SHORT COMMUNICATION

Fumigant toxicities of essential oils and two monoterpenes against potato tuber moth (*Phthorimaea operculella* Zeller)

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Summary

Introduction: The potato tuber moth (PTM) is the major economic pest of potato. Different approaches were tried to prevent and control this pest including natural pesticides and synthetic fumigants. **Objectives:** This study was conducted to evaluate the insecticidal activity of the essential oils of thyme and myrtle. In addition to evaluating the insecticidal activity of carvacrol and eucalyptol against the different life stages of potato tuber moth using a fumigation bioassays. **Methods:** Thyme and myrtle oils were extracted from wild *Thymus syriacus* Boiss. and wild *Myrtus communis* L. by hydrodistillation. Fumigation experiments were conducted on potato tuber moth of different stages of development (eggs, larvae, pupae, and adults), using standard methods. The potato tuber moth was treated for different periods using different concentrations of the essential oils. One-way analysis of variance (ANOVA) was applied on the mortality percentages data to estimate the significance of differences between treatments at $p < 0.05$. Probit analysis was used to estimate the LC_{50} , LC_{90} and LT_{50} . **Results:** Adult stage was the most sensitive to essential oils vapours with LC_{50} value of $0.5 \mu\text{l/l}$ air. Whereas, pupal stages were the most tolerant. The essential oil of thyme possessed the strongest fumigant toxicity against eggs with a LC_{50} value of $6.1 \mu\text{l/l}$ air. The two monoterpenes showed varied fumigant toxicity against adult stage. Carvacrol achieved 100% mortality at $0.125 \mu\text{l/l}$ air after 6 h, and $0.025 \mu\text{l/l}$ air after 48h exposure with LT_{50} period of 0.5 h. **Conclusion:** The present work demonstrated that *T. syriacus* essential oil is a promising natural fumigant against the different developmental stages of PTM.

Key words: *Phthorimaea operculella*, essential oil, myrtle, thymus, carvacrol, eucalyptol

INTRODUCTION

The potato tuber moth (PTM), (*Phthorimaea operculella* Zeller), is one of the major economic pests of potato [1]. The infested tubers become completely unmarketable [2]. Different approaches were tried to prevent and control this pest [3]. One approach was using insecticides. However, chemical control is difficult to apply due to the latent feeding of the caterpillars and the ability of this species to develop resistance towards the traditional insecticides including carbamates and pyrethroids [4-7]. Although, there are some reports about the efficacy of insecticides in controlling *Phthorimaea operculella* [8-10]. Other studies reported resistance of tuber moth to some insecticides in many countries [11]. Another approach was to store potatoes in cold stores; However, not all farmers can afford its increasing cost. Insecticides and their residues in tubers, many cause human intoxication and contaminate the environment.

An alternative strategy was the development of chemical substitutes such as synthetic fumigants. However, those synthetic fumigants had adverse effects on the environment [12], and insects many develop resistance against them [13, 14].

In recent years, more attention was paid to naturally produced chemicals that can be used to control insects. Researchers described more than 866 different plant species that produce 256 biologically active molecules with toxicity against insects [15]. Of these natural products are volatiles essential oils which and can act as fumigants, and may also be adapted to protect stored products [16-18]. The *Lamiaceae* and *Myrtaceae* are two of the aromatic plant families that have been proved effective in insect pest management, mainly due to their essential oils [17-19]. In Peru, covering stored tubers with dried and crushed leaves of *Minthostachys* sp. (*Lamiaceae*) proved to be effective against potato tuber moth [20]. Raman *et al.* [21] studied the influence of dried foliage of some plants (*Eucalyptus globulus*, *Lantana camara* and *Minthostachys* sp.), in protecting potato tubers from damaging by potato tuber moth in storage. Sharma *et al.* [22] studied the deterrent activity of twelve plant species of *Labiatae* on oviposition of potato tuber moth. They found that some plant species exhibited high deterrent activity against the oviposition of *Phthorimaea operculella*. Khashyap *et al.* [23] used the dried powder of eight plant species on PTM infestation in stores. In Egypt, Sharaby *et al.* [24] studied the effects of dusting potato tubers with different concentrations of dried plant powders on some biological aspects of the adult stage of PTM; The plants tested were, *Allium cepa*, *Colocasia antiquorum*, *Pelargonium graveolens*, *Matricaria chamomilla*, and Talcum powder as a control.

