Journal of Entomological Research

Volume 12, Issue 2, pages: 1-12

Islamic Azad University, Arak Branch
ISSN 2008-4668
http://jer.iau-arak.ac.ir

Acute toxicity and sublethal effects of extracted essential oils of *Piper nigrum* and *Artemisia khorassanica* on *Trogoderma granarium* (Col.: Dermestidae)

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Abstract

The Khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermestidae), is a serious pest of cereal grains such as wheat. In the present research, the lethal and sublethal effects of essential oils (EOs) from *Piper nigrum* L. and *Artemisia khorassanica* Podl. were determined against 1st instar larvae of *T. granarium*. To study the sublethal effects, 1st instar larvae were exposed to the LC_{30} of each EO, and the life table parameters of the surviving insects were assessed. *Artemisia khorassanica* (LC_{50}: 39.88 µl/liter air) had higher fumigant toxicity for *T. granarium* when compared to *P. nigrum* (LC_{50}: 71.46 µl/liter air). Furthermore, the insecticidal effects of *A. khorassanica* (LT_{50}: 13.51 h) were faster than *P. nigrum* (LT_{50}: 15.75 h). Significant differences in the larval and pupal durations were observed in the EO treatments when compared to the control. In addition, the exposure to sublethal concentration of the EOs tested significantly reduced immature survival rate, adult longevity and fecundity. The net reproductive rate (R_0), intrinsic rate of increase (r) and finite rate of increase (λ) was significantly affected by EOs tested being lowest in the insects exposed to *A. khorassanica*. According to our findings, both EOs tested, especially *A. khorassanica*, are useful for the effective control of *T. granarium* in warehouses.

Key Words: Khapra beetle, essential oil, chemical composition, toxicity effect, life table parameter.

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Received:10 Mar. 2020 – Accepted: 2 Jul 2020

Introduction

Wheat (*Triticum aestivum* L.) is an important grain crop grown around the world (Mebarkia *et al*., 2010). In the storage, the grains are susceptible to several pests of which the Khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermestidae) is one of the most important insect pests (EPPO, 2013, 2015; Mohammadzadeh and Izadi, 2018). It causes substantial quantitative and qualitative losses, and reductions in weight and market value of seeds (Burges, 2008; Majd-Marani *et al*., 2017). Furthermore, the germination of the grains is adversely affected due to larval feeding (Naseri and Borzoui, 2016). Chemical pesticides are extensively used around the world to protect the stored commodities against insect pests (Hori and Kasaishi, 2005; Naseri *et al*., 2017). However, there are reports that *T. granarium* populations have developed resistance to these chemicals (Ghimire *et al*., 2017; Arthur *et al*., 2018; Kavallieratos *et al*., 2019). In addition, those chemicals acting as fumigants leads to pesticide residues in grains and might be toxic for the users if not carefully handled (Borzoui *et al*., 2016).

In view of the problems caused by the application of pesticides and the growing attention for the environmentally benign tools to pest control that minimize these damages, there have been extensive studies on the possible use of plant substances as alternatives to synthetic insecticides (reviewed by Jindal *et al*., 2013). Plant essential oils (EOs) have played a very important role in crop protection against storage pests in different parts of the world (Regnault-Roger, 1997; Campolo *et al*., 2018). These compounds are safe, highly effective, and ecologically acceptable (Viciolle *et al*., 2012; EPA, 2013). Species of the plant genus *Artemisia* and *Piper* have received more attention due to the fact that they are chemically characterized by flavonoids and piperines, respectively (Abad *et al*., 2012. Tran *et al*., 2019). Different essential oils are documented to show acute toxic effects against insect pests. For example, *Piper nigrum* L. has demonstrated contact toxicity to *Spodoptera litura* (Fab.) (Fan *et al*., 2011), and *Artemisia khorassanica* Podl. is acutely toxic to the Angoumois grain moth, *Sitotroga cerealella* Olivier (Naseri *et al*., 2017).

