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Research Article

Insecticidal activity of essential oils from *Artemisia absinthium* L., *Artemisia dracunculus* L. and *Achillea millefolium* L. against *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae)

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Abstract: The potato tuber moth, *Phthorimaea operculella* (Zeller) is one of the important pests of solanaceous plants, especially potato *Solanum tuberosum* L., in many temperate areas of the world including Iran. In this study, essential oils were extracted from *Artemisia absinthium* L., *Achillea millefolium* L. and *Artemisia dracunculus* L. using Clevenger apparatus. One-day-old eggs were treated by sublethal concentrations (LC_{30}) of essential oils, and their effects were studied on reproductive parameters and population growth parameters. Probit analysis of ovicidal effects showed that LC_{50} values for *A. absinthium*, *A. millefolium* and *A. dracunculus*were 2.60, 2.36 and 1.08 µl/l air, respectively. The percentage of larval penetration into potato tubers was lower than untreated control. The values of intrinsic rate of increase (r_m) in control and treatments of *A. absinthium*, *A. millefolium* and *A. dracunculus* were 0.107, 0.079, 0.081 and 0.087 day^{-1}, respectively. The results of this study showed that tested essential oils have a good potential to protect stored potatoes from *P. operculella* infestation.

Keywords: *Phthorimaea operculella*, reproductive parameters, *Solanum tuberosum*, population parameters, sublethal concentration

Introduction

The potato tuber moth (PTM), *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) is an economic insect pest of potato *Solanum tuberosum* L. in field and during storage (Haines, 1977; Raman and Palacios, 1982). Several cultivated and wild solanaceous plants can be attacked by PTM; however, potato is a preferred host plant (Balachowsky and Real, 1966; Moawad and Ebadah, 2007). Larval feeding and mining in the foliage or tubers of potato plants can lead to severe qualitative and quantitative losses, and marketable value of damaged tubers would be decreased (Moawad and Ebadah, 2007).

In many countries, chemical insecticides have been widely used as a primary tool to protect potato crops under field and storage conditions (Moawad and Ebadah, 2007; Mahdavi *et al.*, 2017). However, the improper and extensive application of these synthetic compounds has led to the rapid development of PTM resistance, and detrimental effects on human health and environment (Dikshit *et al.*, 1985; Llanderal-Cazares *et al.*, 1996). Therefore, it is necessary

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to replace chemical control methods with safer and more eco-friendly ones. Nowadays, efforts are increasing about the application of natural products such as plant extracts and essential oils due to their favorable effects including low mammalian toxicity and reduced environmental pollution (Sharaby *et al.*, 2009; Rafiee-Dastjerdi *et al.*, 2013).

Essential oils isolated from medicinal plants have a good potential in crop protection strategies against a range of pre- and postharvest insect pests (Regnault-Roger, 1997; Shaaya *et al.*, 1997). These oils have both lethal and sublethal effects on adult and immature stages of insects (Alzogaray *et al.*, 2011). Several studies are available about the insecticidal impacts of plant-based essential oils against PTM (Guerra *et al.*, 2007; Sharaby *et al.*, 2009; Rafiee-Dastjerdi *et al.*, 2013; Naghizadeh *et al.*, 2016). For example, Moawad and Ebadah (2007) studied the effects of four plant essential oils on different stages of PTM, and reported that tested oils are able to protect potato tubers during storage. The bioactivity of *Majorana hortensis* Moench essential oil against immature stages and adults of PTM was evaluated by Abd El-Aziz (2011), who reported significant insecticidal effects against this pest. Khorrami (2012) studied sublethal effects of essential oils from *Lavandula angustifolia* L. and *Origanum vulgare* Mill on population parameters of PTM, and noted that *L. angustifolia* oil decreased population growth of the pest more than *O. vulgare* oil. Naghizadeh *et al.* (2016) investigated the effects of essential oils extracted from *Artemisia absinthium* L., *Achillea millefolium* L. and *Artemisia dracunculus* L. on oviposition deterrence and life table parameters of PTM. They noted that examined oils had negative effects on most of the biological and life table parameters of the pest.

