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Original article (Orijinal araştırma)

The effects of some essential oils on the life table parameters of green peach aphid *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae)

Bazı bitkisel yağların şeftali yeşil yaprakbiti *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae)'nin yaşam çizelgesi parametreleri üzerindeki etkileri

Ali KAYAHAN[1]

Abstract

In this study, essential oils (EOs) of *Citrus limon* (L.), *Citrus sinensis* (L.) (Sapindales: Rutaceae), *Allium sativum* (L.) (Asparagales: Amaryllidaceae) and *Brassica nigra* (L.) (Brassicales: Brassicaceae) were evaluated for their insecticidal effects on the green peach aphid *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae). The lethal and sublethal effects of these EOs on *M. persicae* were studied under laboratory conditions. This study was conducted at Yozgat Bozok University, Faculty of Agriculture, Department of Plant Protection in 2023. The experiments were evaluated at different concentrations for 24 hours after treatment. The lethal concentrations (LC_{50}, LC_{90}) of the EOs were calculated based on the data obtained. The life table parameters of newly born aphids were studied at sublethal concentrations (LC_{40}, LC_{30}) of EOs, and these parameters were calculated using the Euler-Lotka equation. The results show that the mortality rate increases with growing concentration of essential oils. The lethal concentration (LC_{50}) of essential oils were calculated to be 3.47, 4.37, 4.51, and 5.16 µL/L, respectively. The sublethal concentrations (LC_{40}, LC_{30}) of essential oils caused an increase in adult longevity, a decrease in fecundity of surviving aphids and intrinsic rate of increase. From the data obtained, the EOs of *C. limon* and *C. sinensis* were more effective than other EOs in the study. It was found that other essential oils (*A. sativum* and *B. nigra*) may also be effective against *M. persicae*, even if their effect is low.

Keywords: Green peach aphid, intrinsic rate of increase, net reproduction rate, essential oils, lethal concentration

Öz

Bu çalışmada, *Citrus limon* (L.), *Citrus sinensis* (L.) (Sapindales: Rutaceae), *Allium sativum* (L.) (Asparagales: Amaryllidaceae) ve *Brassica nigra* (L.) (Brassicales: Brassicaceae) bitkisel yağlarının, şeftali yaprakbiti *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae) üzerindeki insektisidal etkileri değerlendirilmiştir. Bu bitkisel yağların *M. persicae* üzerindeki öldürücü ve öldürücü olmayan etkileri laboratuvar koşullarında incelenmiştir. Bu çalışma 2023 yılında Yozgat Bozok Üniversitesi, Ziraat Fakültesi Bitki Koruma Bölümünde yürütülmüştür. Denemeler uygulamadan 24 saat sonra farklı bitkisel yağ konsantrasyonları için değerlendirilmiştir. Elde edilen verilere göre bitkisel yağların letal dozları (LC_{50}, LC_{90}) hesaplanmıştır. Bitkisel yağların öldürücü olmayan dozlarında (LC_{30}, LC_{40}) yaşam çizelgesi parametreleri belirlenmiştir ve bu parametreler Euler-Lotka eşitliğine göre hesaplanmıştır. Sonuçlar bitkisel yağ dozlarının artmasıyla ölüm oranın arttığını göstermektedir. Bitkisel yağların *M. persicae* üzerindeki LC_{50} dozları sırasıyla 3.47, 4.37, 4.51 ve 5.16 µL/L olarak hesaplanmıştır. Bitkisel yağların öldürücü olmayan dozları ise (LC_{30}, LC_{40}) ergin ömrünün artmasına, doğurganlığının azalmasına ve kalıtsal üreme oranının azalmasına neden olmuştur. Elde edilen verilere göre *C. limon*, *C. sinensis* bitkisel yağlarının çalışmadaki diğer bitkisel yağlardan daha etkili olduğu görülmüştür. Diğer bitkisel yağların da (*A. sativum* ve *B. nigra*) *M. persicae*'ye karşı düşük de olsa etkili olabileceği belirlenmiştir.

Anahtar sözcükler: Şeftali yeşil yaprakbiti, kalıtsal üreme yeteneği, net üreme gücü, bitkisel yağlar, letal doz

[1] Yozgat Bozok University, Faculty of Agriculture, Department of Plant Protection, 66100, Yozgat, Türkiye
* Corresponding author (Sorumlu yazar) e-mail: aalikayahan@gmail.com
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Introduction

The Green peach aphid *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae) causes damage to more than 400 plants. For this reason, it is one of the most harmful species (Blackman & Eastop, 2000). This harmful insect can increase its population rapidly owing to its parthenogenetic reproduction and short lifespan (Foster et al., 2000). Keeping the population of *M. persicae* under control is only possible with chemical insecticides. Consequently, this harmful insect has gained resistance to different chemicals (Elbert et al., 2008; Bass et al., 2014; Sial, 2019). The use of high amounts of insecticides on agricultural pests creates negative effects on the environment and human health. As a result, the natural equilibrium is disturbed and residue problems arise on the products (Grdısa & Gršić, 2013; Gill & Garg, 2014, Rother, 2018). In recent years, due to such problems of insecticides, it has been searched for compounds of plant origin with little negative effect (Liao et al., 2017; Kunbhar et al., 2018). It is thought that insecticides obtained from plants can be a good alternative to synthetic ones (Isman, 2000; Govindarajan et al., 2016; Khan et al., 2017; Sammour et al., 2018). Volatile compounds in plants do not cause residue problems like other chemicals and their half-lives are quite short in nature. For this reason, compounds derived from plants are preferred in biological control studies (Arnason et al., 1989; Hedin et al., 1997; Regnault-Roger et al., 2012). These compounds are non-lethal to predators, parasitoids and mammals (Scott et al., 2003). In recent years, there have been many studies on the insecticidal activities of essential oils and their components in plants (Isman & Miresmailli, 2011; Ntalli & Menkissoglu-Spiroudi, 2011; Regnault-Roger et al., 2012; Miresmailli & Isman, 2014; Pavela & Benelli, 2016; Chaubey, 2019; Feng et al., 2020; Gaur & Kumar, 2020; Sayed et al., 2021). According to studies conducted in recent years, plant species belonging to 60 families with insecticidal effects can be used as biopesticides (Sukh & Opender, 2017; Isman, 2006). Although there are exceptions such as nicotine, botanical pesticides have a low toxic effect on the environment and essential oils degrade faster in nature than other synthetic chemicals (Moretti et al., 2002; Regnault-Roger & Philogène, 2008). Some researchers have conducted different studies to understand the effect of sublethal concentrations of vegetable oil-based insecticides (Plata-Rueda et al., 2020; Pavela et al., 2020, 2021; Yeguerman et al., 2020; Benelli et al., 2022). The use of essential oils in different concentrations on insects has different effects. Essential oils and the components they contain have different effects, as well as lethal effects, in the adult and pre-adult stages of insects (Alzogaray et al., 2011; Alghamdi, 2018; Abdelaal et al., 2021; Sayed et al., 2022; Al-Harbi et al., 2021). Considering some studies, it is reported that the egg laying rate decreases, adult emergence is suppressed and less damage occurs to the crops (Keita et al., 2001; Rahman & Talukder, 2006). But some studies of citrus EOs have focused on toxicity of aphids. It is known that the extract prepared with lemon (*Citrus limon*) has an insecticidal effect against the rose aphid (*Macrosiphum roseiformis*) (Gupta et al., 2017). In addition, *C. aurantium*, *C. sinensis* and *C. limon* essential oils have been reported to show high toxicity against the woolly beech aphid, *Phyllaphis fagi* (L., 1761) (Hemiptera: Aphididae) (Yazdgerdian et al., 2015). Similar situations apply to vegetable oils obtained from *Allium sativum* and *Brassica nigra*. In other words, they have a toxic effect on different insect species. Considering the studies, it is seen that *A. sativum* has a lethal effect on aphids (Alghamdi, 2018), mosquitoes (Mahanta et al., 2020) and some stored pests (Omar & Zayed, 2021).

In this study, the lethal and sublethal effects of 4 different commercially available vegetable oils [*Citrus limon* (L.), *Citrus sinensis* (L.) (Sapindales: Rutaceae), *Allium sativum* (L.) (Asparagales: Amaryllidaceae), *Brassica nigra* (L.) (Brassicales: Brassicaceae)] on *Myzus persicae* were determined.