In Syria, potato (*Solanum tuberosum* L.) is an important vegetable crop with area of cultivation of 29 878 ha, and a total production of 539 611 t in 2014 [25]. To control this pest, Saour [26] studied the potential use of the chloronicotinyl insecticide (Thiacloprid 480 SC) in controlling this pest. Ibrahim *et al.* [27] tried to use some plant extracts (namely: cumin, lemon, camphor, mint, basil, thyme and lantana) as insect repellents against potato tuber moth under laboratory conditions. In this work we describe a laboratory study to assess the potential use of some essential oils and the monoterpenes: carvacrol and eucalyptol as natural insecticides against potato tuber moth at different developmental stages (eggs, larvae, pupae and adults).

MATERIAL AND METHODS

Essential oils

The essential oils tested were thyme and myrtle oils. The leaves of wild *Thymus syriacus* Boiss (*Labiatae*), and wild *Myrtus communis* L. (*Myrtaceae*) were harvested at the flowering stage in April and May 2014, from Damascus and Latakia regions in Syria. Voucher specimens of those species were deposited in the laboratory of Plant Biotechnology Department, Atomic Energy Commission of Syria (AECS). Leaves were initially air-dried for 6 days at room temperature, then powdered. Oil extracts were obtained by hydrodistillation for 3 h using a Clevenger-type apparatus [28]. Oil yields were 1.65% w/w for thyme, and 1.7% w/w for myrtle, estimated on the basis of the dry weight of the plant material. Hydro-distillated mass was about 100 g DW.

The essential oil of *Thymus syriacus* contains about 15 compounds, mainly carvacrol (36.73%), and the essential oil of *Myrtus communis* contains about 19 compounds, mainly α -pinene (32.10%) and eucalyptol (12.20%) [29, 30].

Monoterpenoid constituents

Several researchers reported mono- and sesquiterpenoids as the major components of essential oils [31-33]. The essential oils were tested contain carvacrol and eucalyptol. We also tested the effects of those monoterpenoid constituents separately. We used carvacrol, (97% purity), from Fluka (Germany); and eucalyptol, (99% purity), from Sigma (USA).

Insects

Insects used in this study were from a laboratory stock culture obtained by field collection. Larvae were reared on wax-coated potato placed in plastic containers (40x25x10 cm). The newly emerged adults were collected and confined in 350 ml transparent plastic jars (10 pairs in each jar). A band of filter paper was added to the bottom of each jar for oviposition, and 10% sucrose solution was presented as a food source. Temperature was maintained at $25 \pm 1^\circ\text{C}$ with relative humidity of $70 \pm 5\%$, under a day-night cycle of 12 h [34].

Fumigation experiments

A series of fumigation experiments in three replicates were conducted to test the insecticidal effect of thyme and myrtle essential oils and the two monoterpenes: carvacrol and eucalyptol on potato tuber moth.

Fumigation of larvae

Untreated clean tubers were deposited in glass jars of 1000 ml capacity, (200 g tubers per jar), the PTM larvae (<24 h of age) were gently placed on the tubers (30 larvae/jar) using a fine camel-hair brush. Different concentrations of the oils were blotted on paper strips measuring 3x3 cm using an automatic pipette. The concentration of the essential oil vapor was calculated on the basis of μl essential oil/l air. Five thyme oil concentrations were tested: 0.10, 0.50, 1, 3 and 3.5 $\mu\text{l/l}$ air, and six for myrtle: 0.05, 0.10, 0.50, 1, 3 and 5 $\mu\text{l/l}$ air. Different concentrations of the two essential oils were used to determine the highest concentration that kills 100% of tested larvae and the lowest none-effective concentration. Control jars containing tubers with larvae were also included. Jars were closed tightly and incubated under the conditions mentioned above for 48 h. After that, paper strips were removed, then tubers transferred to transparent plastic containers (20x12x10 cm) with air holes on sides and layer of sterile sand covering the bottom and covered with a fine netting. Containers were then incubated under the same experimental conditions and monitored for the development of larvae to adults (about 40 days).

Fumigation of pupae

After copulation and oviposition period, within the first 5 days after confinement [35], the eggs (<24 h of age) deposited on filter paper were removed and counted (100–150 egg), then divided into equal groups. Each group of eggs were placed in a separate glass Petri dish. Essential oils were applied on a filter-paper. For thyme oil the concentrations tested were: 0.5, 1, 2, 4 and 5 μl oil/160 cm^3 air. For myrtle oil the concentrations tested were: 1, 2, 3, 4, 5, 7, 9, and 11 $\mu\text{l}/160 \text{ cm}^3$ air. Controls were also included. After seven days of treatment, the percentage of hatched eggs was assessed.