The genus *Artemisia* is one of the medicinal plants growing naturally in wide regions of the world including Iran (Negahban *et al.*, 2007; Dhen *et al.*, 2014). It is reported that, *Artemisia* species have fumigant, antifeedant and repellent effects against a large number of stored-product insects (Negahban *et al.*, 2007; Borzoui *et al.*, 2016; Naseri *et al.*, 2017). Yarrow, *A. millefolium*, is a medicinal herb that has mainly been used in traditional medicine (Benedek*et al.*, 2008). However, essential oils isolated from this species possess insecticidal and repellent activities against several insect pests (Ebadollahi and Ashouri, 2011; Naghizadeh *et al.*, 2016). With attention to the economic importance of PTM, in this research, we studied the efficacy of essential oils from *A. absinthium*, *A. millefolium* and *A. dracunculus* on egg mortality and larval penetration of PTM. Also, the sublethal effects of tested essential oils were evaluated on reproductive parameters and stable population growth parameters of the pest. The results of this study could be useful in choosing suitable essential oil(s) for the management of this key pest.

Materials and Methods

Insect

The colony of PTM was obtained from a laboratory of Department of Plant Protection, Faculty of Agriculture and Natural Resources, University of Mohaghegh Ardabili, Iran in summer 2012. Adults were kept in plastic containers (9 × 17 × 24 cm) and reared on potato tubers. The bottom of containers was covered with a thin layer of clean sand for pupation (El-Sinary, 1995). Colony rearing and experiments were carried out under laboratory conditions at 25 ± 1 ºC, 65 ± 5% RH and a photoperiod of 8: 16 (L: D) h.

Plants and their essential oils

Dried flowers of *A. absinthium* and *A. millefolium* were purchased from local market of Ardabil. Also, fresh leaves of *A. dracunculus* were purchased from local market, dried in shade and ventilation conditions. The required organs of plants were powdered and their essential oils were extracted by using Clevenger-type apparatus for three hours. The extracted essential oils were stored in vials covered by aluminum paper at 4 ºC.

Gas chromatography-mass spectrometry analysis

Gas chromatography-mass (GC-MS) analysis was conducted on a Hewlett–Packard (HP, Palo Alto, CA) HP 7890A GC equipped with a split / splitless injector and 5975C mass selective detector system (Adams, 1995).

Determination of LC_{50} on one-day-old eggs

To determine the range of concentrations for each essential oil, preliminary tests were conducted. These concentrations for essential oils of *A. absinthium*, *A. millefolium* and *A. dracunculus* were 1.60-4.00 (4.00, 3.16, 2.52, 2.00 and 1.60 µl/l air), 1.36- 3.80 (3.80, 2.96, 2.28, 1.76 and 1.36 µl/l air), and 0.56- 2.12 (2.12, 1.52, 1.12, 0.80 and 0.56 µl/l air), respectively. Twenty-one-day old eggs were put into 250 ml glass vials. The filter papers (3 cm in diameter) were placed in the cap of glass vials. Each of essential oil concentration was applied on filter papers using sampler, and the caps of glass vials were covered with parafilm. In the control, distilled water was used. After egg incubation, the number of hatched eggs was recorded in the control and the treatments. This experiment was replicated four times.

Percentage of larval penetration

In this experiment, each potato tuber was dipped in 0.25% of essential oils (5 µl of essential oil diluted in 2 ml of acetone) and after evaporation of acetone, they (three potato tubers) were transferred into plastic containers (19.5 cm in diameter, depth 7.5 cm). In the control, each potato tuber was dipped in 2 ml of acetone alone. Then 20 newly hatched larvae were put on each tuber and the percentage of larval penetration was recorded, after three days, based on larval feces deposited in entry holes. This experiment was replicated three times.