The use of EOs can result in lethal and sublethal effects on insect pests, acting as toxins, antifeedants, and growth regulators. These effects can modify insects' population dynamics by influencing development, survival, and fecundity (Singh *et al*., 2003; Hernández-Lambraño *et al*., 2014; Osman *et al*., 2016; Nouri-Ganbalani and Borzoui, 2017; Abdelgaleil and El-Sabrout, 2018; Gaire *et al*., 2019). A life table is a comprehensive and convenient method for comparing the survival and reproductive potential of a population treated with different pesticides. As the age-stage, two-sex life table approach can accommodate variable development times among individuals and include both sexes, it can accurately display the actual life history of the insect pests and life table have been widely applied in the analysis of population development. In the case of the stored product pests, a considerable amount of work has been published on the effect of EOs on developmental time and life table parameters (Saleem *et al*., 2014; Yang *et al*., 2014; Borzoui *et al*., 2016; Bande-Borujeni *et al*., 2018). However, no life table study of *T. granarium* after exposure to sublethal concentrations of EOs has been published, and only a few studies have examined the effect of EOs on larval and adult development. Understanding the demography of *T. granarium* when exposed to sublethal concentrations of EOs is the cornerstone for developing an ecofriendly management program.

This study reports the lethal effects of *P. nigrum* and *A. khorassanica* on the mortality of first instar of *T. granarium*. The sublethal effects of the essential oils, such as effects on immature survival, longevity, and fecundity, were also evaluated in order to test the compatibility of their use to control *T. granarium*.

Material and Methods

Insects

Khapra beetle was originally collected from stored rice seeds at Karaj, Iran. These insects were reared on broken wheat seeds and were maintained under standard laboratory conditions with a temperature of 33±1°C, 65±5% relative humidity (RH) and a 14:10 (L:D) h photoperiod.

Essential oils

Seeds of *P. nigrum* were collected during summer season from Tehran, Iran (35.6892° N, 51.3890° E) and leaves of *A. khorassanica* from Sabzevar, Iran (36.2152° N, 57.6678° E). Essential oils were extracted from 50 grams of dry materials subjected to hydrodistillation using a modified Clevenger apparatus during 4 h, on a laboratory scale. The extracted oils obtained were dried over anhydrous sodium sulfate and stored in airtight containers in a refrigerator at 4°C.

Gas chromatography/mass spectrometry analysis

After extraction, the EOs was analyzed using a Hewlett–Packard (HP, Palo Alto, CA) HP 7890A GC equipped with a split/splitless injector and 5975C mass selective detector system using electron ionization at 70 eV and 280°C with a Ulbon HR-1 GC column (unless otherwise specified equivalent to a OV-1 fused silica capillary (0.25 mm by 50 m). The carrier gas was helium (99.999%) at a flow rate of 1.0 mL/min. The relative percentage of the individual compounds was calculated by averaging the GC peak area % reports.

Fumigant toxicity

The fumigant toxicity of EOs against first instar larvae of *T. granarium* was evaluated under standard laboratory conditions. Whatman filter papers (No. 1, cut into 2-cm-diameter pieces) were impregnated with an appropriate concentration of *P. nigrum* (40, 55.66, 71.31, 85.87, and 100 µl/liter air) and *A. khorassanica* (20, 29.12, 38.61, 47.70, and 60 µl/liter air) without using any solvent. The saturated filter paper was attached to the undersurface of the cap of a glass bottle (50 ml) and the cap was screwed onto the bottle. The bottles were kept in a growth chamber that was set at the above described standard rearing conditions. Each concentration and control was replicated independently five times where 15 first instar larvae (<24 h old) were released in each replicate. Larval mortality was recorded 24 h after exposure to the essential oils.

A bioassay was conducted to assess the median effective time to cause 50% mortality of *T. granarium* at the highest concentration of *P. nigrum* (100 µl/liter air) and *A. khorassanica* (60 µl/liter air) (Borzoui et al. 2016). The mortality of first instar larvae was recorded at 4-h intervals. Each EO and control was replicated independently five times.