Fumigation of adults

In order to test the toxicity of essential oils on the adults (<24 h of age), adults in groups of 30 individuals were put into 1000 ml glass jars. Then, essential oils were applied on filter paper strips attached to the inner side of the jars lids. Concentrations of thyme and myrtle oils tested were: 0.05, 0.10, 0.25, 0.50, 0.75, 1 and 2 $\mu\text{l/l}$ air. The jars were then kept in the incubator and mortality was determined after 24 h from the beginning of exposure. The control jars were maintained under the same conditions without any essential oil.

Fumigation of adults with monoterpenoids

To determine the insecticidal activity of carvacrol and eucalyptol, adults (<24 h old) in groups of 30 individuals were put into 2000 ml glass jars. Filter papers (3x3 cm) were impregnated with carvacrol or eucalyptol at two concentrations (0.05, 0.25 μ l), then attached to the bottom of the screw caps of the glass jars. Adults mortality was determined after 3, 6, 24, 27 and 48 h from exposure. Adults were considered dead when no leg nor antennal movements were observed. We applied carvacrol and eucalyptol, the main effective constituents in these oils, only on insects at the adult stage as a control indicator on the insecticidal activity of these oils.

STATISTICAL ANALYSIS

Mortality percentages were estimated according to equation No. 1. Corrected mortality estimates were done using Schneider-Orelli's formula No. 2. One-way analysis of variance (ANOVA) was applied on percentages data using SPSS software, version 17, to estimate the significance of differences between means at $p < 0.05$. Statistical analysis of data was carried out by employing probit analysis to estimate the LC_{50} and LC_{90} and slopes were generated [36].

- (1) mortality percentage = number of dead / number of introduced*100
- (2) corrected mortality rate % = (mortality % in treated – mortality % in control)/ (100 – mortality % in control)*100

RESULTS

Thyme and myrtle essential oils vapors showed diverse insecticidal toxicity levels on the different development stages of potato tuber moth (PTM). Statistical analysis indicated a significant difference ($p < 0.05$), in PTM mortality in relation to stage of life, oil kind and concentration. The mortality significantly increased by increasing the essential oil concentration. Adults exposure to high doses of essential oils of thyme and myrtle (2 μ l/l air) resulted in a 100% mortality after 24 h exposure, whereas, a concentration of 0.05 μ l/l air resulted in only a 4% mortality for thyme essential oil vapors and a 2% mortality for myrtle essential oil vapors (fig. 1, 2). There was an evident positive dose-effect relationship for the range of doses between the lowest and the highest doses applied for the two essential oils. The above results were reflected in the LC_{50} values representing toxicity levels of both essential oils.

Figure 1.

Mortality percentages of potato tuber moth stages due to treatment with different concentrations of thyme oil. Means denoted with identical letters do not differ significantly according to the ANOVA test

Figure 2. Mortality percentages of potato tuber moth stages due to treatment with different concentrations of myrtle oil. Means denoted with identical letters do not differ significantly according to the ANOVA test