Sublethal effects of essential oils on reproductive and population parameters

In order to determine the sublethal effects of tested essential oils, 150 one-day-old eggs were transferred into 1000 ml glass jars. The filter papers (4 cm in diameter) were placed in the cap of glass jars. The sublethal concentration (LC_{30}) of essential oils of *A. absinthium*, *A. millefolium* and *A. dracunculus* (2.16, 2.00 and 0.88 µl/l air, respectively) were applied on filter papers using sampler, and the caps of glass jars were covered with parafilm. In control, distilled water was used. The eggs were transferred into plastic containers (9 × 17 × 24 cm) containing potato tubers after 24 hours. The eggs were examined daily and the number of hatched eggs and their incubation period were recorded. These experiments were continued until adults' emergence. The larval duration, number of pupae and pupal duration were calculated for each treatment and control. In the adult stage, 22, 25, 21 and 25 pairs of adults (males + females) were transferred into plastic containers (12.5 cm in diameter, depth 6 cm) with a hole covered by mesh for *A. absinthium*, *A. millefolium*, *A. dracunculus* treatments and control, respectively. Then, the filter papers were put on the meshes and number of eggs laid and percentage of eggs hatched were recorded daily. These experiments were continued until all tested females died (Tables 1 and 2).

Table 1 The equations of reproductive parameters used in this study (Carey, 1993).

Daily reproductive rates

$$\text{Mean eggs per day} = \frac{\sum_{x=\alpha}^{\beta} L_x M_x}{\sum_{x=\alpha}^{\omega} L_x} \quad (1)$$

$$\text{Mean fertile eggs per day} = \frac{\sum_{x=\alpha}^{\beta} L_x h_x M_x}{\sum_{x=\alpha}^{\omega} L_x} \quad (2)$$

Life time reproductive rates

$$\text{Gross fecundity rate} = \sum_{x=\alpha}^{\beta} M_x \quad (3)$$

$$\text{Gross fertility rate} = \sum_{x=\alpha}^{\beta} h_x M_x \quad (4)$$

$$\text{Net fecundity rate} = \sum_{x=\alpha}^{\beta} L_x M_x \quad (5)$$

$$\text{Net fertility rate} = \sum_{x=\alpha}^{\beta} L_x h_x M_x \quad (6)$$

α = the age of female at the first oviposition, β = the age of female at the last oviposition, ω = the female longevity, L_x = the days lived in interval x and $x+1$, M_x = the average number of eggs laid by a female in age x, h_x = the hatching rate.

Table 2 The equations of population growth parameters used in this study (Carey, 1993).

Reproductive rates	
Gross reproductive rate (GRR)= $\sum_{x=\alpha}^{\beta} m_x$	(1)
Net reproductive rate (R_0)= $\sum_{x=\alpha}^{\beta} l_x m_x$	(2)
Growth rates	
Intrinsic rate of increase (r_m) = $\sum_{x=\alpha}^{\beta} e^{-r_m x} l_x m_x = 1$	(3)
Finite rate of increase (λ) = e^r(4)	
Growth time	
Mean generation time (T) = $\frac{\ln R_0}{r_m}$	(5)
Doubling time (DT) = $\frac{\ln 2}{r_m}$	(6)

l_x = the individuals live relation in age x.
m_x = the average number of females produced by a female in age x.

Data analysis

In order to determine LC_{50} values, the data were analyzed by probit method using SPSS 16.0 (SPSS, 2007). The relationship between data was estimated by one-way analysis of variance (ANOVA) using SPSS 16.0 (SPSS, 2007). For larval penetration test, the means were compared by Tukey's test ($P < 0.05$). The pseudo-values of population parameters were calculated by jackknife method (Meyer *et al.,* 1986), and the means were compared by pairwise test usingSAS 9.1 software program (Maia *et al.,* 2000).

Results

Chemical analysis of essential oils

The GC-MS analysis of tested essential oils is presented in Tables 3, 4 and 5 (only major compounds are given). Thirty-five compounds were detected in the essential oil from *A. absinthium*, representing 97.74% of the total essential oils samples. However, ninety-three and thirty-four compounds were found in the essential oils from *A. millefolium* and *A. dracunculus*, representing 98.51 and 98.73% of the total essential oils samples, respectively. In *A. millefolium* essential oil, germacrene-D (15.12%) and 2,4-hexadiene, 3-methyl- (14.50%) were identified as major compounds. However, thujone (48.22%) and benzene, 1-methoxy-4-(2-propenyl)- (CAS) (85.73%) were detected as major constituents of *A. absinthium* and *A. dracunculus* essential oils, respectively.

Determination of LC_{50} on one-day-old eggs

The LC_{50} values of tested essential oils are shown in Table 6. The results showed that *A. dracunculus* essential oil had the most toxicity (LC_{50}: 1.08 µl/l air) as compared with the other two essential oils on one-day-old eggs of PTM.

