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Original article (Orijinal araştırma)

Lethal and sublethal effects of lambda-cyhalothrin on *Aphis fabae* (Scopoli, 1763), *Myzus persicae* (Sulzer, 1776) and *Acyrthosiphon pisum* (Harris, 1776) (Hemiptera: Aphididae)

Lambda-cyhalothrin'nin *Aphis fabae* (Scopli, 1763), *Myzus persicae* (Sulzer, 1776) ve *Acyrthosiphon pisum* (Harris, 1776) (Hemiptera: Aphididae) üzerindeki letal ve subletal etkileri

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Abstract

In this study, sublethal doses of lambda-cyhalothrin to the species *Aphis fabae* (Scopoli, 1763), *Myzus persicae* (Sulzer, 1776) and *Acyrthosiphon pisum* (Harris, 1776) (Hemiptera: Aphididae) were determined, and the effects of these doses on the life cycles of the species were revealed and evaluated. The lethal effects of different concentrations (0.3125, 0.625, 1.25, 2.5, 5, 10 and 20 µL L^{-1}) prepared by distilled water of lambda-cyhalothrin on the species were determined according to Abbott. Based on the results obtained, the effects of LC_{30} and LC_{40} concentrations of the insecticide on the life cycles of the species were determined. The insecticide caused different mortality rates in the species. The sublethal concentrations of the insecticide were found to be effective for the life cycles of the species. In all three species, intrinsic rate of increase (r_m), net reproduction rate (R_0) and gross reproduction rate (*GRR*) values were found to decrease when insecticide was applied. The results will provide guidance to researchers working in this specific field. However, it would be beneficial to replicate this study under field conditions to obtain clear information.

Keywords: Aphids, ecotoxicology, life table parameters, pyrethroid, toxicity

Öz

Bu çalışmada, lambda-cyhalothrin'in *Aphis fabae* (Scopoli, 1763), *Myzus persicae* (Sulzer, 1776) ve *Acyrthosiphon pisum* (Harris, 1776) (Hemiptera: Aphididae) üzerinde subletal dozları belirlenmiş ve bu dozların türlerin yaşam döngüleri üzerindeki etkileri ortaya konularak değerlendirilmiştir. Lambda-cyhalothrin'in saf su ile hazırlanan farklı konsantrasyonlarının (0.3125, 0.625, 1.25, 2.5, 5, 10 ve 20 µL L^{-1}) türler üzerindeki öldürücü etkileri Abbott'a göre belirlenmiştir. Elde edilen sonuçlara göre insektisitin LC_{30} ve LC_{40} konsantrasyonlarının türlerin yaşam döngüleri üzerindeki etkileri araştırılmıştır. Çalışmada kullanılan insektisitin türlerde farklı ölüm oranlarına neden olduğu gözlenmiştir. Ayrıca insektisitin subletal konsantrasyonlarının türlerin yaşam döngüleri üzerinde etkili olduğu bulunmuştur. Her üç türde de insektisit uygulandığında kalıtsal üreme yeteneği (r_m), net üreme gücü (R_0) ve toplam üreme oranı (*GRR*) değerlerinin düştüğü tespit edilmiştir. Elde edilen sonuçların bu konuda çalışan araştırmacılara yol gösterici olacağı düşünülmektedir. Ancak daha net sonuçlar elde etmek için bu çalışmayı saha koşullarında tekrarlamak faydalı olacaktır.

Anahtar sözcükler: Yaprak bitleri, ekotoksikoloji, yaşam çizelgesi parametreleri, piretroid, toksisite

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Introduction

Aphids cause growth disorders in plants and even the death of the plant in the case of a very dense population. Due to this negative situation in production, there is a loss of quality and yield of plants. In addition, aphids cover the plant surface with a substance they produce during their feeding, causing sooty mold formation on the plant. This causes secondary factors (fungi etc.) to multiply in the environment and indirectly cause damage to the plant. In addition, aphids cause indirect damage to plants because they secrete toxic substances and transmit phytopathogenic viruses (Lodos, 1986; Catherall et al., 1987; Kovalev et al., 1991; Elmalı & Toros, 1997; Will & Vilcinskas, 2015; Boissot et al., 2016; Kloth et al., 2017).