Tables 1 and 2 show that LC_{50} values for thyme and myrtle oils as calculated by probit analysis. LC_{50} for thyme and myrtle were $0.5 \mu\text{l/l}$ air and $1 \mu\text{l/l}$ air, respectively. The same toxicity levels also apply for adults. Eggs were more sensitive to thyme essential oil vapour than to myrtle essential oil vapour. It is evident from figure 1 that thyme essential oil showed a higher toxicity to PTM eggs than myrtle essential oil. This study found that $5 \mu\text{l}/160 \text{ cm}^3$ of thyme oil, ($31.25 \mu\text{l/l}$ air), caused a 100% mortality compared to 71% mortality caused by the same concentration of myrtle oil. Probit analysis showed that PTM eggs were more susceptible ($LC_{50} = 6.1 \mu\text{l/l}$ air) to thyme oil than myrtle oil ($LC_{50} = 26.2 \mu\text{l/l}$ air). The corresponding LC_{90} were $415 \mu\text{l/l}$ air and $89.75 \mu\text{l/l}$ air for thyme oil and myrtle oil, respectively. So LC_{50} for thyme oil was 5 times lower, i.e. more toxic than myrtle oil for the same exposure period. In the case of pupae, both essential oils caused a 100% mortality. The highest effect observed was at $8 \mu\text{l}/160 \text{ cm}^3$ air ($50 \mu\text{l/l}$ air) and $16 \mu\text{l}/160 \text{ cm}^3$ air ($100 \mu\text{l/l}$ air) for thyme and myrtle essential oils, respectively. Thyme oil at $8 \mu\text{l}/160 \text{ cm}^3$ against this stage caused a 100% mortality compared to 48% caused by myrtle oil at the same concentration, i.e. it is 2 times more toxic (fig. 1, 2). LC_{50} and LC_{90} values for those essential oils are summarized in table 1 and 2 these values revealed that the most effective essential oil against PTM pupae was thyme oil. LC_{50} and LC_{90} values for thyme oil were 5.7 and $51.09 \mu\text{l/l}$ air, respectively (tab. 1). For the larval stage, the highest effect for the two essential oils were at $3.5 \mu\text{l/l}$ air for thyme oil (fig.1), and $5 \mu\text{l/l}$ air for myrtle oil (fig. 2). No infections for potato tubers were observed. On the other hand, thyme essential oil showed fumigant activity against PTM larvae at 0.50 and $1 \mu\text{l/l}$ air, but, with an infection on potato tubers and on the control. This indicates that higher doses are needed for efficient management of this pest. Strong differences in mortality percentages of adults were observed depending on the treatment, exposure time and concentrations. The carvacrol was relatively more toxic compared to eucalyptol. The carvacrol at the concentration of $0.025 \mu\text{l/l}$ air caused 81% mortality after 3 h exposure, and 100% mortality after 48 h. While eucalyptol at the same concentration achieved only 17% mortality after 48 h exposure (fig. 3). At $0.125 \mu\text{l/l}$ air, carvacrol caused 100% mortality after 6 h. This mortality was 15% for treatment with eucalyptol for the same exposure time (fig. 3). Probit analysis showed that PTM adults are more susceptible to carvacrol than to eucalyptol ($LT_{50} = 0.5 \mu\text{l/l}$ air) (tab. 3).

Table 1.

Fumigant toxicity of *Thymus syriacus* essential oil against potato tuber moth (*Phthorimaea operculella*), using different concentrations

<i>Ph. operculella</i>	LC_{50} [$\mu\text{l/l}$ air]	LC_{90} [$\mu\text{l/l}$ air]	Slope $\pm$ SE	F_{cal}	F_{05}	d.f	χ^2
Adults	0.5	1.9	2.2 ± 0.5	18.2	6.6	6	11
Eggs	6.1	11.8	4.4	32.2	10.1	4	7.8
Pupae	5.7	51.09	1.4 ± 0.2	6.6	40.5	6	11

Units LC_{50} and $LC_{90} = \mu\text{l/l}$ air, applied at 25 ± 1 °C. d.f = Degrees of freedom. $p=0.0001$

Table 2.

Fumigant toxicity of *Myrtus communis* essential oil against potato tuber moth (*Phthorimaea operculella*), using different concentrations

<i>Ph. operculella</i>	LC ₅₀ [μl/l air]	LC ₉₀ [μl/l air]	Slope±SE	F _{cal}	F ₀₅	d.f	χ ²
Adults	0.5	1	3.8±0.5	182.6	7.7	5	9.5
Eggs	26.2	40.5	6.8±0.9	53.7	6	7	12.6
Pupae	52.9	89.7	5.6±0.8	34.1	6	7	12.5

Units LC₅₀ and LC₉₀ =μl/l air, applied at 25 ± 1 °C. d.f = Degrees of freedom. p=0.0001

Table 3.

LT₅₀ and LT₉₀ values for carvacrol and eucalyptol on potato tuber moth adults at dose of (0.025 μl/l air) for various exposure times

Concentration (μl/l air)	Compounds	LT ₅₀ [h] ^a	LT ₉₀ [h] ^a	Slope±SE	F _{cal}	F ₀₅	d.f	χ ²
0.025	carvacrol	0.5	7.6	1.1±0.4	10.2	10.1	4	7.8
	eucalyptol	ns ^b	ns ^b	0.7±0.4	8	10	4	7.8

^a Units LT₅₀ and LT₉₀ = 3, 6, 24, 27, 48 h, applied at 25 ± 1 °C. d.f = Degrees of freedom. ^b Non significant.

Figure 3.