Table 3 Major chemical compounds of essential oil from *Artemisia absinthium*.

Compound name	Retention time (min)	Amount (%)
β-Thujone	8.726	2.21
Thujone	9.047	48.22
2-Cyclohexene-1-one, 2-methyl-5-(1-methylethyl)-, (S)- (CAS)	12.852	2.19
Geranyl acetate	22.053	2.91
Butanoic acid, 3-methyl-, 1-ethenyl-1, 5-dimethyl-4-hexenyl ester	22.099	2.48
Calacorene	22.156	1.33
Bornylene	23.770	1.05
Δ-3-Carene	23.867	7.91
Nerol	24.050	6.63
3-Carene	24.531	1.98
2-Pentadecanone, 6,10,14-trimethyl-	29.886	1.03
Phenyl 2-phenylisopropyl sulfide	31.042	7.46
Cyclotrisiloxane, hexamethyl-	37.851	2.88

Table 4 Major chemical compounds of essential oil from *Artemisia millefolium*.

Compound name	Retention time (min)	Amount (%)
α-Pinene, (-)-	5.333	2.87
Camphene	5.608	1.56
1, 3, 6-Heptatriene, 2, 5, 5-trimethyl-	6.541	1.07
Benzene, 1-methyl-2-(1-methylethyl)- (CAS)	7.044	3.06
1, 8-Cineole	7.204	6.75
2, 4-Hexadiene, 3-methyl-	7.336	14.50
γ-Terpinene	7.719	1.00
1, 5-Heptadiene-4-one, 3, 3, 6-trimethyl-	7.754	1.39
Camphor	9.796	5.69
2, 4-Hexadienal (CAS)	10.254	1.95
Borneol	10.403	8.26
3-Cyclohexene-1-ol, 4-methyl-1-(1-methylethyl)-	10.666	1.62
Bicyclo [3.1.1] hept-2-en-4-ol, 2, 6, 6-trimethyl-, acetate	13.424	4.71
Bicyclo [2.2.1] heptane-2-ol, 1, 7, 7-trimethyl-, acetate, (1S-endo)- (CAS)	14.414	2.11
Germacrene-D	21.303	15.12
Bicyclogermacrene	21.681	1.86
1H-Cycloprop [e] azulen-7-ol, decahydro-1, 1, 7-trimethyl-4-methylene-, [1ar-(1aα, 4aα, 7β, 7aβ, 7bα	23.907	1.49
2,3,4,5,6-Pentamethylpyridine	24.038	1.53
Naphthalene, 1, 2, 3, 4, 4a, 5, 6, 8a-octahydro-7-methyl-4-methylene-1-(1-methylethyl)-, (1α, 4aα, 8aα)-	25.332	1.40

Table 5 Major chemical compounds of essential oil from *Artemisia dracunculus*.

Compound name	Retention time (min)	Amount (%)
DL-Limonene	7.141	2.55
Cis-Ocimene	7.290	2.62
1, 3, 6-Octatriene, 3, 7-dimethyl-, (E)- (CAS)	7.491	1.55
Benzene, 1-methoxy-4-(2-propenyl) - (CAS)	11.565	85.73
Benzene, 1, 2-dimethoxy-4-(2-propenyl)- (CAS)	18.849	1.46

Percentage of larval penetration

The effect of tested essential oils on percentage of larval penetration of PTM (first instar) is given in Table 7. There was a significant difference between essential oil treatments with control. Compared to control, the essential oils isolated from tested plants reduced penetration rate of first instar larvae ($F = 10.08$; $df_{t, e} = 3, 8$; $P < 0.05$).

Sublethal effects of essential oils on reproductive parameters

Sublethal effects of tested essential oils on reproductive parameters of PTM are given in Table 8. The gross fecundity rate ($F = 11.25$; $df_{t, e} = 3, 89$; $P < 0.05$) and gross fertility rate ($F = 14.12$; $df_{t, e} = 3, 89$; $P < 0.05$) were the lowest in PTM treated with *A. millefolium* oil. The net fecundity rate ($F = 23.50$; $df_{t, e} = 3, 89$; $P < 0.05$) and the net fertility rate ($F = 28.38$; $df_{t, e} = 3, 89$; $P < 0.05$) had significant reductions in the essential oils treatment compared with control. Moreover, the mean eggs per day ($F = 17.40$; $df_{t, e} = 3, 89$; $P < 0.05$) and mean fertile eggs per day ($F = 21.59$; $df_{t, e} = 3, 89$; $P < 0.05$) were the lowest when PTM was treated with tested essential oils.

