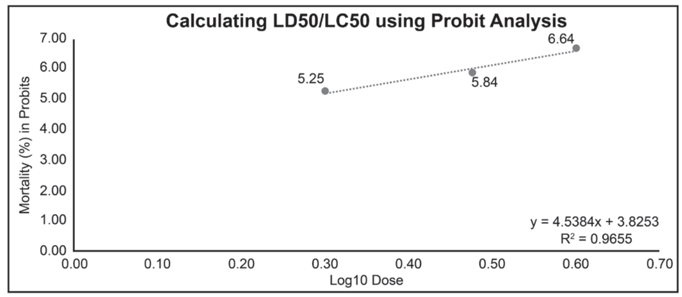

Fig. 4. Log concentration-mortality regression line for the activity of caraway oil on *Tribolium castaneum*.

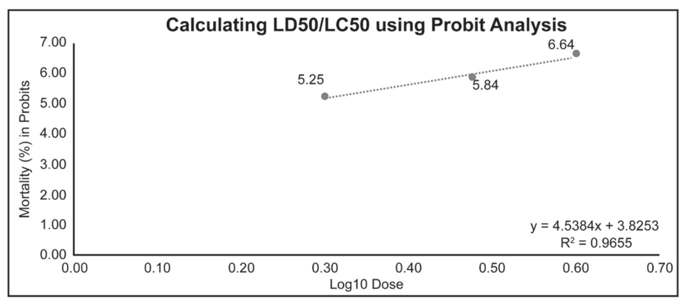

Fig. 5. Log concentration-mortality regression line for the activity of saad oil on *Tribolium castaneum*.

insect species. Caraway, lavender, and onion oils were most effective in controlling *T. castaneum* and *O. surinamensis*. These findings are consistent with the results of previous studies that have investigated the toxic effects of plant oils on these 2 insects (Al-Jabr 2006; Mondal & Khalequzzaman 2006; Ahmed et al. 2009; Lu et al. 2011; Hamed et al. 2012; Madkour et al. 2013; Iieke & Ogungbite 2014; Aref & Farashiani 2015; Khanzada et al. 2015). These studies indicated that edible plant oils affect the developmental stages of *T. castaneum*, resulting in low adult emergence and pest fecundity in grain treated with plant oils.

Talukder et al. (1998) demonstrated that the toxic effects of plant oils are due to the presence of oleic, linoleic, and palmitic acids, and alkalis that may block insect tracheae, thereby inhibiting respiration during contact or fumigation tests. Yoon et al. (2011) showed a repellent effect of lavender oil for the spotted lantern fly, *Lycorma delicatula* (White) (Hemiptera: Fulgoridae) (also referred to as "spot clothing wax cicada" or "Chinese blistering cicada" in the literature) and established that linalool (a monoterpene) was the most effective constituent present in this oil. Similarly, Lucic et al. (2015) demonstrated the toxic effects of the lavender plant parts and essential oil on 3 stored-wheat pests, including *T. castaneum*. Other studies have concluded that plant

Table 3. Mortality of *Oryzaephilus surinamensis* adults exposed to different concentrations of plant oils.

Plant oil	Concentration (µL per mL)	SD	Mortality (%) (mean ± SE)	Slope function (S ± SE)	LC_{50} (µL per mL)
Lavender	1	5.00	65 ± 2.50 a	1.28 ± 0.17	0.60
	2	0.00	70 ± 0.00 b		
	3	5.77	75 ± 2.88 c		
	4	0.00	90 ± 0.00 d		
Onion	1	0.00	100 ± 0.00 a	—	—
	2	0.00	100 ± 0.00 a		
	3	0.00	100 ± 0.00 a		
	4	0.00	100 ± 0.00 a		
Flaxseed	1	17.32	55 ± 8.66 a	2.41 ± 0.10	1.00
	2	11.55	70 ± 5.77 b		
	3	5.77	85 ± 8.66 c		
	4	5.77	95 ± 2.88 d		
Caraway	1	5.77	65 ± 2.88 a	2.41 ± 0.10	0.81
	2	11.54	70 ± 5.77 b		
	3	5.77	95 ± 2.88 c		
	4	0.00	100 ± 0.00 d		
Saad	1	23.09	60 ± 11.55 a	1.51 ± 0.15	0.77
	2	11.55	70 ± 5.77 b		
	3	5.77	75 ± 11.54 c		
	4	0.00	90 ± 11.54 d		

Means within each plant oil followed by different letters are significantly different ($P < 0.05$; 1-way ANOVA and Tukey's HSD test).