Materials and Methods

This study was conducted at Yozgat Bozok University, Faculty of Agriculture, Department of Plant Protection in 2023.

Essential oils (EOs)

The vegetable oils used in this study (*Citrus limon*, *Citrus sinensis*, *Allium sativum*, *Brassica nigra*) were commercially obtained from Botalife®.

Production of pepper plant

The bell pepper plant (*Capsicum annuum* L. var. *grossum*) used in the experiments were grown in 200 mL plastic containers with a 1: 1 soil: peat mixture. The plants were grown in a climate-controlled room at a temperature of 27±1°C, relative humidity of 65±5% and a long daylight photoperiod of 16: 8.

Culture of *Myzus persicae*

The last stage nymph *M. persicae* individuals were transferred to the pepper plants that reached the height (15 cm) and the number of leaves (6 pieces) to be used in the experiments, and they were reproduced in cages (50x50x50 cm) covered with tulle. The initial population of aphids infested to clean plants was obtained from mass production in the laboratory. Aphids were collected on pepper plants in Serik in Antalya and identified by Prof. Dr. İsmail Karaca (Isparta University of Applied Sciences, Isparta Türkiye) in nature were used for the experiments. Aged and decaying plants were replaced with clean plants at weekly intervals to ensure the continuity of mass production. Aphid rearing was performed in climate-controlled rooms at a temperature of 25±1°C, 65±5% proportional humidity and 16: 8 (light: dark) light conditions.

Mixture of fumigant and contact toxicity of essential oils

In the first phase of the study, the lethal effect of different concentrations (0.5, 1, 2, 4, 6, 8, 10, 12 µL/L) of plant oils (*C. limon*, *C. sinensis*, *A. sativum*, *B. nigra*) on *M. persicae* was determined. Petri dishes with filter paper of 9 cm diameter were used for the experiments. The prepared concentrations were included as 1 ml in each Petri dish in the filter paper. The nymphs (2nd and 3rd stages) were transferred to this paper using a thin sable brush. Then, the individuals were put in contact with the concentration on the paper (tarsal, ventral and labial contact), assuming that the plant oils were affected by the toxicity of the fumigant. Then, leaves of bell pepper plants were added to the Petri dish to feed the aphids. After 24 hours, the live and dead individuals were recorded and the effects of the oils were determined. Tween20 (2%) was used to dissolve the oils in the experiments. For each concentration, 10 Petri dishes were used and for each Petri dish, 10 aphids were used. Tween20 (2%) was used as a control. Experiments were conducted in air-conditioned rooms at a temperature of 25±1°C, relative humidity of 65±5%, and a long daylight photoperiod of 16: 8. To determine mortality rates over live and dead individuals, Abbott's formula was used and the percentage of mortality rates was calculated (Abbott, 1925). Analysis of variance (ANOVA) was applied to the results obtained. If the difference between the means was statistically significant, Tukey HSD post-hoc test was used to compare group means ($\alpha<0.05$). The lethal concentrations of the plant oils (LC_{30}, LC_{40}, LC_{50}, and LC_{90}) were determined using the mortality rates obtained in this phase of the study. Probit analysis was used to determine these concentrations.

$$\text{Percent effect} = \left(\frac{\text{Number of live individuals in the control} - \text{Number of live individuals in the application}}{\text{Number of live individuals in the control}}\right) \text{X } 100$$

Estimating life table parameters

The effects of LC_{30} and LC_{40} concentrations of plant oils on *M. persicae* were determined. The prepared concentrations were absorbed by the filter papers in the Petri dishes, and the one-day-old individuals transferred to the petri dish using a sable brush. Damp cotton is left on the bottom of the filter paper to prevent the leaves from fading. Bell pepper leaves were then laid out as food for the aphids. The daily development of individuals was then monitored; newborns were recorded and removed from the Petri dishes. Counts continued until the aphids died. This part of the experiments was performed with 50 replicates for each concentration. To ensure air circulation in the Petri dish, the lids of the standard size Petri dishes were opened and covered with tulle to prevent escape of the animals. Experiments were performed in air-conditioned rooms at a temperature of 25±1°C, relative humidity of 65±5%, and a long daylight photoperiod of 16: 8.

The data obtained from the experiments were recorded to determine the development of age-related life tables for each temperature used. The parameters of the life tables of *Myzus persicae* were calculated using RmStat-3 software (Özgökçe & Karaca, 2010) according to the Euler-Lotka equation (Birch, 1948), and analyzed separately. In the study, resampling was performed using the bootstrap method and the data obtained here were compared. Tukey multiple comparison test was used to compare the periods with Minitab (Ver. 16) at the level of significant difference p<0.05. The following equations were used to calculate the parameters:

Age-related survival rate (l_x), Fertility rate (m_x) (Birch, 1948);

Reproductive value (V_x)

$$V_x = \frac{\sum_{y=x} \left(e^{r_m \cdot y} . l_y . m_y\right)}{l_x . e^{-r_m \cdot x}}$$ (Imura ,1987);

Net Reproduction Rate (R_0)

$$R_0 = \sum l_x . m_x$$ (Birch, 1948);

Intrinsic Rate of Increase (r_m)

$$\sum e^{(-r_m \cdot x)}\, l_x . m_x = 1$$ (Birch, 1948);

Mean Generation Time (T_0)

$$T_o = \frac{\ln R_0}{r_m}$$ (Birch, 1948);

Gross Reproduction Rate (*GRR*)

$$GRR = \sum m_x$$ (Birch, 1948);

Daily maximum reproductive value (λ)

$$\lambda = e^{r_m}$$ (Birch, 1948);

Doubling time (T_2)

$$T_2 = \frac{\ln 2}{r_m}$$ (Kairo & Murphy, 1995).

Results

Toxicity of essential oils on *Myzus persicae*

It was observed that the vegetable oils used in the study were effective on *Myzus persicae*. In addition, especially as the concentration increased, the mortality rate increased (p<0.05). The mortality rate at the highest concentration (12 µl/L) of *C. limon* was 94.73%; The mortality rate at the lowest concentration (0.5 µl/L) of *Brassica nigra* was 16.67% (Figure 1).

Considering the lethal concentrations of vegetable oils on *M. persicae*, the lowest LC_{50} (3.47 µl/L) and LC_{90} (9.71 µl/L) values were observed in *C. limon* application, depending on mortality rates. LC_{50} and LC_{90} values of vegetable oils are given in Table 1.

Table 1. Toxicity of different essential oils on *Myzus persicae* after 24 h

Essential oils	N	LC_{30} (µl L^{-1}) (95% CI)[a]	LC_{40} (µl L^{-1}) (95% CI)[a]	LC_{50} (µl L^{-1}) (95% CI)[a]	LC_{90} (µl L^{-1}) (95% CI)[a]	Slope ±SE[b]	X^2 (df)[c]
Citrus limon	900	0.91 (0.26-1.46)	2.23 (1.70-2.71)	3.47 (3.00-3.92)	9.71 (8.93-10.68)	1.234±0.119	33.56 (7)
Citrus sinensis	900	1.61 (0.97-2.17)	3.04 (2.51-3.53)	4.37 (3.89-4.86)	11.13 (10.24-12.25)	1.218±0.118	22.78 (7)
Allium sativum	900	1.66 (0.99-2.23)	3.13 (2.59-3.64)	4.51 (4.02-5.01)	11.49 (10.55-12.67)	1.179±0.121	24.11 (7)
Brassica nigra	900	2.77 (2.20-3.29)	4.19 (3.69-4.67)	5.16 (5.04-6.02)	12.21 (11.28-13.38)	1.398±0.108	13.49 (7)

[a] 95% confidence intervals; [b] Standart error; [c] Chi-square value (x^2) (Pearson) and degrees of freedom (*df*).