The black bean aphid, *Aphis fabae* (Scopoli, 1763) (Hemiptera: Aphididae) is a small and black-colored pest (Kennedy et al., 1962). The plants it feeds on include more than 200 wild plants, but also vegetables, sugar beets, broad beans, beans, potatoes, sunflowers and tomatoes (Völkl & Stechmann, 1998; Barnea et al., 2005; Fericean et al., 2012). *Acyrthosiphon pisum* (Harris, 1776) (Hemiptera: Aphididae), one of the most important pea pests was first detected on the alfalfa plant, *Medicago sativa* (L.) (Leguminosae) in Turkey (Düzgüneş & Tuatay, 1956). These pests cause deformations in the fruits and a reduction in grain weight by sucking up the sap in the young shoots of the plant (Bouchery, 1977; Cors & Depfort, 1993). Although this species is known to be one of the main causes of damage to wild plants, it also causes harm to beans, lentils, clover, sainfoin, vetch and some legumes (Stary, 1970; Ali & Habtewold, 1994). The green peach aphid *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae) is known as a species that causes damage to more than 400 plants. This species not only causes damage by absorbing plant sap, but also indirect damage by transmitting more than 100 viral diseases (Blackman & Eastop, 2007). Like other aphids, it reproduces parthenogenetically and can rapidly increase its population thanks to its short development time (Foster et al., 2000). The population of these pests can only be kept under control with chemical insecticides. This has led to the fact that this species has become resistant to various chemicals (Elbert et al., 1998; Bass et al., 2014; Gill & Garg, 2014; Sial et al., 2018; An et al., 2020).

Insecticides disrupt physiological functions of insects (fecundity, development, sex ratio, behavioral conditions, nutrition, egg laying, and orientation) and make them ineffective (Galvan et al., 2005; Desneux et al., 2007). Pyrethroids show flesh faster compared to other insecticides and are very effective in control of various pests such as aphids, moths and thrips. In addition, they are widely used in agricultural production areas thanks to their low prices (Liu et al., 2015; Zhang et al., 2015). Lambda-cyhalothrin is a non-systemic insecticide from the pyrethroid group with rapidly degradable properties. It is very effective against insects (aphids etc.) that cause damage in agricultural production. While lambda-cyhalothrin acts on insects, it acts on sodium channels of axon membrane and disrupts normal function. It prevents sodium channels that are important for nerve transmission from closing; sequential nerve stimulation occurs, resulting in the death of the insect (He et al., 2008).

Sublethal doses of insecticides can have different effects on the biology, physiology, and behavior of plant pests (Desneux et al., 2007; Liu et al., 2008). Moreover, these doses may stress the insects rather than kill them (Piiroinen et al., 2014; Wang et al., 2017). This event occurs due to environmental conditions that prevent an insect from continuing its normal biological cycle (Ghalambor et al., 2007). The resulting stress can have negative effects on insect development, offspring/egg production, feeding and mating behavior (Arn'o & Gabarra, 2011; Quan et al., 2016). These negative effects impact the insect population, and it is believed that these effects can be genetically transmitted to the offspring of generations exposed to sublethal doses (Stark & Banks, 2003; Guo et al., 2013). In addition, different effects occur between generations in insects exposed to different sublethal doses of different insecticides. For this reason, it is recommended that life tables data be obtained to evaluate the results of this study (Stark & Banks, 2003). From some studies, sublethal doses of pyrethroids and some insecticides are nonlethal to both aphids and some insects, but have different negative effects on agricultural pests (Kidd et al., 1996; Desnuex et al., 2004, 2005; Quan et al., 2016; Xiao et al., 2016; Qu et al., 2020; Afza et al., 2021; Alfaro-Tapia et al., 2021; Garily-Moradi et al., 2021; Tan et al., 2021; Shi et al., 2022). In this study, sublethal doses of lambda-cyhalothrin to the species *A. fabae*, *M. persicae* and *A. pisum* were determined, and the effects of these doses on species life cycles were demonstrated and evaluated. Although there are studies on the effects of sublethal doses of insecticides on aphids, this study was conducted to address the deficiencies in the effects on different aphids.

Materials and Method

In this study, an insecticide containing the active ingredient lambda-cyhalothrin (Passat 50 g/L, Ferbis, Türkiye) was used to determine its effect on aphids.