Mortality percentages of potato tuber moth adults exposed to various periods of time to monoterpenoids (carvacrol, eucalyptol) vapors

DISCUSSION

Various publications have documented the toxicity of essential oils extracted from aromatic plants against insects [17, 37, 38]. The essential oils or their components that show fumigant action are generally of low toxicity to mammals. The oral LD₅₀ values (mg/kg body weight) of some of the essential oils for rats are 2.84 for thyme oil, 4.44 for eucalyptus oil, 0.81 for carvacrol and 2.48 for eucalyptol [39]. In this study, the tested essential oils demonstrated fumigant toxicity to PTM stages. The insecticidal activity varied with insect stage, concentration of the oil and exposure time. Our results are in agreement with those reported by Moawad and Ebadah [2], Sharaby *et al.* [24], Rafiee-Dastjerdi *et al.* [40]. That essential oils and terpenes protect potato tubers against potato tuber moth infestation during storage. *T. syriacus* oil demonstrated a higher fumigant toxicity than *M. communis* essential oil against PTM stages except for the adults, where mortality percentages for both oils were a 100% at 2 µl/l air concentration after 24 h exposure. Fumigant properties of some thymus species have been reported against a number of insects [41]. However, these studies did not report the fumigant activity of *T. syriacus* on insect pests. The fumigant activity of essential oils from *M. communis* has been evaluated against a number of stored product insects [17, 42]. The oil of *T. persicus* has a strong fumigant activity against *Sitophilus oryzae* L. adults at different concentrations and exposure times [41]. Insecticidal and repellent activities of *Thymus vulgaris* L. have been reported against *Tribolium castaneum* (Herbst) [43]. Ovicidal fumigant toxicity of *M. communis* L. essential oil was tested on *Trogoderma granarium* (Everts). It was found that the adult stage was the most sensitive to essential oil vapors than all other developmental stages. Whereas, larvae were the most tolerant with 94% and 100% mortality obtained after exposure to 562.5 µl/l air for 24 and 48 h respectively [17]. It was shown that *M. communis* oil have lower toxicity against *Plodia interpunctella* (Hübner) adults (66.7% mortality at 25 µl/l air) [42]. Jahanshir [44] found that *M. communis* essential oil at 100 µl/l air concentration achieved a 100% mortality against *Tribolium castaneum* (Herbst) and *Tribolium confusum* (Du val) adults after 72 h of exposure. By comparison, this study showed that a 12.5 µl/l air, (2 µl/160 cm³ air) see figures 1 and 2, of both two tested essential oils resulted in a 100% mortality to adults of PTM when fumigated for 24 h. The larvae, eggs and pupae were more sensitive to thyme oil than to myrtle oil. Two natural terpenes termed ZP-51 and SEM-76 were isolated from aromatic plants belonging to *Labiatae* family. Those terpenes have a strong fumigant toxicity effect on *T. granarium* larvae, at 1.5 µl/l air. They showed a 87% and 99% mortality, respectively [45]. Rozman *et al.* [46] showed that carvacrol (the major constituent in thyme oil) achieved a 72.5% and 82.5% mortality against *Sitophilus oryzae* and *Rhyzopertha dominica*, respectively after 24 h exposure. Eucalyptol is one of the monoterpenoids and there are numerous reports regarding its insecticidal activity against pests [47]. It achieved a 100% and 97% mortality against *S. oryzae* and *R. dominica*, respectively. Lee *et al.* [48] showed that carvacrol (LC₅₀ = 79.4 µl/l air)