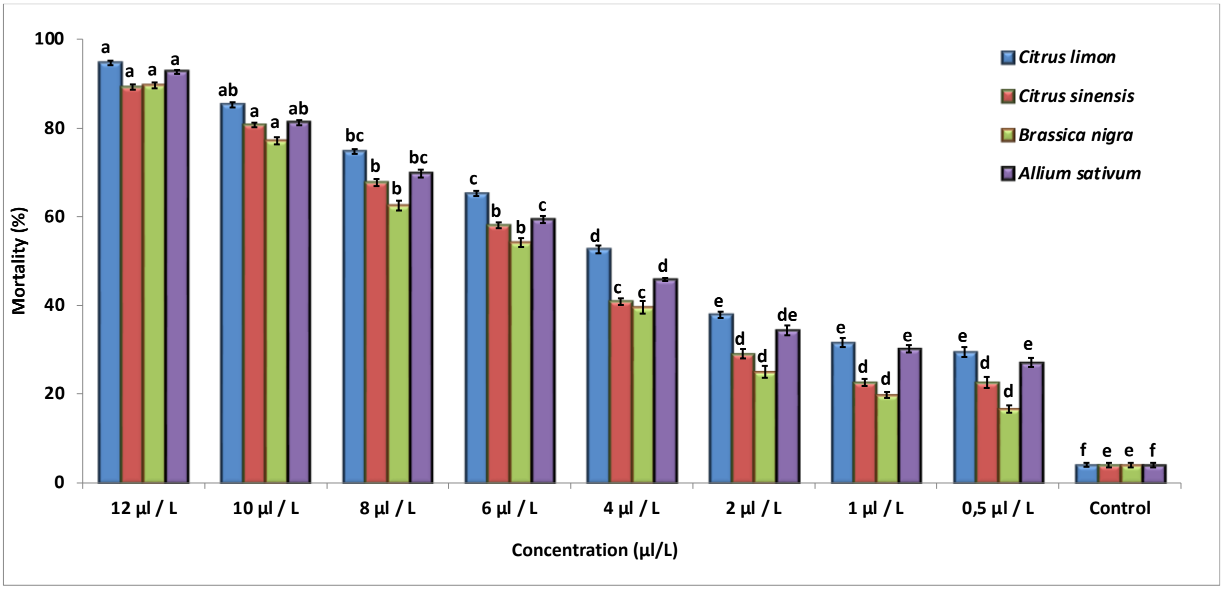

Figure 1. Mortality percentage of *M. persicae* exposed to different concentrations of different EOs (*C. limon*, *C. sinensis*, *A. sativum* and *B. nigra*) for 24 h. Comparisons were made between the application doses of the EOs. Means above columns followed by different letters were significantly different according to Tukey ($F_{C.limon}$: 156.58; $df_{C.limon}$: 8, 86; $P_{C.limon}$: 0.001 / $F_{C.sinensis}$: 125.97; $df_{C.sinensis}$: 8, 86; $P_{C.sinensis}$: 0.001 / $F_{B.nigra}$: 88.17; $df_{B.nigra}$: 8, 86; $P_{B.nigra}$: 0.001 / $F_{A.sativum}$: 88.17; $df_{A.sativum}$: 8, 86; $P_{A.sativum}$: 0.001, Error bars in the figure have shown standard error.).

Sublethal effects of vegetable oils on the life cycle parameters of *Myzus persicae*

Different lethal concentrations (LC_{30} and LC_{40}) were calculated depending on the mortality rates at the end of 24 hours in order to calculate the sublethal effects of EOs (Table 2).

Table 2. Life table parameters of *Myzus persicae* under influence of different concentrations of essential oils (*Citrus limon*, *Citrus sinensis*, *Allium sativum*, *Brassica nigra*)

Parameters*	Control**		*Citrus limon*				*Citrus sinensis*				*Allium sativum*				*Brassica nigra*			
			LC_{30}		LC_{40}		LC_{30}		LC_{40}		LC_{30}		LC_{40}		LC_{30}		LC_{40}	
r_m	0.35±0.0041	e	0.27±0.0052	e	0.27±0.0049	e	0.29±0.0033	d	0.29±0.0034	d	0.30±0.0031	bc	0.30±0.0025	c	0.31±0.0034	b	0.31±0.0037	b
R_0	55.95±1.2500	a	26.27±1.5400	e	25.89±1.4100	e	31.07±2.3300	d	30.68±1.9900	d	36.84±1.2100	bc	34.00±1.7600	c	39.55±2.3200	b	38.37±1.5600	b
T_0	11.45±0.0176	h	11.93±0.0031	a	11.65±0.00284	f	11.83±0.00258	c	11.62±0.002	g	11.87±0.0024	b	11.69±0.0023	e	11.89±0.0023	b	11.79±0.0024	d
GRR	62.27±0.0519	a	44.02±0.0188	f	38.59±0.0182	ı	47.76±0.0561	d	40.89±0.0278	h	48.74±0.0458	c	43.66±0.0357	c	51.33±0.0457	b	45.97±0.0193	e
T_2	1.973±0.0035	g	2.529±0.0020	b	2.545±0.0020	a	2.324±0.0011	d	2.353±0.001	c	2.281±0.0104	f	2.298±0.0011	f	2.242±0.0008	g	2.28±0.0009	f
λ	1.421±0.0008	a	1.315±0.0003	g	1.313±0.0003	h	1.347±0.0002	e	1.343±0.0002	f	1.355±0.0002	c	1.352±0.0002	c	1.362±0.0002	b	1.356±0.0002	c
N	50		50		50		50		50		50		50		50		50	

* r_m: Intrinsic rate of increase; R_0: Net reproduction rate; T_0: Mean generation time; *GRR*: Gross reproduction rate; T_2: Doubling time; λ: Finite rate of increase.

** Different letters for same parameters in the same row were significantly different according to Tukey (Mean±SE) (F_{rm}: 8942.79; df_{rm}: 8, 41; P_{rm}: 0.001 / F_{Ro}: 34700.45; df_{Ro}: 8, 41; P_{Ro}: 0.001 / F_{To}: 591.17; df_{To}: 8, 41; P_{To}: 0.001 / F_{GRR}: 32985.22; df_{GRR}: 8, 41; P_{GRR}: 0.001 / F_{T2}: 9592.49; df_{T2}: 8, 41; P_{T2}: 0.001 / F_{λ}: 8794.18; df_{λ}: 8, 41; P_{λ}: 0.001).

Calculated concentrations were applied to aphids and their effects were determined. Accordingly, while intrinsic rate of increase (r_m) and net reproduction rate (R_0) values show a decrease compared to the control; mean generation time (T_0) was determined to be higher than the control (p<0.05). The r_m (0.309 and 0.305 nymphs/female/day) and R_0 (39.547 and 38.372 nymphs/female) values close to the control application were calculated in two concentrations of *B. nigra* (p<0.05). The lowest r_m (0.272 nymphs/female/day) and R_0 (25.893 nymphs/female) values were observed in the LC_{40} concentration of *C. limon* (p<0.05). When the gross reproduction rate *GRR* was calculated, it was determined that the lowest value was at the LC_{40} concentration of *C. limon*, and the highest value was at the LC_{30} concentration of *B. nigra* after the control application (Table 2).

As a result of the application of LC_{40} and LC_{30} concentrations of the EOs applied in the study on *M. persicae*, decreases in survival rate (l_x), fecundities (m_x) and reproduction value (V_x) were observed compared to the control. According to the data obtained, it was determined that the lowest l_x, m_x and V_x values were in *C. limon* concentrations. It was observed that these values increased in other EOs concentrations (Figure 2).