Sublethal effects of *P. nigrum* and *A. khorassanica* on *T. granarium*

In order to assess the potential sublethal effects of the tested EOs on *T. granarium*, about 100 first instar larvae (< 24 h old), obtained from synchronous culture, were treated with LC_{30s} of *P. nigrum* (55.38 µl/liter air) and *A. khorassanica* (28.68 µl/liter air) using the exposure system noted above. The control larvae were not treated with any solvent. After 24 h of exposure and assessment of the proportion of larvae that survived, cohorts of 50 surviving insects were transferred each to an untreated Petri dish (diameter 6 cm, depth 1 cm) containing 0.1 g of broken wheat seeds. The duration of immature stages and their survival were assessed daily. After the emergence of the surviving adults, one male and one female adult were paired in plastic tubes (diameter 2 cm, height 5 cm) containing 1 g of wheat seeds

(Borzoui et al. 2015). The number of pairs of tested adults for each control and treated insects depended on immature survival rate and ranged from 17 to 29 couples. The adults were daily transferred to the new tubes with food provided. The pairs were checked every day, and the eggs laid were counted until the adults died.

The result of each experiment was tested for curve fit using PROC GENMOD procedures (Robertson *et al*., 2007; SAS Institute, 2011), and the data were analyzed using PROC PROBIT in order to determine median lethal concentrations on standard and log scales with associated 95% fiducial limits.

All data on the survival of immature stages, duration of the immature stages, and longevity of adults were analyzed using the age-stage, two-sex life table theory (Chi and Liu, 1985; Chi, 1988). The life history data were compared using the paired bootstrap test, according to the protocol suggested by Chi (2017) and Nouri-Ganbalani *et al*. (2018). The age-specific survival rate (l_x) was calculated for each stage of development, and age-specific fecundity (m_x) for each day of oviposition. The population parameters of net reproductive rate (R_0), intrinsic rate of natural increase (r), finite rate of increase (λ), and mean generation time (T), were calculated to the bootstrap method with 40,000 samples, as suggested by Efron and Tibshirani (1993) and Huang and Chi (2013).

In the age-stage, two-sex life table, l_x and m_x values are calculated as:

$$l_x = \sum_{j=1}^{k} s_{xj}$$

$$m_x = \frac{\sum_{j=1}^{k} s_{xj} f_{xj}}{\sum_{j=1}^{k} s_{xj}}$$

where k is the last stage of the study cohort.

The net reproductive rate (R_0) defined as the total number of offspring that an individual can produce during its lifetime and is calculated as follow:

$$R_0 = \sum_{x=0}^{\infty} l_x m_x$$

The intrinsic rate of increase (r) is calculated by using the iterative bisection method from the Euler-Lotka equation with age indexed from zero as follows:

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$$

The finite rate of increase (λ) is calculated as follows:

$$\lambda = e^{r}$$

The mean generation time (T) is represents as the length of time that a population requires to increase to the R_0-fold of its size at the stable age-stage distribution, and is calculated as follows:

$$T = \frac{\ln R_0}{r}$$

The population parameters were compared using the paired bootstrap test, according to the protocol suggested by Chi (2017), Riahi *et al*. (2016) and Khanamani *et al*. (2017).

Results

Chemical analysis of the essential oils

The results of the chemical analysis of *P. nigrum* and *A. khorassanica* EOs are shown in Tables 1 and 2. Sixty-three compounds were found in the essential oil from *P. nigrum*, while eighty-one compounds were identified in the EO from *A. khorassanica*. Delta 3-Carene (24.6%), trans-Caryophyllene (24.2%), and dl-Limonene (18.3%) for the oil from *P. nigrum*, and Camphor (23.4%), 1,8-Cineole (13.1%), and Levomenol (11.6%) from *A. khorassanica* were detected as major constituents.

Fumigant toxicity

The LC_{50} values of *P. nigrum* and *A. khorassanica* EOs are listed in Table 3. The LC_{50} values show that the EO from *A. khorassanica* (39.88 µl/liter air) was more toxic than *P. nigrum* (71.46 ml/liter air) at 24 h after exposure.

The LT_{50} values of *P. nigrum* and *A. khorassanica* EOs are listed in Table 4. The LT_{50} values show that the time of mortality caused by *A. khorassanica* EO (13.51 h) was shorter than *P. nigrum* (15.75 h).