Sublethal effects of essential oils on population parameters

Sublethal effects of tested essential oils on population growth parameters of PTM are presented in Table 9. Compared to the control, the net reproductive rate (R_0), the intrinsic rate of increase (r_m), and the finite rate of increase (λ) showed significant differences after treatment with LC_{30} of the tested oils ($P < 0.05$).The mean generation time (T) was significantly longer in *A. absinthium* treatment than control ($P < 0.05$). Also, the doubling time (DT) showed a significant increase after exposure to the sublethal concentration of tested essential oils compared with control ($P < 0.05$).

Table 6 Probit analysis of fumigant toxicity of essential oils from *Artemisia absinthium*, *Artemisia millefolium* and *Artemisia dracunculus* on one-day-old eggs of *Phthorimaea operculella*.

Essential oils	Number of eggs	Slope ± SE	LC_{30} (95% Confidence limits) (µl/l air)	LC_{50} (95% Confidence limits) (µl/l air)
A. absinthium	480	6.75 ± 0.68	2.16 (2.00-2.32)	2.60 (2.48-2.76)
A. millefolium	480	6.77 ± 0.70	2.00 (1.48-2.28)	2.36 (2.00-2.72)
A. dracunculus	480	6.23 ± 0.62	0.88 (0.64-1.04)	1.08 (0.88-1.24)

Table 7 Effect of essential oils from *Artemisia absinthium*, *Artemisia millefolium* and *Artemisia dracunculus* on mean (± SE) percentage of larval penetration of *Phthorimaea operculella*.

Essential oils	Concentration (%)	Penetration (%)
A. absinthium	0.25	39.17 ± 3.11^{b}
A. millefolium	0.25	36.50 ± 3.40^{b}
A. dracunculus	0.25	43.17 ± 3.56^{b}
Control	-	57.67 ± 1.17^{a}

Means in column with the different letters are significantly different (Tukey test, P < 0.05).

Table 8 Mean (± SE) reproductive parameters of *Phthorimaea operculella* treated with essential oils of *Artemisia absinthium*, *Artemisia millefolium*, *Artemisia dracunculus* and control.

Essential oils	Gross fecundity rate	Gross fertility rate	Net fecundity rate	Net fertility rate	Mean eggs per day	Mean fertile eggs per day
A. absinthium	66.36 ± 7.17^{bc}	58.59 ± 6.33^{b}	23.46 ± 2.53^{b}	20.71 ± 2.23^{b}	1.09 ± 0.11^{b}	0.96 ± 0.10^{b}
A. millefolium	47.14 ± 5.65^{c}	38.73 ± 4.65^{c}	23.05 ± 2.75^{b}	18.94 ± 2.26^{b}	0.89 ± 0.10^{b}	0.73 ± 0.09^{b}
A. dracunculus	77.18 ± 7.38^{b}	63.88 ± 6.11^{b}	25.69 ± 2.42^{b}	21.26 ± 2.00^{b}	1.18 ± 0.11^{b}	0.98 ± 0.09^{b}
Control	101.15 ± 7.54^{a}	91.71 ± 6.83^{a}	52.60 ± 3.88^{a}	47.69 ± 3.52^{a}	2.01 ± 0.15^{a}	1.82 ± 0.14^{a}

Means in a column with the different letters are significantly different (SNK test, P < 0.05).

Table 9 Mean (± SE) population growth parameters of *Phthorimaea operculella* treated with essential oils of *Artemisia absinthium*, *Artemisia millefolium*, *Artemisia dracunculus* and control.