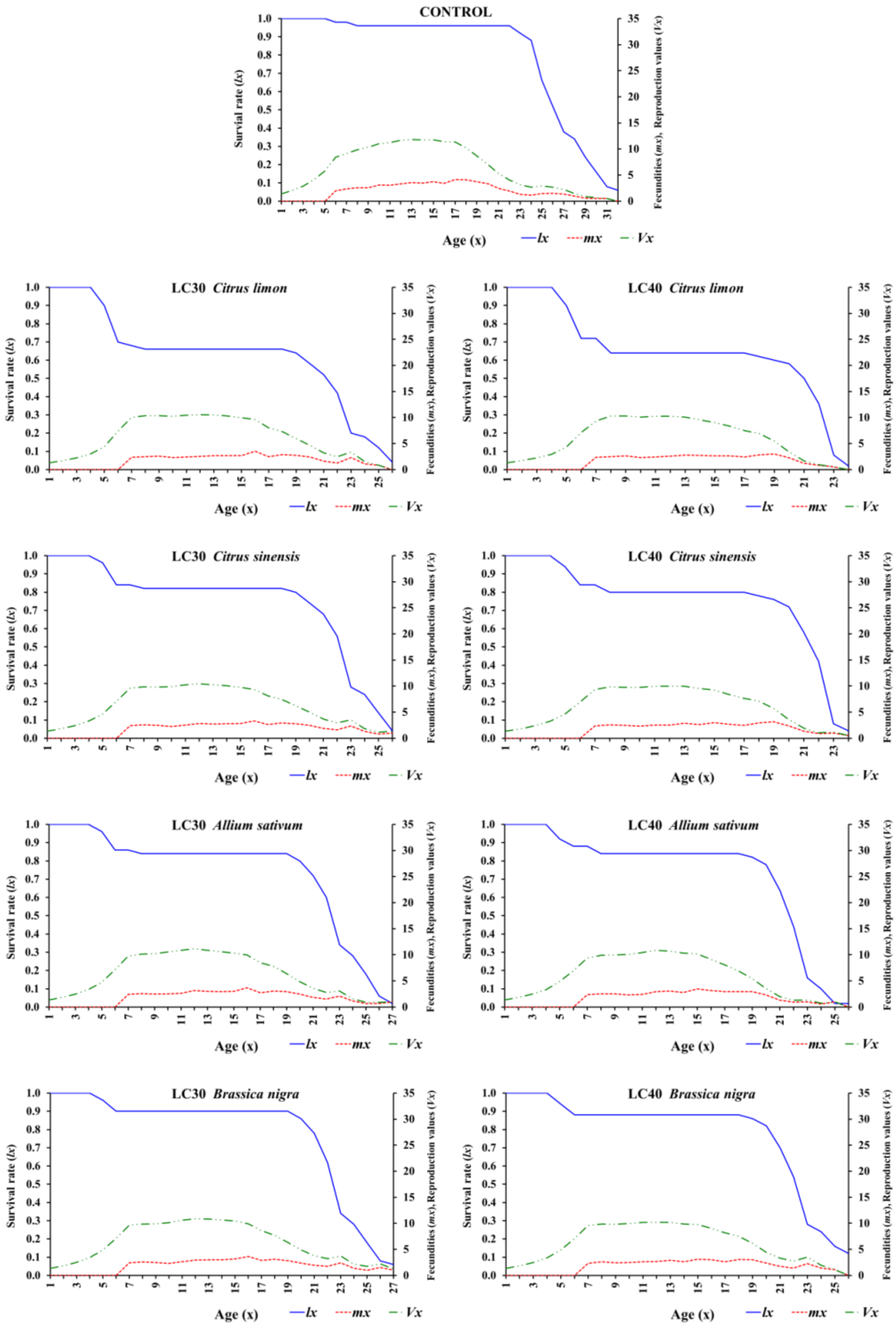

Figure 2. Survival rate, fecundity and reproductive value of *Myzus persicae* under influence of different concentrations of essential oils

Discussion

The data obtained from the experiments show that the EOs used (especially *C. limon* and *C. sinensis*) are effective against *Myzus persicae*. It was noted that in recent years, more studies have been conducted to investigate the effects of plant-based pesticides (from different vegetable families) on pests. (Schoonhoven, 1982; Jacobson, 1989; Isman, 1995; Durmuşoğlu et al., 2011; Sayeda & El-Mogy, 2011; Balcı et al., 2020). Although the effects of biopesticides used in the control of agricultural pests are not fully known, they are shown to have different effects on them. For this reason, the dose, concentration, and application frequency of the bioinsecticides used are very important (Bakkali et al., 2008). In addition, the effects of different plant oils on aphids or other pests have been studied in recent years, and they have been found to be effective on pests, although they vary among species (Işık & Görür, 2009; Górski & Tomczak, 2010; Yazdgerdian et al., 2015; Górski et al., 2016; Albouchi et al., 2018; Benelli et al., 2018; Czerniewicz et al., 2018; Behi et al., 2019; Ravan et al., 2019).

In some studies, extracts from the peels of citrus fruits such as *C. sinensis* and *Citrus paradisi* (L.) (Sapindales: Rutaceae) were found to be quite effective against aphids. It was found that particularly high concentrations of extracts increased the mortality rate (Iqbal et al., 2011; Amiri et al., 2013). Kimbaris et al. (2010) investigated the effect of *C. sinensis* EOs on various aphids (*Aphis fabae* Scopoli 1763, *Macrosiphoniella sanborni* (Gillette, 1908), *Acyrthosiphon pisum* Harris 1776 and *Myzus persicae* (Hemiptera: Aphididae)). In the data obtained, the LC_{50} values were reported to be 1.17, 1.25, 1.92 and 1.43 µL/L, respectively. The results have shown that the plant oil extracted from *C. sinensis* is effective against aphids. Gupta et al. (2017) observed that extracts obtained from the peel of *Citrus limon* were effective on *Macrosiphum roseiformis* (L., 1758) (Hemiptera: Aphididae). According to the LC_{50} values obtained by them, the highest toxicity was calculated to be 6.68 mg/ml and it was found that it could be effective against aphids. In addition, extracts from different parts of citrus plants *Rhyzopertha dominica* (Fabricius, 1792) (Coleoptera: Bostrichidae), *Sitophilus oryzae* Schoenherr, 1838 (Coleoptera: Curculionidae) (Tripathi et al., 2003), *Callosobruchus maculates* (Fabricius, 1775) (Coleoptera: Chrysomelidae) (El-Sayed & Abdel-Razik, 1991), *Tribolium castaneum* (Herbst, 1797) (Coleoptera: Tenebrionidae), *Trogoderma granarium* Everts, 1898 (Coleoptera: Dermestidae) (Zia et al., 2013), *Zabrotes subfasciatus* Boheman, 1833 (Coleoptera: Chrysomelidae) (Zewde & Jembere 2010), *Musca domestica* (L., 1758) (Diptera: Muscidae) (Palacios et al., 2009), *Planococcus ficus* Ben-Dov, 1994 (Hemiptera: Pseudococcidae) (Karamaouna et al., 2013), *Thaumetopoea wilkinsoni* Tams, 1924 (Lepidoptera: Notodontidae) (Çetin et al., 2006), *Attagenus fasciatus* (Thunberg, 1795) (Coleoptera: Dermestidae), *Lasioderma serricorne* (Fabricius, 1792) (Coleoptera: Ptinidae) (Bakr et al., 2010), and mosquitoes (Akram et al., 2010; Effiom et al., 2012) is supported by the literature. Choi et al. (2004) determined the toxicity of 53 vegetable oils to *Tetranychus urticae* C. L. Koch, 1836 (Acari: Tetranychidae). They reported that two citrus oils (bergamot and sweet orange) killed the pest 87% and 61%, respectively. Campolo et al. (2020), in their study on the effect of citrus oils, found that the formulation obtained from sweet orange had a toxic effect on the eggs and larvae of *Tuta absoluta* Stainton, 1856 (Lepidoptera: Gelechiidae). Campolo et al. (2017) found that the effect of formulations based on mandarin and lemon EO was lower than that of orange. When the results obtained are evaluated and compared with the literature, it is seen that the oils obtained from plants belonging to the *Citrus* genus have a toxic effect, especially on aphids. For this reason, it is thought that these oils have potential in controlling these pests.

Alghamdi (2018) determined the effect of essential oil of four different plants [*Moringa oleifera* Lam., 1785 (Brassicales: Moringaceae), *Eruca sativa* (L.), *Raphanus sativus* (L.) (Brassicales: Brassicaceae), *Allium sativum* (L.) (Asparagales: Amaryllidaceae)) on rose aphid (*Macrosiphum rosae* (L., 1758) (Hemiptera: Aphididae)] and field bean aphid (*Aphis fabae*). In this study, conducted with different concentrations, it was found that the number of deaths increased with growing oil concentration. For both aphids, the highest mortality rate was found in arugula oil and the lowest rate in moringa oil. Based on the results, it was concluded that the oils used in the study could be effective against aphids. In their study, Mahanta et al. (2020) investigated the effects of different plant oils (*A. sativum*, *Ocimum sanctum* L. (Lamiales: Lamiaceae) and *Citrus grandis* (Sapindales: Rutaceae)) on *Culex quinquefasciatus* Say, 1823 (Diptera: Culicidae). It was found that the vegetable oil extracted from *A. sativum* had higher toxic effect on *C. quinquefasciatus* than the others and its LC_{50} value was 18.23 µL/L. Omar & Zayed (2021) investigated the effect of *A. sativum* vegetable oil on *T. castaneum* and *R. dominica* and reported that the EO had toxic effect on the mentioned stored pests. The LC_{50} values calculated via mortality rates were reported to be 0.794 and 0.380 mg/ml, respectively. The *A. sativum* vegetable oil used in our study showed a toxic effect on *M. persicae*, although not as strong as citrus. As per previous studies, it is considered to be particularly effective in controlling aphids.