Sublethal effects of *P. nigrum* and *A. khorassanica* on *T. granarium*

The tested EOs caused multiple sublethal effects on the surviving of *T. granarium* in the bioassays (Table 5, 6, and 7, Fig. 1). Exposure of 1st instar larvae to the sublethal concentrations of tested EOs prolonged the duration of every developmental stage (larvae and pupae) when compared to the control (Table 5). Similarly, a significant difference in adult's longevity between exposure treatments was observed in comparison with control (Table 6). Also, exposure to LC_{30} concentration of *P. nigrum* and *A. khorassanica* significantly reduced reproductive parameters such as oviposition period (4.58 and 3.17 days, respectively) and fecundity (28.76 and 11.29 eggs/female, respectively) when compared to the control condition (6.48 days and 57.03 eggs/female, respectively) (Table 6).

The age-specific survival rate (l_x) and the age-specific fecundity (m_x) of *T. granarium* exposed to EOs tested are shown in Fig. 1. The l_x of immature stages, adult female, and male of *T. granarium* was the highest in the control and the lowest in the *A. khorassanica*-treated insects (Fig. 1). The age-specific fecundity (m_x) describes the number of daily offspring produced by *T. granarium* individuals at age *x* and stage *j*. The maximum m_x in females came from larvae exposed to *P. nigrum* and *A. khorassanica* oils, and control was 2.42, 5.16, and 5.48 eggs female^{-1} d^{-1}, respectively, that occurred at the ages of 74, 83, and 70 d, respectively (Fig. 1)

The sublethal effects of *P. nigrum* and *A. khorassanica* EOs on the life table parameters of *T. granarium* are given in Table 7. Compared with control, the net reproductive rate (R_0) showed significant differences after exposure to the LC_{30} of the tested oils. Also, the intrinsic rate of increase (r) was significantly different between control and treatments. Among tested oils, the population exposed to *P. nigrum* had a much higher r value (0.030 d^{-1}) than those exposed to *A. khorassanica* (0.015 d^{-1}). The finite rate of increase (λ) followed the same pattern as the intrinsic rate of increase. Furthermore, the generation time (T) of the population was different among control and treatments so that *T. granarium* exposed to EOs of *A. khorassanica* had the longest generation times (73.15 d).

Discussion

Both *P. nigrum* and *A. khorassanica* showed highly toxic effects against *T. granarium* larvae in the present study, as it has been shown with other stored product pests (Upadhyay and Jaiswal 2007, Borzouei *et al*. 2016, Hussein *et al*. 2018). The LC_{50} values indicated that the toxicity of *A. khorassanica* was higher than that of *P. nigrum* (Table 3). The differences

in the toxicity of the EOs tested could be attributed to their active volatiles (mostly monoterpenes; especially camphor), which are differently toxic to pests (Chen *et al*., 2013; Tang *et al*., 2013; Fu *et al*., 2015).

Although lethal doses kill insect pests directly, sublethal doses were also shown to affect several aspects of insect life history. These mainly include reduction of egg-laying period, fecundity and egg hatching (Papachristos and Stamopoulos, 2002). In our study, the increase of the immature stages period caused by *P. nigrum* and *A. khorassanica* may be due to the ability of these EOs to penetrate the body and to act on the physiology of *T. granarium* larvae and change its rate of development (Nouri-Ganbalani and Borzoui, 2017). Correspondingly, the fecundity of *T. granarium* females was reduced by 51% and 80% after larval exposure to LC_{30} of *P. nigrum* and *A. khorassanica*, respectively. In another study, Esmaeily *et al*. (2017) reported that a sublethal dose of EO gained from *Artemisia annua* L. negatively affected the larval periods and fecundity of *Tetranychus urticae* Koch (Acari: Tetranychidae). Also, the LC_{50} concentration of *Mentha viridis* L. had a negative effect on the oviposition period and fecundity of *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae) (Papachristos and Stamopoulos, 2002).

In our study, the treatment of *T. granarium* 1st instar larvae with the LC_{30} of *P. nigrum* and *A. khorassanica* significantly reduced the age-specific survival rate of different developmental stages and age-specific fecundity of females. In other studies with *Sitotroga cerealella* Olivier (Lepidoptera: Gelechiidae), sublethal concentrations of *A. khorassanica* significantly decreased the age-specific survival rate of immature stages (Naseri *et al*., 2017), and sublethal concentrations of *P. nigrum* significantly reduced fecundity in *Tribolium castaneum* Herbst (Coleopetera: Tenebrionidae) (Chaubey, 2007).