Production of plants for aphids

In the experiments, the bell pepper plant (*Capsicum annuum* L. var. *grossum*), used for the production of *M. persicae*, and the faba bean plant (*Vicia faba* L. var. *major*), used for the production of *A. fabae,* and *A. pisum*, were grown in plastic containers (200 ml) with soil in a 1:1 ratio to peat. Production was carried out in a climate room with 25±1°C, 60±5% proportional humidity and 16:8 (light:dark) light conditions.

Mass production of aphids

The aphids in the last nymphal stage were transferred to bell pepper and field bean plants that had reached the length (15 cm) and number of leaves (6 pieces) intended for the experiments. They were propagated separately in different cages of 50x50x50 cm covered with tulle. The initial population of aphids infested on clean plants was obtained from ongoing mass production in the laboratory. Aphids, which were collected on pepper plants in Serik in Antalya and identified by Prof. Dr. İsmail Karaca in nature, were used for the experiments. To ensure continuity of mass production, old and decaying plants were replaced with new plants at weekly intervals. Aphid production was carried out in a climate room with 25±1°C, 60±5% proportional humidity, and 16:8 (light:dark) light conditions.

Lethal effect of lambda-cyhalothrin on the aphids

The lethal effects of different concentrations (0.3125, 0.625, 1.25, 2.5, 5, 10, and 20 µL L^{-1}) of the insecticide (It was prepared as 7 concentrations by diluting 50% from the highest dose on the label of the insecticide) used in the first phase of the study were determined on *A. fabae*, *M. persicae* and *A. pisum*. Petri dishes with filter paper of 9 cm diameter were used for the experiments. The prepared concentrations were sucked into the filter paper at 1 ml in each Petri dish. One-day-old aphids were transferred to these papers using a thin sable brush, ensuring contact with the dose on the paper (tarsal, ventral and labial contact). Subsequently, the plant leaves were left in the Petri dish for the aphids to feed on. Twenty-four hours after the start of the experiments, the live and dead individuals were recorded and the effect of the insecticide was determined. At this time, 10 Petri dishes were used for each dose and 10 aphids were used for each Petri dish. Pure water was used for the control application. The experiments were conducted in a climatic room with 25±1°C, 60±5% proportional humidity, and 16: 8 (light: dark) light conditions. This phase of the experiment was repeated separately for each aphid species.

Abbott's formula was used to determine mortality rates over living and dead individuals and the percentage of mortality rates was calculated (Abbott, 1925). Analysis of variance (ANOVA) was applied to the obtained results. If the difference between the means was statistically significant, groups were compared using Tukey's HSD. The level of this significance was determined according to the TUKEY multiple comparison test. Lethal concentrations of the insecticide on aphids (LC_{30}, LC_{40}, LC_{50}) were determined using the mortality rates obtained at this stage of the study. PROBIT analysis was used to determine these concentrations.

$$\text{Percent effect} = \left(\frac{\text{Number of live individuals in control-Number of live individuals in application}}{\text{Number of live individuals in control}}\right) \text{X } 100$$ (Abbott, 1925).

Sublethal effect of lambda-cyhalothrin on the aphids

The effects of LC_{30} and LC_{40} concentrations of the insecticide applied in this phase of the experiment on *A. fabae*, *A. pisum* and *M. persicae* were determined. The prepared doses 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 were exposed to the dose. Cotton was left on the bottom of the filter paper to prevent the leaves from fading, and it was moistened, and plant leaves were placed as food for the aphids. Then, the daily development of individuals was monitored, and the newborns were recorded and removed from the environment. The counts were continued until the aphids died. This part of the experiments was performed with 60 replicates for each dose. Standard size Petri dishes were opened to allow air circulation in the Petri dish and covered with tulle to prevent escape. This procedure was performed separately for each aphid species. Experiments were performed in a climate room with 25±1°C, 60±5% proportional humidity and 16: 8 (light: dark) light conditions.