There are also different studies on *A. sativum*, one of the oils used in the study. Ali & Rodina (2002), in a study, found that a mustard extract obtained with ethanol had high toxicity on the cotton aphid *Aphis gossypii* Glover, 1877 (Hemiptera: Aphididae). At the same time, studies on the effect of the same plant on different pests are also notable. The essential oil extracted from mustard (*Brassica nigra* (L.) (Brassicales: Brassicaceae) showed very high toxicity to *Bruchidius incarnatus* (Boheman, 1833) (Coleoptera: Chrysomelidae), one of the pests of stored products (Sabbour & El-Aziz, 2010). *Callosobruchus chinensis* L., 1758 (Coleoptera: Chrysomelidae) was found to be removed from the environment by the powder extracted from this plant (Li et al., 2008). Ali & Mohamed (2018) determined the effect of *B. nigra* seeds on *Spodoptera littoralis* Boisduval, 1833 (Lepidoptera: Noctuidae). It was reported that the seeds have the ability to prevent feeding on the harmful species. Koneckal et al. (2018) reported that the vegetable oil extracted from *Brassica alba* (L.) (Brassicales: Brassicaceae) has toxic effects on several Lepidoptera pests [*Cydia pomonella* L., 1758 (Lepidoptera: Tortricidae), *Dendrolimus pini* L., 1758 (Lepidoptera: Lasiocampidae), and *Spodoptera exigua* (Hübner, 1808) (Lepidoptera: Noctuidae)]. The lethal concentration (LC_{50}) values were calculated as 0.422, 11.74 and 11.66 mg/ml, respectively. From the results, the vegetable oil used causes high mortality especially in *C. pomonella* and can be used as a biopesticide in similar lepidopterans. In previous studies, EOs and various substances derived from plants of the genus *Brassica* were found to be particularly effective against stored pests. In our study, *B. nigra* EO, which is used against green peach aphid, was found to have some toxicity, especially at high concentrations, although less than other oils and it is suggested that it may be effective against this type of pest.

Ali & Mohamed (2018) determined the effect of *B. nigra* seeds on *Spodoptera littoralis* Boisduval, 1833 (Lepidoptera: Noctuidae). It was reported that the seeds have the ability to prevent feeding on the harmful species. Koneckal et al. (2018) reported that the vegetable oil extracted from *Brassica alba* (L.) (Brassicales: Brassicaceae) has toxic effects on several Lepidoptera pests [*Cydia pomonella* L., 1758 (Lepidoptera: Tortricidae), *Dendrolimus pini* L., 1758 (Lepidoptera: Lasiocampidae), and *Spodoptera exigua* (Hübner, 1808) (Lepidoptera: Noctuidae)]. The lethal concentration (LC_{50}) values were calculated as 0.422, 11.74 and 11.66 mg/ml, respectively. Based on the results, it is concluded that the vegetable oil used causes high mortality especially in *C. pomonella* and can be used as a biopesticide in similar lepidopterans. In previous studies, EOs and various substances derived from plants of the genus *Brassica* were found to be particularly effective against stored pests. In our study, *B. nigra* EO, which is used against green peach aphid, was found to have some toxicity, especially at high concentrations, although less than other oils and it is suggested that it may be effective against this type of pest.

There are also studies on the effects of different vegetable oils on *M. persicae*, which is one of the important plant pests and the subject of our study. Kimbaris et al. (2010) studied the effect of different plant oils (*Mentha piperita* L., *Mentha pulegium* L. *Ocimum basilicum* L. (Lamiales: Lamiaceae)and *C. sinensis*) on *M. persicae* and reported that the LC_{50} values were 0.99, 1.12, 1.20 and 1.43 µL/L, respectively. It can be said that the essential oils of the genus *Mentha* are more potent than those of *C. sinensis*. It was found that the plant oils, *Cymbopogon citratus* (DC.) Stapf (Poales: Poaceae), *Cymbopogon winterianus* Jowitt ex Bor (Poales: Poaceae) and *Eucalyptus citriodora* K.D. Hill & L.A.S Johnson (Myrtales: Myrtaceae) used in different studies with *M. persicae* had a toxic effect on the pest and their LC_{50} values were 2.8, 3.6 and 4.0 mL/L, respectively (Costa et al., 2013; Pinheiro et al., 2013; Costa et al., 2015). Albouchi et al. (2018) studied the effects of *Melaleuca styphelioides* Sm. (Myrtales: Myrtaceae) plant oil on various aphids [*A. gossypii*, *Aphis spiraecola* Patch, 1914 (Hemiptera: Aphididae) and *M. persicae*] and found that it was toxic to them. Based on the data obtained, they calculated LC_{50} values of 3660.99, 619.09 and 756.65 µL/L, respectively. Gouvea et al. (2019) determined the toxicity of aqueous and ethanolic extracts of *Acmella oleracea* L. (Asterales: Asteraceae) on *M. persicae* and *Lipaphis erysimi* (Kaltenbach, 1843) (Hemiptera: Aphididae). Accordingly, ethanol extract caused the death of both aphid species by 90% within 70 hours and reduced their fecundity. Mülayim et al. (2020) studied the fumigation effect of some plant oils [thyme, *Origanum onites* L. (Lamiales: Lamiaceae), anise, *Pimpinella anisum* L. (Apiales: Apiaceae), fennel, *Foeniculum vulgare* (Apiales: Apiaceae), and lavender, *Lavandula angustifolia* L. (Lamiales: Lamiaceae)] against *Aphis craccivora* C.L. Koch, 1854 (Hemiptera: Aphididae) and *M. persicae*. The mortality rate for *A. craccivora* was calculated to be 96.67% in thyme oil at a dose of 60 µl/l air, one of the EOs used. Fennel and thyme essential oils are believed to have the potential to act as biofumigants against *A. craccivora* and *M. persicae*. Nikolova et al. (2021) determined the effects of *Origanum vulgare* subsp. *hirtum* L. (Lamiales: Lamiaceae) on *M. persicae*. In their studies conducted with different concentrations, it was found that the mortality rate increased with increasing concentration and the highest mortality rate was 3 µL/mL. Jasman & Slomy (2021) determined the effect of plant oils from *Mentha longifolia* L. (Lamiales: Lamiaceae) and *Anethum graveolens* L. (Apiales: Apiaceae) on *M. persicae*. At the end of the study, it was found that *M. longifolia* EO was more toxic than *A. graveolens*. Based on the data obtained, it was concluded that *M. longifolia* can be used to control *M. persicae*.

Although vegetable oils, which have a short half-life in nature, have a high toxic effect on pests, their effects on the environment are fully known. For this reason, it is beneficial to use it in low concentrations as in our study and repeat it under field conditions. In addition, it was concluded that the vegetable oils may be useful in controlling the population of *M. persicae* and similar pests. However, the content of the plant oil used must be determined in order to determine from which active ingredient the resulting toxicity is derived. For this reason, it is useful to determine the content of EOs in this study as well as in other studies.

References

Abbott, W. S., 1925 A method of computing the effectiveness of an insecticide. Journal of Economical Entomology, 18 (2): 265-267.

Abdelaal, K., M. Essawy, A. Quraytam, F. Abdallah, H. Mostafa, K. Shoueir, H. Fouad, F. A. S. Hassan & Y. Hafez, 2021. Toxicity of essential oils nanoemulsion against *Aphis craccivora* and their inhibitory activity on insect enzymes. Processes, 9 (4): 624.

Akram, W., H. A. A. Khan, F. Hafeez, H. Bilal, Y. K. Kim & J. J. Lee, 2010. Potential of Citrus seed extracts against dengue fever mosquito, *Aedes albopictus* (Skuse) (Culicidae: Diptera). Pakistan Journal of Botany, 42 (4): 3343-3348.

Albouchi, F., N. Ghazouani, R. Souissi, M. Abderrabba & S. Boukhris-Bouhachem, 2018. Aphidicidal activities of *Melaleuca styphelioides* Sm. essential oils on three citrus aphids: *Aphis gossypii* Glover, *Aphis spiraecola* Patch and *Myzus persicae* (Sulzer). South African Journal of Botany, 117 (1): 149-154.