Essential oils	R_0 (female/generation)	r_m (day^{-1})	λ (day^{-1})	T (day)	DT (day)
A. absinthium	11.31 ± 0.25^{b}	0.079 ± 0.001^{b}	1.082 ± 0.001^{b}	30.88 ± 0.03^{a}	8.79 ± 0.08^{a}
A. millefolium	12.09 ± 0.25^{b}	0.081 ± 0.001^{b}	1.085 ± 0.001^{b}	30.71 ± 0.04^{ab}	8.51 ± 0.07^{a}
A. dracunculus	14.00 ± 0.26^{b}	0.087 ± 0.001^{b}	1.091 ± 0.001^{b}	30.20 ± 0.04^{bc}	7.91 ± 0.06^{a}
Control	24.55 ± 0.36^{a}	0.107 ± 0.000^{a}	1.113 ± 0.000^{a}	29.86 ± 0.03^{c}	6.46 ± 0.03^{b}

Means in a column with the different letters are significantly different (Pairwise, P < 0.05).
GRR = gross reproductive rate, R_0 = net reproductive rate, r_m = intrinsic rate of increase, λ = finite rate of increase, T = mean generation time, DT = doubling time.

Discussion

It is reported that the insecticidal activity of plant essential oils is dependent on the type and constituents of the oils, period of exposure and method used in bioassay (Moawad and Ebadah, 2007; Abd El-Aziz, 2011; Dhen *et al.*, 2014). The major compounds of essential oils of *Artemisia* species examined in this study were thujone (48.22%) and benzene, 1-methoxy-4-(2-propenyl)- (CAS) (85.73%). Nezhadali and Parsa (2010) reported that the main compounds of *A. absinthium* were camphor (14.83%), *p*-cymene (10.35%), and isoledene (8.52%). A study conducted by Lawrence (1992) showed beta-thujone (17.5-42.3%) and cis-sabinyl acetate (15.1-53.4%) as the main compounds in *A. absinthium* essential oil. According to Ayoughi *et al.* (2011), the major essential oil compositions of *A. dracunculus* were (z)-anethole (51.72%), (z)-β-ocimene (8.32%), and methyleugenol (8.06%). Variations in the type and percentage of chemical compounds of *Artemisia* species in our study with those detected by above-mentioned authors could be attributed to different factors such as geographical origins of the tested plants, extraction method used, and aerial or flower parts used for the oil extraction (Nezhadali and Parsa, 2010; Dhen *et al.*, 2014.)

In this study, *A. dracunculus* essential oil showed the highest fumigant toxicity, among the examined oils, on one-day-old eggs of PTM. Khorrami (2012) reported that essential oils from *L. angustifolia* and *O. vulgare* were effective against one-day-old eggs of PTM, and LC_{50} values of these oils were 0.40 and 0.44 μl/l air, respectively. Comparison of LC_{50} values in this study with those reported by Khorrami (2012) indicated higher toxicity of oils from *L. angustifolia* and *O. vulgare* than those obtained in our study. Abd El-Aziz (2011) showed that at the highest concentration of *Majorana hortensis* Moench. essential oil, the hatching rate of PTM was 0 and 67.3% in the contact and fumigation methods, respectively. It is reported that volatile substances of plant essential oils can penetrate into insects' egg and influence on embryonic growth (Raja *et al.*, 2001). Studying fumigant toxicity of some essential oils on one-day old adults of PTM, Rafiee-Dastjerdi *et al.* (2013) noted that essential oil of *Satureja hortensis* (Linnaeus), with the lowest LC_{50} (0.048 μl/l air), showed the highest toxicity.

In the present study, the percentage of larval penetration was the lowest in the tubers treated with tested essential oils compared with untreated control, suggesting that tested oils had negative effects on movement and feeding behavior of larvae. Moawad and Ebadah (2007) showed that potato tubers dusted at 1.5% of *Elettaria cardamomum* L. and *Rosmarinus officinalis* L. oils reduced percentage of larval penetration of PTM to 13.3% and 23.3%, respectively. Moawad (2000) expressed that the potato tubers dusted with1% natural and commercial oils of *Mentha citrata* Ehrh., *Cymbopogon citratus* DC., *Myristica fragran*s Houtt. and α-ionone reduced the percentage of larval penetration of PTM. Also, Rama (1989) showed that dusting potato tubers with Neemerich oil, *Azadirachta indica* A. Juss. had toxic effects against eggs and larvae of PTM.