This study shows that as a result of fumigant exposure to *P. nigrum* and *A. khorassanica* EOs the life table parameters of *T. granarium* (i.e., R_0, r_m, λ, and T) were reduced. The lower value of r_m in the populations exposed to EOs tested is mainly attributed to the longer immature developmental times, lower survivorship, and lower fecundity of the insects. Reduction in these parameters can decrease the speed of *T. granarium* population growth. This finding was in compliance with those of Borzoui *et al*. (2016), who observed a reduction in R_0, as well as r_m for *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) exposed to *A. khorassanica* EO. Also, Nedaei (2017) observed a decrease in population dynamics of *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) exposed to *P. nigrum*.

In conclusion, according to the results of the present study, *P. nigrum* and *A. khorassanica* oils showed high fumigant toxicity against the 1st instar larvae of *T. granarium*. These EOs affect the life history of this main stored product pest. Also, the life table parameters of *T. granarium* were dependent upon the survival rate and the fecundity, which was decreased. Our results indicated that among the two EOs, *A. khorassanica* has relatively higher toxicity for this pest. The higher toxicity effects of *A. khorassanica* oil could be attributed to some well-known toxic compounds such as camphor, 1,8-cineol, and beta-thujone. However, more studies are necessary to improve our knowledge about the safety of these essential oils for the human, environment, and nontarget species.

Acknowledgement

We thank the Islamic Azad University Tehran (Iran), for cooperation by support for the experiment.

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Figure caption

Figure 1. Age-specific survival rate (l_x) of *Trogoderma granarium* after exposure to LC_{30} concentration of *Piper nigrum* and *Artemisia khorassanica* essential oils.

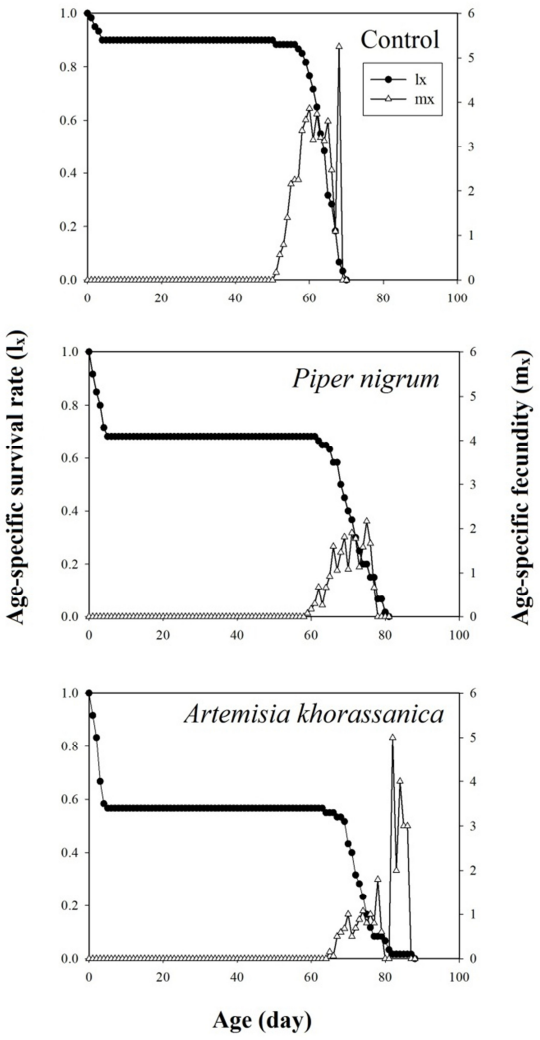

Table 1. Chemical constituents of the essential oils from *Piper nigrum*.