Alghamdi, A. S., 2018. Insecticidal effect of four plant essential oils against two aphid species under laboratory conditions. Journal of Applied Biology, 6 (2): 27-30.

Al-Harbi, N. A., N. M. Al Attar, D. M. Hikal, S. E. Mohamed, A. H. Abdel Latef, A. A. Ibrahim & M. A. Abdein, 2021. Evaluation of insecticidal effects of plants essential oils extracted from basil, black seeds and lavender against *Sitophilus oryzae*. Plants, 10 (5): 829.

Ali, A. M. H. & A. E. Mohamed, 2018. Antifeedant effect of *Brassica nigra* seeds against cotton leafworm *Spodoptera littoralis* and its potential antibacterial activity. GSC Biological and Pharmaceutical Sciences, 5 (2): 32-40.

Ali, I. H. H. & A. H. Rodina, 2002. Toxicity of certain weed extracts and their combinations with aphicides against *Aphis gossypii* Glov. Arab Universities Journal of Agricultural Sciences, 10 (3): 1105-1113.

Alzogaray, R. A., A. Lucia, E. N. Zerba & H. M. Masuh, 2011. Insecticidal activity of essential oils from eleven *Eucalyptus* spp. and two hybrids: lethal and sublethal effects of their major components on *Blattella germanica*. Journal of Economic Entomology, 104 (2): 595-600.

Amiri, M. P., M. Rouhani, H. Mostafavi & M. R. Aminizadeh, 2013. Enetomotoxic effect of plant extracts against the cowpea aphid, *Aphis craccivora* (Hem: Aphididae). International Journal of Agricultural Research, 3 (3): 569-573.

Arnason, J. T., B. J. R. Philogene & P. Morand, 1989. Insecticides of Plant Origin. ACS Symp Ser. No 387. American Chemical Society, Washington, Dc: USA, 213 pp.

Bakkali, F., S. Averbeck, D. Averbeck & M. Idaomar, 2008. Biological effects of essential oils a review. Food and Chemical Toxicology, 46 (2): 446-475.

Bakr, R. F. A., H. M. A. Fattah, N. M. Salim & N. H. Atiya, 2010. Insecticidal activity of four volatile oils on two museum insects pests. Egyptian Academic Journal of Biological Sciences, 2 (2): 57-66.

Balcı, H., F. Ersin & E. Durmuşoğlu, 2020. *Azadirachta indica* A. Juss (Meliaceae) ve *Melaleuca alternifolia* (Maiden & Betche) Cheel (Myrtaceae) ekstraktlarının klasik ve nano formülasyonlarının *Tetranychus urticae* Koch (Acari: Tetranychidae) ve *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae)'ye etkilerinin belirlenmesi. Türkiye Biyolojik Mücadele Dergisi, 11 (2): 237-251 (in Turkish with abstract in English).

Bass, C., A. M. Puinean, C. T. Zimmer, I. Denholm, L. M. Field, S. P. Foster, O. Gutbrod, R. Nauen, R. Slater & M. S. Williamson, 2014. The evolution of insecticide resistance in the peach potato aphid, *Myzus persicae*. Insect Biochemistry and Molecular Biology, 51 (1): 41-51.

Behi, F., O. Bachrouch & S. Boukhris-Bouhachem, 2019. Insecticidal Activities of *Mentha pulegium* L., and *Pistacia lentiscus* L., Essential Oils against Two Citrus Aphids *Aphis spiraecola* Patch and *Aphis gossypii* Glover. Journal of Essential Oil-Bearing Plants, 22 (2): 516-525.

Benelli, G., R. Pavela, R. Petrelli, L. Cappellacci, G. Santini, D. Fiorini, S. Sut, S. Dall'Acqua, A. Canale & F. Maggi, 2018. The essential oil from industrial hemp (*Cannabis sativa* L.) by-products as an effective tool for insect pest management in organic crops. Industrial Crops and Production, 122 (1): 308-315.

Benelli, G., C. Ceccarelli, V. Zeni, R. Rizzo, G. L. Verde, M. Sinacori & A. Canale, 2022. Lethal and behavioural effects of a green insecticide against an invasive polyphagous fruit fly pest and its safety to mammals. Chemosphere, 287: 132089.

Birch, L. C., 1948. The intrinsic rate of natural increase of an insect population. Journal of Animal Ecology, 17 (1): 15-26.

Blackman, R. L. & V. F. Eastop, 2000. Aphids on the World's Crops: An Information and Identification Guide. John Wiley & Sons, Chichester, UK, 466 pp.

Campolo, O., A. Cherif, M. Ricupero, G. Siscaro, K. Grissa-Lebdi, A. Russo, L. M. Cucci, P. Di Pietro, C. Satriano, N. Desneux, A. Biondi, L. Zappal & V. Palmeri, 2017. Citrus peel essential oil nanoformulations to control the tomato borer, *Tuta absoluta*: chemical properties and biological activity. Scientific Reports, 7 (1): 13036

Campolo, O., I. Puglisi, R. N. Barbagallo, A. Cherif, M. Ricupero, A. Biondi, V. Palmeri, A. Baglieri & L. Zappal, 2020. Side effects of two citrus essential oil formulations on a generalist insect predator, plant and soil enzymatic activities. Chemosphere, 257 (1): 127252.

Chaubey, M. K., 2019. Essential oils as green pesticides of stored grain insects. European Journal of Biological Research, 9 (4): 202-244.

Choi, W. I., S. G. Lee, H. M. Park & Y. J. Ahn, 2004. Toxicity of plant essential oils to *Tetranychus urticae* (Acari: Tetranychidae) and *Phytoseiulus persimilis* (Acari: Phytoseiidae). Journal of Economic Entomology, 97 (2): 553-558.

Costa, A. V., P. F. Pinheiro, V. M. Rondelli, V. T. de Queiroz, A. C. Tuler, K. B. Brito, P. Stinguel & D. Pratissoli, 2013. *Cymbopogon stratus* (Poaceae) essential oil on *Frankliniella schultzei* (Thysanoptera: Thripidae) and *Myzus persicae* (Hemiptera: Aphididae). Journal of Biosciences, 29 (6): 1840-1847.

Costa, A. V., P. F. Pinheiro, V. T. Queiroz, V. M. Rondelli, A. K. Marins, W. R. Valbon & D. Pratissoli, 2015. Chemical composition of essential oil from *Eucalyptus citriodora* leaves and insecticidal activity against *Myzus persicae* and *Frankliniella schultzei*. Journal of Essential Oil-Bearing Plants, 18 (2): 374-381.

Czerniewicz, P., G. Chrzanowski, I. Sprawka & H. Sytykiewicz, 2018. Aphicidal activity of selected Asteraceae essential oils and their effect on enzyme activities of the green peach aphid, *Myzus persicae* (Sulzer). Pesticide Biochemistry and Physiology, 145 (1): 84-92.

Çetin, H., F. Erler & A. Yanicoglu, 2006. Toxicity of essential oils extracted from *Origanum onites* L. and *Citrus aurantium* L. against the pine processionary moth, *Thaumetopoea wilkinsoni* Tams. Folia Biologica (Kraków), 54 (3-4): 153-157.

Durmuşoğlu, E., A. Hatipoğlu & H. Balcı, 2011. Bazı bitkisel kökenli insektisitlerin laboratuvar koşullarında *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae) larvalarına etkileri. Türkiye Entomoloji Dergisi, 35 (4): 651-663 (in Turkish with abstract in English).

Effiom, O. E., D. A. Avoaja & C. C. Ohaeri, 2012. Mosquito repellent activity of phytochemical extracts from peels of citrus fruit species. Global Journal of Science Frontier Research, 12 (1): 1-4.

El-Sayed, F. M. A. & M. Abdel-Razik, 1991. Citrus oil as protectant against infestation by *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). Bulletin of the Entomological Society of Egypt / Economic Series, 14 (1): 423-427.

Elbert, A., M. Haas, B. Springer, W. Thielert & R. Nauen, 2008. Applied aspects of neonicotinoid uses in crop protection. Pest Management Sciences, 64 (11): 1099-1105.