The data were recorded to determine the development of age-related life tables for each dose used. The parameters of the aphid life tables were calculated using RmStat-3 software (Özgökçe & Karaca, 2010) according to the Euler-Lotka equation (Birch, 1948) and analyzed separately. Tukey multiple comparison test was used for comparison of the periods with Minitab (ver. 16) at a significant difference level, $p<0.05$. Several equations were used to calculate the parameters, which are:

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

Net reproduction Rate (R_0), $R_0 = \sum l_x . m_x$ (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

The results of the study have shown that high doses of insecticide caused a high mortality rate in the applied aphids. When the insecticide was applied to *A. fabae*, it was found that 5 µl L^{-1} and subsequent high concentrations caused more than 90% mortality and the resulting mortality was statistically different from low concentrations ($P<0.05$). Although similar situations were observed in the other two aphids (*M. persicae* and *A. pisum*), it was found that the mortality rate of 90% was at concentrations of 10 and 20 µl L^{-1}, in contrast to *A. fabae*. The mortality rates obtained were also statistically different from the low concentrations ($p<0.05$). Examining the data obtained, the lowest mortality rate (32.97%) was observed at the lowest dose (0.3125 µl L^{-1}) applied to *A. pisum* (Figure 1).

Lethal concentrations calculated by probit analysis were determined based on the mortality rates obtained. Accordingly, the lowest LC_{30}, LC_{40}, and LC_{50} values were found for *A. fabae* (0.156, 0.274 and 0.462 µl L^{-1}, respectively) and the highest values were found for *A. pisum* (0.238, 0.474 and 0.806 µl L^{-1}, respectively). All lethal concentrations resulting from the study are listed in Table 1.

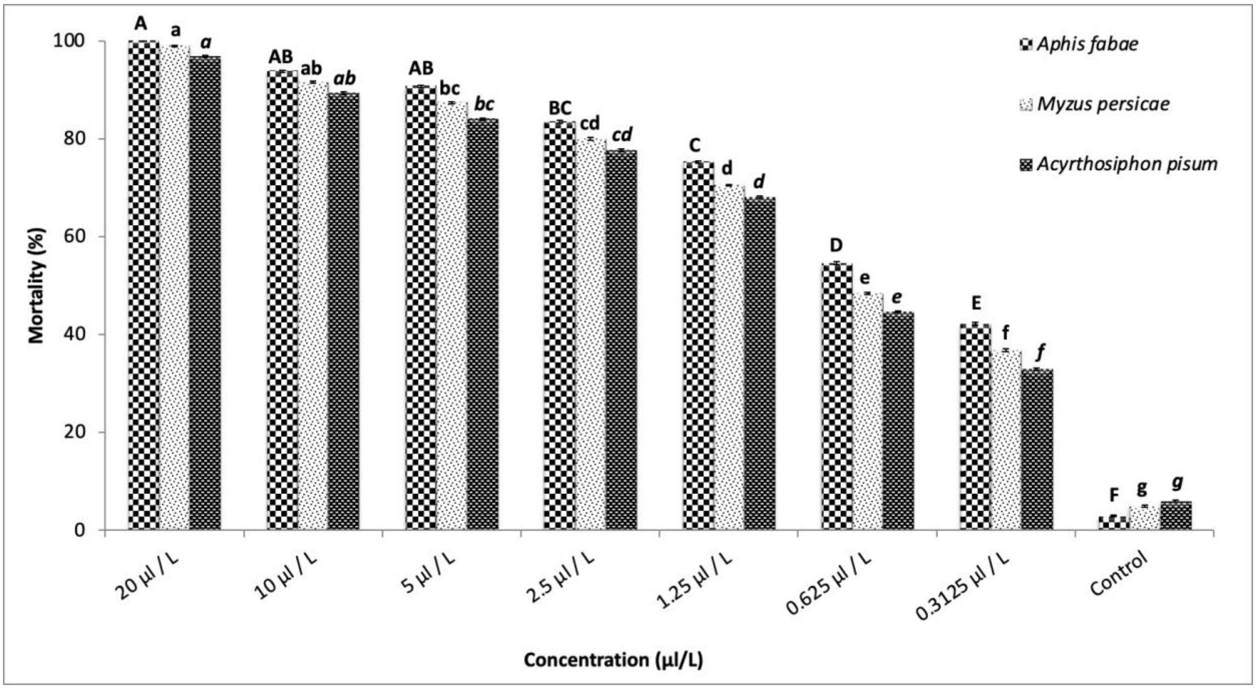

Figure 1. Mortality percentage of aphids (*Aphis fabae*, *Myzus persicae* and *Acyrthosiphon pisum*) exposed to different concentrations of lambda-cyhalothrin for 24 h. Means represented by different letters for each aphid species were significantly different according to Tukey ($F_{A.fabae}$: 187.95; $df_{A.fabae}$: 7, 79; $P_{A.fabae}$: 0.001 / $F_{M.persicae}$: 203.77; $df_{M.persicae}$: 7, 79; $P_{M.persicae}$: 0.001 / $F_{A.pisum}$: 196.93; $df_{A.pisum}$: 7, 79; $P_{A.pisum}$: 0.001).