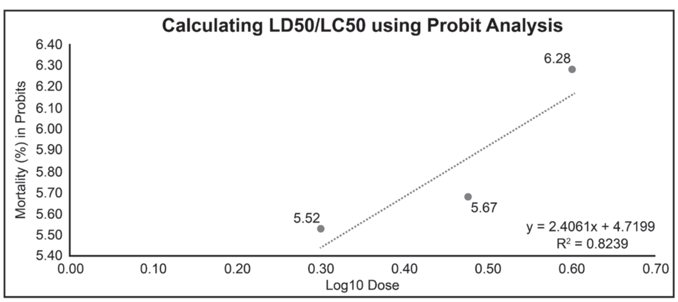

Fig. 6. Log concentration-mortality regression line for the activity of lavender oil on *Oryzaephilus surinamensis*.

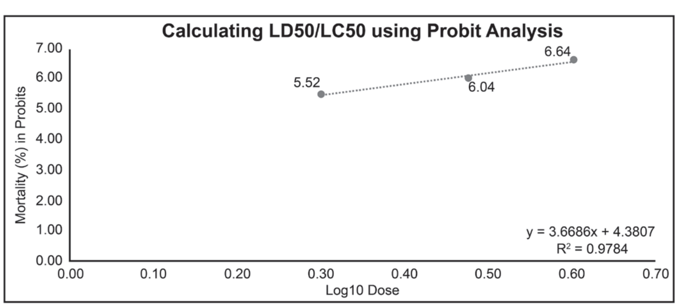

Fig. 7. Log concentration-mortality regression line for the activity of flaxseed oil on *Oryzaephilus surinamensis*.

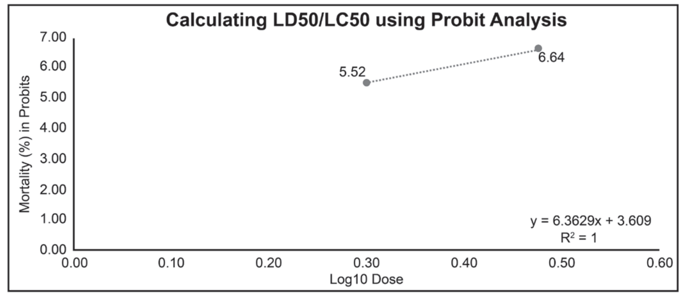

Fig. 8. Log concentration-mortality regression line for the activity of caraway oil on *Oryzaephilus surinamensis*.

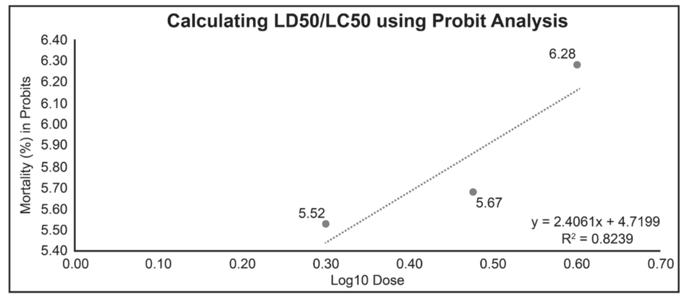

Fig. 9. Log concentration-mortality regression line for the activity of saad oil on *Oryzaephilus surinamensis*.

essential oils from the family Linaceae, including lavender oil, may cause feeding inhibition, repellence, and insecticidal action to control various insect pests (Papachristos & Stamopoulus 2004; Gonzalez-Coloma et al. 2006). Furthermore, Magd-El-Din (2001) demonstrated that caraway oil exhibited a high toxicity for *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae) and other pests. Fang et al. (2010) found that the essential oil of *C. carvi* showed a strong toxicity in controlling *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae) and *T. castaneum* with (*R*)-carvone and D-limonene being the principal toxic constituents for these 2 insects.

Several studies have demonstrated that plant extracts can be more effective in controlling pest insects than individual active compounds, owing to natural synergism, that also may delay the development of insecticide resistance (Yoon et al. 2011; Bilal et al. 2015). In this study, *O. surinamensis* was found to be more susceptible to the toxic effects of the oils, whereas *T. castaneum* was more resistant, as previously reported by Al-Jabr (2006). Interestingly, in the present study we found that *A. cepa* oil was highly toxic to *O. surinamensis*; however, other studies that investigated the effect of *A. cepa* oil on insect pests did not report similar results (Tunaz et al. 2009; Denloye 2010).

In conclusion, the results of the present study indicate that onion, lavender, and caraway oils are promising alternatives for the control of *T. castaneum* and *O. surinamensis* in stored products. Synthetic insecticides cause adverse effects on the environment, including pest resistance, pollution, and toxicity to non-target organisms. Plant essential oils are less likely to elicit pest resistance and are less toxic to the environment. However, further studies are needed to evaluate the cost of these oils and their effectiveness in controlling a wider range of insect pests.

Acknowledgments

The authors would like to thank Fatimah Alzahrani for her assistance during the preparation of the manuscript.

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