Feng, Y. X., Y. Wang, Z. F. Geng, D. Zhang, B. Almaz & S. S. Du, 2020. Contact toxicity and repellent efficacy of *Valerianaceae* spp. to three stored-product insects and synergistic interactions between two major compounds camphene and bornyl acetate. Ecotoxicology and Environmental Safety, 190 (1): 110106.

Foster, S. P., I. Denholm & A. L. Devonshire, 2000. The up-sand downs of insecticide resistance in peach-potato aphids (*Myzus persicae*) in the UK. Crop Protection, 19 (8-10): 873-879.

Gaur, S. K. & K. Kumar, 2020. Toxicity and insect growth regulatory effects of root extract from the medicinal plant, *Withania somnifera* (Linnaeus) against red flour beetle, *Tribolium castaneum* (Coleoptera: Tenebrionidae). Archives of Phytopathology and Plant Protection, 53 (17-18): 856-875.

Gill, H. K. & H. Garg, 2014. "Pesticides: Environmental Impacts and Management Strategies, 187-230". In: Pesticides-Toxic Aspects (Eds. M. L. Larramendy & S. Soloneski). Intech, Rijeka, 187 pp.

Górski, R. & M. Tomczak, 2010. Usefulness of natural essential oils in the control of foxglove aphid (*Aulacorthum solani* Kalt.) occurring on eggplant (*Solanum melongena* L.). Ecological Chemistry and Engineering, 17 (3): 345-349.

Górski, R., K. Sobieralski & M. Siwulski, 2016. The effect of hemp essential oil on mortality *Aulacorthum solani* Kalt. and *Tetranychus urticae* Koch. Ecological Chemistry and Engineering, 23 (3): 505-511.

Gouvea, S. M., G. A. Carvalho, E. G. Fidelis, A. V. Riberio, E. S. Farias & M. C. Picaço, 2019. Effects of paracress (*Acmella oleracea*) extracts on the aphids *Myzus persicae* and *Lipaphis erysimi* and two natural enemies. Industrial Crops and Production, 128 (1): 399-404.

Govindarajan, M., M. Rajeswary, S. L. Hoti & G. Benelli, 2016. Larvicidal potential of carvacrol and terpinen-4-ol from the essential oil of *Origanum vulgare* (Lamiaceae) against *Anopheles stephensi*, *Anopheles subpictus*, *Culex quinquefasciatus* and *Culex tritaeniorhynchus* (Diptera: Culicidae). Research in Veterinary Science, 104 (1): 77-82.

Grdıša, M. & K. Gršıć, 2013. Agriculturae Botanical Insecticides in Plant Protection. Conspectus Scientificus, 78 (2): 85-93.

Gupta, G., U. Agarwal, H. Kaur, N. R. Kumar & P. Gupta, 2017. Aphicidal effects of terpenoids present in *Citrus limon* on *Macrosiphum roseiformis* and two generalist insect predators. Journal of Asia-Pacific Entomolology, 20 (4): 1087-1095.

Hedin, P. A., R. M. Hollingworth, E. P. Masler, J. Miyamoto & D. G. Thompson, 1997. Phytochemicals for Pest Control. ACS Symp Ser. No 658, American Chemical Society, Washington Dc: USA, 372 pp.

Imura, O., 1987. Demographic attributes of *Tribolium freeman* Hinton (Coleoptera: Tenebrionidae). Applied Entomology and Zoololgy, 22 (4): 449-455.

Iqbal, M. F., M. H. Kahloon, M. R. Nawaz & M. J. Javid, 2011. Effectiveness of some botanical extracts on wheat aphids. Journal of Animal and Plant Sciences, 21 (1): 114-115.

Isman, M. B. & S. Miresmailli, 2011. Plant essential oils as repellents and deterrents to agricultural pests. In Recent Developments in Invertebrate Repellents. Washington, DC. ACS Symposium Series, (Eds. G. Paluch et al.), American Chemical Society, 5 (1):67-77.

Isman, M. B., 1995. Leads and prospects for the development of new botanical insecticides. Reviews of Pesticides Toxicology, 3 (1): 1-20.

Isman, M. B., 2000. Plant essential oils for pest and disease management. Crop Protection, 19 (8-10): 603-608.

Isman, M. B., 2006. Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. Annual Review of Èntomology, 51: 45-66.

Işık, M. & G. Görür, 2009. Aphidicidial activity of seven essential oils against the cabbage aphid, *Brevicoryne brassicae* L. (Hemiptera: Aphididae). Munis Entomology and Zoology Journal, 4 (2): 424-431.

Jacobson, M., 1989. Botanical Insecticides. Past, Present and Future. In: Insecticides of Plant Origin (Eds. J. T. Arnason, B. J. R. Philogene & P. Morand), American Chemical Society Symposium Series, 387 (1): 1-10.

Jasman, A. K. & A. K. Slomy, 2021. Effect Aqueous Plant Extracts of *Mentha longifolia* and *Anethum graveolens* on Green Peach Aphid (*Myzus persicae* (Sulzer) (Aphididae: Homoptera). Indian Journal of Ecology, 48 (Special Issue 13): 272-274.

Kairo, M. T. K. & S. T. Murphy, 1995. The life history of *Rodolia iceryae* Janson (Coleoptera: Coccinellidae) and the potential for use in innoculative releases against *Icerya pattersoni* Newstead (Homoptera: Margarodidae) on coffee. Journal of Applied Entomolology, 119 (1-5): 487-491.

Karamaouna, F., A. Kimbaris, A, Michaelakis, D. Papachristos, M. Polissiou, P. Papatsakona & E. Tsora, 2013. Insecticidal activity of plant essential oils against the vine mealybug, *Planococcus ficus*. Journal of Insect Science, 13 (1): 142.

Keita, S. M., C. Vincent, J. P. Schmit, J. T. Arnason & A. Belanger, 2001. Efficacy of essential oil of *Ocimum basilicum* L. and *O. gratissimum* L. applied as an insecticidal fumigant and powder to control *Callosobruchus maculatus* (Fab.) (Coleoptera: Bruchidae). Journal of Stored Products Research, 37 (4): 339-349.

Khan, S., C. N. T. Tanin, E. Bonneure, S. Mangelinckx, G. Smagghe & M. M. Shah, 2017. Insecticidal activity of plant-derived extracts against different economically im-portant pest insects. Phytoparasitica, 45 (1): 113-124.

Kimbaris, A. C., D. P. Papachristos, A. Michaelakis, A. F. Martinou & M. G. Polissiou, 2010. Toxicity of plant essential oil vapours to aphid pests and their coccinellid predators. Biocontrol Science and Technology, 20 (4): 411-422.

Koneckal, E., A. Kaznowski, W. Marcinkiewicz, D. Tomkowiak, M. Maciąg & M. Stachowiak, 2018. Insecticidal activity of *Brassica alba* mustard oil against lepidopteran pests *Cydia pomonella* (Lepidoptera: Tortricidae), *Dendrolimus pini* (Lepidoptera: Lasiocampidae), and *Spodoptera exigua* (Lepidoptera: Noctuidae). Journal of Plant Protection Research, 58 (2): 206-209.

Kunbhar, S., L. B. Rajput, A. Ahmed Gilal, G. Akber Channa & J. G. M. Sahito, 2018. Impact of botanical pesticides against sucking insect pests and their insect predators in brinjal crop. Journal of Entomology and Zoology Studies, 6 (2): 83-87.

Li, W. Z., J. J. An & G. X. Fu, 2008. Repellent effects of 12 spices and the agropectins from their corresponding extracts on *Callosobruchus chinensis* adults. Journal of Henan University of Tech (Natural Science Edition), 29 (1): 45-47.

Liao, M., J. J. Xiao, L. J. Zhou, X. Yao & F. Tang, 2017. Chemical composition, insecticidal and biochemical effects of *Melaleuca alternifolia* essential oil on the *Helicoverpa armigera*. Journal of Applied Entomology, 141 (9): 721-728.

Mahanta, S., B. Khanikor & R. Sarma, 2020. *Allium sativum* (Liliales: Asparagales) essential oil-based combinations-a potential larvicide for *Culex quinquefasciatus* (Diptera: Culicidae). International Journal of Tropical Insect Sciences, 40 (1): 837-844.

Miresmailli, S. & M. B. Isman, 2014. Botanical insecticides inspired by plant-herbivore chemical interactions. Trends in Plant Sciences, 19 (1): 29-35.