Compound	Rotention time (min)	Composition (%)
Alpha-Pinene	7.5	5.0
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-, (1S)-	8.7	10.1
beta-Myrcene	9.0	2.3
Delta 3-Carene	9.7	24.6
dl-Limonene	10.3	18.3
gamma-Terpinene	11.0	0.6
Alpha-Terpinolene	11.9	1.2
Propanal, 2-methyl-3-phenyl-	16.3	1.0
Benzenemethanol, .alpha.-methyl-	17.7	0.6
delta-Elemene	19.0	2.6
alpha-Copaene	20.0	2.3
8-Isopropenyl-1,5-dimethyl-cyclodeca-1,5-diene	20.4	0.6
trans-Caryophyllene	21.3	24.2
alpha-Humulene	22.1	1.3
alpha-Selinene	23.0	1.3
delta-Cadinene	23.7	0.8

Table 2. Chemical constituents of the essential oils from *Artemisia khorassanica*

Compound	Rotention time (min)	Composition (%)
alpha-Pinene	6.0	3.9
Camphene	6.4	4.1
beta-Pinene	7.1	1.1
delta-3-Carene	8.1	8.6
1,8-Cineole	8.8	13.1
alpha-Terpinolene	10.3	1.2
Camphor	12.2	23.4
Borneol	12.8	8.2
beta-Fenchyl alcohol	13.5	1.3
Bicyclo[2.2.1]heptane	16.1	3.0
alpha-Terpinolene	17.7	0.5
Caryophyllene	19.6	1.6
Naphthalene	20.4	1.8
alpha-Humulene	20.5	1.2
beta-Bisabolene	21.8	0.8
delta-Cadinene	22.2	1.4
Dehydroxy-isocalamendiol	24.7	1.0
alpha-Cadinol	25.0	3.0
2-Furanmethanol	25.3	0.8
Levomenol	26.0	11.6

Table 3. Fumigant toxicity of *Piper nigrum* and *Artemisia khorassanica* essential oils on the 1st instar larvae of *Trogoderma granarium*.

Essential oil	n[a]	χ^2	Slope ±SE	Lethal concentrations (µL/L air)		
				LC_{30} (95% FL)	LC_{50} (95%FL)	LC_{90} (95%FL)
P. nigrum	375	59.63	4.73 ± 0.61	55.38 (49.18 – 60.21)	71.46 (66.37 – 76.95)	133.27 (115.66 – 167.33)
A. khorassanica	375	54.98	3.66 ± 0.49	28.68 (24.66 – 31.85)	39.88 (36.34 – 43.94)	89.25 (73.60 – 122.77)

Lethal concentrations and 95% fiducial limits (FL) were estimated using logistic regression (SAS Institute 2002).

[a] The total number of larvae used for bioassay test

Table 4. LT_{50} values of *Piper nigrum* and *Artemisia khorassanica* essential oils on the 1st instar larvae of *Trogoderma granarium*.

Essential oil	Concentration (µL/L air)	χ^2	Slope ±SE	Lethal time (hours)		
				LT_{30} (95% FL)	LT_{50} (95%FL)	LT_{90} (95%FL)
P. nigrum	100	205.09	3.03 ± 0.21	10.57 (9.09 – 11.90)	15.75 (14.26 – 17.10)	41.68 (38.09 – 46.55)
A. khorassanica	60	184.14	3.16 ± 0.23	9.22 (7.87 – 10.43)	13.51 (12.15 – 14.73)	34.35 (31.40 – 38.37)

Lethal times and 95% fiducial limits (FL) were estimated using logistic regression (SAS Institute 2002).

Table 5. Mean[1] (±SE) developmental time of immature stages of *Trogoderma granarium* after exposure to *Piper nigrum* and *Artemisia khorassanica* essential oils.

	Immature periods (days)							
Treatments	***n***	**Egg**	***n***	**Larva**	***n***	**Pupa**	***n***	**Total**
Control	54	5.38±0.06b	54	44.85±0.34c	53	4.81±0.09b	53	55.05±0.37c
P. nigrum	41	5.48±0.07b	41	55.21±0.60b	39	4.89±0.10b	39	65.61±0.64b
A. khorassanica	34	5.79±0.07a	34	58.90±0.74a	30	5.33±0.08a	30	69.52±0.78a

[1]The means followed by different letters in the same column are significantly different (Paired bootstrap, $P <$ 0.05).

Table 6. Mean[1] (±SE) longevity and reproductive parameters of *Trogoderma granarium* after exposure to *Piper nigrum* and *Artemisia khorassanica* essential oils.