Table 1. Toxicity of lambda-cyhalothrin on *Aphis fabae*, *Myzus persicae* and *Acyrthosiphon pisum* after 24 h

Aphids	N	Slope±SE[a]	LC_{30} µl L^{-1} (95% CI)[b]	LC_{40} µl L^{-1} (95% CI)[b]	LC_{50} µl L^{-1} (95% CI)[b]	x^2 (*df*)[c]	*P* value
Aphis fabae	800	1.117±0.159	0.156 (0.076-0.320)	0.274 (0.134-0.561)	0.462 (0.226-0.948)	0.999 (5)	0.002
Myzus persicae	800	1.043±0.162	0.202 (0.097-0.421)	0.369 (0.177-0.767)	0.646 (0.310-1.344)	0.995 (5)	0.001
Acyrthosiphon pisum	800	0.991±0.167	0.238 (0.112-0.504)	0.474 (0.211-0.947)	0.806 (0.380-1.709)	0.979 (5)	0.001

[a] Standard error

[b] 95% confidence intervals

[c] Chi-square value (x^2) and degrees of freedom (*df*)

In the second phase of the study, the effects of the lethal doses (LC_{30} and LC_{40}) on the aphids were investigated. It was found that the doses administered caused a prolongation of the preadult period of the aphids. When these results were evaluated for *A. fabae*, it was found that both 0.156 µl L^{-1} (LC_{30}) and 0.274 µl L^{-1} dose (LC_{40}) of the insecticide prolonged the total developmental period ($p<0.05$). When evaluating *M. persicae*, it was found that both doses (0.202 and 0.369 µl L^{-1}) caused an increase in nymphal stages and total development time ($p<0.05$). When the effects of lethal doses (0.238 and 0.474 µl L^{-1}) on *A. pisum* were examined, it was found that the LC_{40} dose in particular increased preadult developmental times ($p<0.05$). When total development times were examined, it was found that time increased and both doses and control treatments were statistically different from each other ($p<0.05$) (Table 2).

It was found that the doses applied in the experiments (LC_{30} and LC_{40}) also had effects on the development time of aphids after adulthood and the number of offspring sired by them. When considering oviposition time, adult longevity and total longevity, it was found that the doses applied were not effective in the periods of *A. fabae* and *A. pisum*. Therefore, oviposition time, adult longevity and total longevity are in the same statistical group at both doses for all the aphid species (P>0.05). When the oviposition time and adult longevity of *M. persicae* were evaluated, it was found that the times obtained with the LC_{40} dose were different from those of the control (p<0.05). While the daily number of offspring and the total number of offspring at all doses (LC_{30} and LC_{40}) were different compared with the control (P<0.05), statistical similarity was observed between the cats of the doses on *M. persicae* and *A. fabae* (P>0.05). In addition to these data, aphid biological parameters and differences between dosages are shown in Table 3.

Table 2. Effects of lambda-cyhalothrin on immature stages of *Aphis fabae*, *Myzus persicae* and *Acyrthosiphon pisum*