Moretti, M. D. L., G. Sanna-Passino, S. Demontis & E. Bazzoni, 2002. Essential oil formulations useful as a new tool for insect pest control. AAPS Pharmscitech, 3: 64-74.

Mülayim, O., Ö. Alaoğlu & H. Çetin, 2020. Bazı bitkisel uçucu yağların *Aphis craccivora* (Koch) ve *Myzus persicae* (Sulzer) (Hemiptera: Aphididae)'ya karşı fumigant etkileri. Harran Tarım ve Gıda Bilimleri Dergisi, 24 (2): 195-203 (in Turkish with abstract in English).

Nikolova, M., M. Yovkova, E. Yankova-Tsvetkova, B. Traikova, T. Stefanova, I. Aneva & S. Berkov, 2021. Biocidal activity of *Origanum vulgare* subsp. *hirtum* essential oil. Acta Universitatis Agriculturae Et Silviculturae Mendelianae Brunensis, 69 (5): 569-578.

Ntalli, N. G. & U. Menkissoglu-Spiroudi, 2011. "Pesticides of Botanical Origin: A Promising Tool in Plant Protection, 1-23". In: Pesticides-Formulations, Effects, Fate (Ed. M. Stoytcheva), Rijeka, Croatia, IntechOpen, 805 pp.

Omar, A. F. & M. S. Zayed, 2021. Bioactivity impact of essential oils *Allium sativum* L. and *Citrus reticulata* L. against stored product insects *Tribolium castaneum* (Herbst) and *Rhyzopertha dominica* (F.). Journal of Plant Protection and Pathology, 12 (7): 465-471.

Özgökçe, M. S. & İ. Karaca, 2010. "Yaşam Çizelgesi: Temel Prensipler ve Uygulamalar". Türkiye Entomoloji Derneği I. Çalıştayı, Ekoloji Çalışma Grubu, Isparta, 11-12 pp (in Turkish)

Palacios, S. M., A. Bertoni, Y. Rossi, R. Santander & A. Urzúa, 2009. Efficacy of essential oils from edible plants as insecticides against the house fly, *Musca domestica* L. Molecules, 14 (5): 1938-1947.

Pavela, R. & G. Benelli, 2016. Essential oils as ecofriendly biopesticides? Challenges and constraints. Trends in Plant Sciences, 21 (12): 1000-1007.

Pavela, R., M. R. Morshedloo, H. Mumivand, G. J. Khorsand, A. Karami, F. Maggi & G. Benelli, 2020. Phenolic monoterpene-rich essential oils from Apiaceae and Lamiaceae species: insecticidal activity and safety evaluation on non-target earthworms. Entomologia Generalis, 40 (4): 421-435.

Pavela, R., F. Maggi, E. Mazzara, J. Torresi, K. Cianfaglione, G. Benelli & A. Canale, 2021. Prolonged sublethal effects of essential oils from non-wood parts of nine conifers on key insect pests and vectors. Industrial Crops and Products, 168 (2021): 113590.

Pinheiro, P. F., V. T. Queiroz, V. M. Rondelli, A. V. Costa, T. D. Marcelino & D. Pratissoli, 2013. Insecticidal activity of citronella grass essential oil on *Frankliniella schultzei* and *Myzus persicae*. Ciência e Agrotecnologia, 37 (1): 138-144.

Plata-Rueda, A., G. D. S. Rolim, C. F. Wilcken, J. C. Zanuncio, J. E. Serrão & L. C. Martínez, 2020. Acute toxicity and sublethal effects of lemongrass essential oil and their components against the granary weevil, *Sitophilus granarius*. Insects, 11 (6): 379.

Rahman, A. & F. A. Talukder, 2006. Bioefficacy of some plant derivatives that protect grain against the pulse beetle, *Callosobruchus maculatus*. Journal of Insect Science, 6 (1): 3. Available online: http://www.insectscience.org/6.3

Ravan, S., A. Khani & S. Suf, 2019. Fumigant toxicity and sublethal effects of *Teucrium polium* essential oil on *Aphis fabae* Scopoli A. Chinese Herbal Medicines, 11 (2): 231-235.

Regnault-Roger, C., C. Vincent & J. T. Arnason, 2012. Essential oils in insect control: low-risk products in a high-stakes world. Annuals Reviews of Entomolology, 57 (1): 405-424.

Regnault-Roger, C. & B. J. Philogène, 2008. Past and current prospects for the use of botanicals and plant allelochemicals in in-tegrated pest management. Pharmaceutical Biology, 46 (1-2): 41-52.

Rother, H. A., 2018. Pesticide Labels: Protecting Liability or Health?–Unpacking "misuse" of pesticides. Current Opinion in Environmental Science and Health, 4 (1): 10-15.

Sabbour, M. & S. E-Abd-El-Aziz, 2010. Efficacy of some bioinsecticides against *Bruchidius incarnatus* (Boh.) (Coleoptera: Bruchidae) infestation during storage. Journal of Plant Protection Research, 50 (1): 28-34.

Sammour, E. A., M. A. H. Kandil, N. F. Abdel-Aziz, E. El Maguied-Agamy, A. M. El-Bakry & N. M. Abdelmaksoud, 2018. Field evaluation of new formulation types of essential oils against *Tuta absoluta* and their side effects on tomato plants. Acta Scientific Agriculture, 2 (6): 15-22.

Sayed, S., S. A. Elarnaouty & E. Al, 2021. Suitability of five plant species extracts for their compatibility with indigenous *Beauveria bassiana* against *Aphis gossypii* Glov. (Hemiptera: Aphididae). Egypt Journal of Biological Pest Control, 31 (11): 2-8.

Sayed, S., M. M. Soliman, S. Al-Otaibi, M. M. Hassan, S. A. Elarrnaouty, S. M. Abozeid & A. M. El-Shehawi, 2022. Toxicity, deterrent and repellent activities of four essential oils on *Aphis punicae* (Hemiptera: Aphididae). Plants, 11 (3): 463.

Sayeda, S. A. & M. M. El-Mogy, 2011. Field evaluation of some biological formulations against *Thrips tabaci* (Thysanoptera: Thripidae) in onion. World Applied Sciences Journal, 14 (1): 51-58.

Schoonhoven, L. M., 1982. Biological aspects of antifeedants. Entomologia Experimentalis et Applicata, 31 (1): 57-69.

Scott, I. M., H. Jensen, J. G. Scott, M. B. Isman, J. T. Arnason & B. J. R. Philogene, 2003 Botanical Insecticides for Controlling Agricultural Pests: Piperamides and the Colorado Potato Beetle *Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae). Archives of Insect Biochemistry and Physiology, 54 (4): 212-225.

Sial, M. U., 2019. Resistant mechanisms to neonicotinoids and the detection of R81T mutation with LAMP in *Myzus persicae*. Dissertation. Chinese Academy of Agricultural Sciences.

Sukh, D, K. Opender & S. Dev, 2017. "Insecticides of Natural Origin". Apple Academic Press: Cambridge, MA, USA, 357 pp.

Tripathi, A. K., V. Prajaoati, S. P. Khanuja & S. Kumar, 2003. Effect of d-limonene on three stored-product beetles. Journal of Economic Entomology, 96 (3): 990-995.

Yazdgerdian, A. R., Y. Akhtar & M. B. Isman, 2015. Insecticidal effects of essential oils against woolly beech aphid, *Phyllaphis fagi* (Hemiptera: Aphididae) and rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae). Journal of Entomology and Zoology Studies, 3 (3): 265-271.

Yeguerman, C., E. Jesser, M. Massiris, C. Delrieux, A. P. Murray & J. W. Gonzalez, 2020. Insecticidal application of essential oils loaded polymeric nanoparticles to control German cockroach: Design, characterization and lethal/sublethal effects. Ecotoxicology and Environmental Safety, 189 (2020): 110047.

Zewde, D. K. & B. Jembere, 2010, Evaluation of orange peel of *Citrus sinensis* (L) as a source of repellent, toxicant and protectant against *Zabrotes subfasciatus* (Coleoptera: Bruchidae). Momona Ethiopian Journal of Science, 2 (1): 61-75.

Zia, S., M. Sagheer & A. Razaq, 2013. Comparative bioefficacy of different Citrus peel extracts as grain protectant against *Callosobruchus chinensis*, *Trogoderma granarium* and *Triboliun castaneum*. World Applied Science Journal, 21 (12): 1760-1769.