[1]The means followed by different letters in the same column are significantly different (Paired bootstrap, $P <$

Treatments	***n***	**Male longevity (days)**	***n***	**Female longevity (days)**	**Pre-oviposition period (days)**	**Oviposition period (days)**	**Fecundity (eggs/female)**
Control	24	9.70±0.28a	29	9.13±0.26a	1.03±0.03a	6.48±0.20a	57.03±1.68a
P. nigrum	22	6.68±0.32b	17	7.11±0.36b	1.05±0.05a	4.58±0.24b	28.76±1.85b
A. khorassanica	13	4.30±0.28c	17	5.29±0.33c	1.11±0.08a	3.17±0.25c	11.29±1.25c

0.05)

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Table 7. Life table parameters of *Trogoderma granarium* after exposure to *Piper nigrum* and *Artemisia khorassanica* essential oils[1].

Treatments	**Net reproductive rate (R_0) (offspring per individual)**	**Intrinsic rate of increase (r) (day^{-1})**	**Finite rate of increase (λ) (day^{-1})**	**Mean generation time (T) (days)**
Control	27.55±3.76a	0.055±0.002a	1.056±0.002a	60.02±0.54c
P. nigrum	8.15±1.74b	0.030±0.003b	1.030±0.003b	69.08±0.95b
A. khorassanica	3.19±0.74c	0.015±0.003c	1.015±0.003c	73.15±1.30a

[1]The means followed by different letters in the same column are significantly different (Paired bootstrap, $P <$ 0.05).

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فصلنامه تخصصی تحقیقات حشره‌شناسی
(علمی- پژوهشی)
جلد ۱۲، شماره۲، سال ۱۳۹۹، (۱۲-۱)

سمیت حاد و اثرات زیرکشندگی اسانس روغنی عصاره‌گیری شده از ***Piper nigrum*** و ***Trogoderma granarium* (Col.: Dermestidae)** روی ***Artemisia khorassanica***

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چکیده

لمبه گندم، Trogoderma granarium Everts (Coleoptera: Dermestidae)، یک آفت جدی غلات از قبیل گندم می‌باشد. در مطالعه‌ی حاضر، اثرات کشندگی و زیرکشندگی اسانس‌های روغنی Piper nigrum L. و Artemisia khorassanica Podl. برعلیه لاروهای سن اول T. granarium بررسی شد. برای مطالعه‌ی اثرات زیرکشندگی، لاروهای سن اول در معرض غلظت LC30 هر اسانس قرار گرفتند و پارامترهای حشرات زنده مانده بررسی شد. Artemisia khorassanica (LC_{50}: 39.88 µl/liter air) سمیت تنفسی بالاتری برای T. granarium در مقایسه با P. nigrum (LC_{50}: 71.46 µl/liter air) داشت. به‌علاوه، اثرات کشندگی A. khorassanica (LT_{50}: 13.51 h) سریع‌تر از P. nigrum (LT_{50}: 15.75 h) بود. تفاوت‌های معنی‌داری در دوره‌های لاروی و شفیرگی در تیمارهای اسانس در مقایسه با کنترل مشاهده شد. به‌علاوه، در معرض قرارگیری با غلظت زیرکشنده اسانس‌های تست شده به‌طور معنی‌داری بقای مراحل نابالغ، طول دوره‌ی بالغین و زادآوری را کاهش داد. نرخ خالص تولیدمثلی (R0)، نرخ ذاتی افزایش جمعیت (r) و نرخ متناهی افزایش جمعیت (λ) به‌طور معنی‌داری توسط اسانس‌های تست شده تحت تأثیر قرار گرفتو کمترین آن‌ها در حشرات در معرض با A. khorassanica مشاهده شد. مطابق با یافته‌های ما، هردوی اسانس‌های تست شده، مخصوصاً A. khorassanica، برای کنترل مؤثر T. granarium در انبارها مفید هستند.

واژه‌های کلیدی: لمبه‌ی گندم، اسانس روغنی، محتوای شیمیایی، سمیت تنفسی، پارامترهای جدول زندگی.

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تاریخ دریافت مقاله:۹۸/۱۲/۲۰ – تاریخ پذیرش مقاله:۹۹/٤/۱۲