was a toxic fumigant on *S. oryzae*. Lee *et al.* [49] reported that eucalyptol was the most toxic fumigant constituent against the adults of *T. castaneum* ($LD_{50} = 7.4 \mu\text{l/l}$ air). Erler [50] showed that carvacrol and eucalyptol achieved a 94.1% and 22.8% mortality, respectively against *T. confusum* adults after 96 h exposure to 46.2 mg/l air. They also achieved a 100% and a 48.6% mortality, respectively against *Ephesia kuehniella* Zeller larvae after 96 h exposure to 148.82 mg/l air, and a 97.3% and 86.8% mortality, respectively against *T. confusum* eggs after 96 h exposure to 46.2 mg/l air. They also achieved a 100% and a 46.5% mortality, respectively against *E. kuehniella* eggs after 96 h exposure to 46.2 mg/l air. Ojimekwe and Adler [51] found that only thymol caused sufficient mortality to allow the determination of LD_{50} and LD_{95} values, whereas other components like eucalyptol and menthol, had a low toxicity against *T. confusum*. The same situation was observed in the present study for eucalyptol. Taking into consideration the LD_{50} and LT_{50} values presented by this study, our results demonstrate a much more toxicity for thyme and myrtle essential oils against PMT adults ($LD_{50} = 0.5$). Carvacrol was more active than eucalyptol against PTM adults (a 100% mortality after 48 h exposure vs. a 17% mortality for the same exposure time). The toxic effect is almost certain due to one or more of the components of these two essential oils particularly monoterpenes. These monoterpenes form 81.07% in the essential oil of thyme and 86.4% the essential oil myrtle of the total compounds contained in those essential oils [29, 30]. Monoterpenes, are of special interest for industrial markets because of their potent biological activities in addition to their toxicity to insects. They can penetrate into insects rapidly and interfere with their physiological functions [52, 50]. Several reports indicated that monoterpenoids causes insect mortality by inhibiting acetyl-cholinesterase enzyme activity [53, 54]. However, other scientists [48] reported that terpenoid toxicity was not necessarily correlated with the ability to inhibit AChE activity. Previous reports [55] suggested that toxicity of the essential oil constituents are related to the octopaminergic nervous system of the insects. There is another suggestion that some monoterpenes may inhibit the cytochrome P450-dependent mono-oxygenases [56]. The above citations suggested that the target sites of action of monoterpenes might be various.

CONCLUSIONS

The present work demonstrated that *T. syriacus* essential oil is promising as a fumigant against the different developmental stages of PTM. Our data presented indicated that carvacrol (36.73%) which is the main compound in *T. syriacus* essential oil is the most promising fumigant. We recommend the chemical synthesis of this compound for producing new insecticides to combating PMT in traditional potato stores. Further studies are needed to isolate other active constituents in those two essential oils and investigating there toxic effects on insects.

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ZASTOSOWANIE FUMIGACJI ZA POMOCĄ OLEJKÓW ETERYCZNYCH I DWÓCH MONOTERPENÓW DO ZWALCZANIA SKOŚNIKA ZIEMNIACZAKA (*PHTHORIMAEA OPERCULELLA* ZELLER)

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Streszczenie

Wstęp: Skośnik ziemniaczak (PTM) jest szkodnikiem powodującym największe szkody w zbiorach ziemniaka. Podejmowano różne próby zapobieżenia i kontrolowania tego szkodnika za pomocą naturalnych pestycydów i syntetycznych fumigantów. **Cele:** Przedstawione badania miały na celu określenie aktywności owadobójczej olejków eterycznych z tymianku i mirtu. Dodatkowo stosując fumigację zbadano aktywność owadobójczą karwakrolu i eukaliptolu przeciwko skośnikowi ziemniaczakowi w różnych stadiach jego rozwoju. **Metody:** Olejki z tymianku i mirtu wyekstrahowano z dzikorosnących osobników *Thymus syriacus* Boiss. i *Myrtus communis* L. metodą hydrodestylacji. Doświadczenia z fumigacją prowadzono na różnych stadiach rozwojowych skośnika (jaja, larwy, poczwarki i okazy dorosłe) przy użyciu standardowych metod. Stosowano różne stężenia oraz czasy działania olejków eterycznych. Do określenia istotności statystycznej różnic w śmiertelności owadów (przy $p < 0.05$) użyto jednoczynnikowej analizy wariancji (ANOVA). Do oznaczenia LC_{50} , LC_{90} and LT_{50} wykorzystano analizę probitową. **Wyniki:** Osobniki dorosłe były najbardziej wrażliwe na opary olejków eterycznych – LC_{50} przy stężeniu $0,5 \mu\text{l/l}$ powietrza. Z kolei poczwarki tolerowały go najlepiej. Opary olejku eterycznego z tymianku najsilniej toksycznie działały na jaja – LC_{50} przy stężeniu $6,1 \mu\text{l/l}$ powietrza. Dwa monoterpeny wykazały różnorakie działanie toksyczne na osobniki dorosłe. Karwakrol powodował 100% śmiertelność przy stężeniu $0,125 \mu\text{l/l}$ powietrza po 6 h i dla stężenia $0,025 \mu\text{l/l}$ powietrza po 48 h ekspozycji, przy okresie LT_{50} wynoszącym 0,5 h. **Wniosek:** W pracy wykazano, że olejek eteryczny z *T. syriacus* jest obiecującym naturalnym fumigantem działającym przeciwko PTM w różnych stadiach rozwojowych.

Słowa kluczowe: *Phthorimaea operculella*, olejek eteryczny, mirt, tymianek, karwakrol, eukaliptol