The present work showed that reproductive parameters of PTM were significantly different between treatments and control. This result is similar to that reported by Khorrami (2012), who noted that the sublethal concentration of essential oils from *L. angustifolia* and *O. vulgare* had a significant reduction on reproductive parameters of this pest. The results of this study showed that the daily reproductive rate of PTM was significantly different between essential oils and control. However, Khorrami (2012) reported no significant difference for daily reproductive rate of PTM between two groups of essential oils and control. The data of daily reproductive rates of PTM in our study were almost close to those reported for PTM treated with *L. angustifolia* and *O. vulgare* essential oils (Khorrami, 2012).

In this study, *GRR* and R_0 values of PTM treated with tested oils varied from 21.18 to 38.59 female/female/generation and 10.38 to 12.80 female/female/generation, respectively. The range of *GRR* and R_0 values, in our study, are more than the values obtained by Khorrami (2012). Such inconsistency could be due to either differences in the type and amount of essential oils compounds, or differences in the bioassay methods in the two studies.

The intrinsic rate of increase (r_m) is a key demographic parameter for predicting the population growth of an animal (Andrewartha and Birch, 1954; Ricklefs and Miller, 2000; Southwood and Henderson, 2000). Compared with control, sublethal concentration of tested essential oils caused a significant reduction in r_m value of PTM (Table 9). The lower r_m value was mainly due to lower survivorship and fecundity, and longer development time of PTM treated with tested essential oils. Moreover, because of the lower R_0 values in essential oils treatment than control, the r_m of treated PTM was lower than the control. The range of r_m value of PTM treated with tested oils, in this study, was lower than that reported for PTM treated by *L. angustifolia* and *O. vulgare* essential oils (Khorrami, 2012), suggesting that sublethal concentration of essential oils examined in our study had more negative effects than those utilized by Khorrami (2012) on population growth of this pest.

Conclusions

The results of this study suggested that the application of tested essential oils, especially *A. millefolium*, against PTM will be useful to protect stored potatoes and decrease the risks of chemical pesticides use.

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فعالیت حشره‌کشی اسانس‌های *Artemisia absinthium* L.، *Artemisia dracunculus* L. و *Achillea millefolium* L. نسبت به *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae)

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چکیده: بید سیب‌زمینی، *Phthorimaea operculella* (Zeller) یکی از آفات مهم گیاهان تیره سولاناسه، به‌ویژه سیب‌زمینی *Solanum tuberosum* L. در بسیاری از مناطق معتدله جهان ازجمله ایران است. در این مطالعه، اسانس‌های گیاهی شامل درمنه افسنتین *Artemisia absinthium* L.، بومادران *Achillea millefolium* L. و ترخون *Artemisia dracunculus* L. با استفاده از دستگاه کلونجر استخراج شدند. تخم‌های یک‌روزه آفت با غلظت زیرکشنده (LC_{30}) اسانس‌ها تیمار شده و اثرات آنها روی پارامترهای تولیدمثلی و پارامترهای رشد جمعیت آفت بررسی شدند. تجزیه پروبیت اثرات تخم‌کشی نشان داد که مقادیر LC_{50} برای اسانس‌های *A. absinthium*، *A. millefolium* و *A. dracunculus* به‌ترتیب ۲/۶۰، ۲/۳۶ و ۱/۰۸ میکرولیتر بر لیتر هوا بود. درصد نفوذ لاروها به‌داخل غده‌های سیب‌زمینی تیمار شده با اسانس‌ها کم‌تر از غده‌های شاهد بود. مقادیر نرخ ذاتی افزایش جمعیت (r_m) در شاهد و تیمارهای *A. absinthium*، *A. millefolium* و *A. dracunculus* به‌ترتیب ۰/۱۰۷، ۰/۰۷۹، ۰/۰۸۱ و ۰/۰۸۷ برروز بود. نتایج این مطالعه نشان داد که اسانس‌های مورد آزمایش از پتانسیل خوبی برای حفاظت از غده‌های انبار شده در برابر آلودگی *P. operculella* برخوردار می‌باشند.

واژگان کلیدی: *Phthorimaea operculella*، پارامترهای تولیدمثلی، *Solanum tuberosum*، پارامترهای جمعیتی، غلظت زیرکشنده