***Aphis fabae* / Lambda-cyhalothrin**									
Biological parameters	Control			LC_{30}			LC_{40}		
	N	Days (Mean±SE)		N	Days (Mean±SE)		N	Days (Mean±SE)	
First instar (N1)	60	1.517±0.065	b	50	1.660±0.073	ab	44	1.773±0.072	a
Second instar (N2)	58	1.328±0.062	c	48	1.458±0.079	b	44	1.523±0.083	a
Third instar (N3)	56	1.339±0.069	c	44	1.455±0.083	b	38	1.579±0.090	a
Forth instar (N4)	54	1.759±0.070	c	40	1.925±0.075	b	37	2.054±0.054	a
Total development times	54	6.019±0.120	c	40	6.625±0.159	b	37	7.000±0.155	a
***Myzus persicae* / Lambda-cyhalothrin**									
Biological parameters	Control			LC_{30}			LC_{40}		
	N	Days (Mean±SE)		N	Days (Mean±SE)		N	Days (Mean±SE)	
First instar (N1)	60	1.633±0.063	b	47	1.957±0.074	ab	40	2.000±0.080	a
Second instar (N2)	58	2.690±0.111	b	43	3.070±0.107	ab	39	3.179±0.103	a
Third instar (N3)	56	2.429±0.067	c	41	2.610±0.085	b	36	2.639±0.090	a
Forth instar (N4)	54	2.537±0.129	c	39	2.897±0.121	b	36	3.000±0.120	a
Total development times	54	9.370±0.243	c	39	10.564±0.229	b	36	10.917±0.201	a
***Acyrthosiphon pisum* / Lambda-cyhalothrin**									
Biological parameters	Control			LC_{30}			LC_{40}		
	N	Days (Mean±SE)		N	Days (Mean±SE)		N	Days (Mean±SE)	
First instar (N1)	60	1.767±0.055	c	54	2.019±0.062	b	47	2.213±0.080	a
Second instar (N2)	58	1.259±0.058	c	52	1.462±0.070	b	46	1.544±0.092	a
Third instar (N3)	56	1.446±0.072	c	51	1.686±0.091	b	46	1.848±0.108	a
Forth instar (N4)	54	1.926±0.058	c	50	2.060±0.078	b	42	2.214±0.080	a
Total development times	54	6.500±0.102	c	50	7.260±0.124	b	42	7.881±0.181	a

* Different letters in the same line were significantly different according to Tukey (p<0.05).

It was found that the doses applied in the experiments (LC_{30} and LC_{40}) were effective on the aphid life plates. When the data obtained were examined, it was found that the mean generation time (T_0) and doubling time (T_2) for all aphids increased with the increase in dose. Using these data, it was determined that there was a statistical difference between the times (p<0.05). When the intrinsic rate of increase (r_m) was examined, it was found that the results were different for all three aphids compared to the control. Although the results were close for the doses administered, there was a statistical difference (p<0.05). When the results were examined in detail, the same situation was observed for the values of net reproduction rate (R_0), gross reproduction rate (*GRR*), and finite rate of increase (λ). It was found that there was a statistical difference between the results obtained for all three-aphid species (p<0.05) (Table 4).

Table 3. Effects of lambda-cyhalothrin on biological parameters of *Aphis fabae*, *Myzus persicae* and *Acyrthosiphon pisum*

Aphis fabae									
Biological parameters	Control			LC_{30}			LC_{40}		
	N	Mean±SE		N	Mean±SE		N	Mean±SE	
Oviposition times (Days)	54	18.907±0.563	a	40	20.425±1.513	a	37	20.270±1.374	a
Adult longevity (Days)	54	20.426±0.554	a	40	22.150±1.542	a	37	22.027±1.391	a
Total longevity (Days)	60	24.200±0.996	a	52	22.942±1.924	a	46	24.065±1.885	a
Daily number of offspring	54	2.205±0.041	a	40	1.398±0.030	b	37	1.315±0.025	b
Total number of offspring	54	45.481±1.516	a	40	31.850±2.390	b	37	29.784±2.105	b
Myzus persicae									
Biological parameters	Control			LC_{30}			LC_{40}		
	N	Mean±SE		N	Mean±SE		N	Mean±SE	
Oviposition times (Days)	54	28.037±0.729	a	39	24.872±1.290	ab	40	24.333±1.307	b
Adult longevity (Days)	54	30.963±0.743	a	39	27.564±1.339	ab	39	26.417±1.323	b
Total longevity (Days)	60	36.950±1.467	a	49	31.347±2.211	a	36	34.250±1.925	a
Daily number of offspring	54	1.879±0.029	a	39	1.407±0.025	b	36	1.427±0.030	b
Total number of offspring	54	58.685±1.729	a	39	39.179±2.085	b	36	38.667±2.328	b
Acyrthosiphon pisum									
Biological parameters	Control			LC_{30}			LC_{40}		
	N	Mean±SE		N	Mean±SE		N	Mean±SE	
Oviposition times (Days)	54	18.907±0.563	a	50	18.500±0.528	a	42	18.548±0.573	a
Adult longevity (Days)	54	20.426±0.554	a	50	20.020±0.523	a	42	20.286±0.559	a
Total longevity (Days)	60	24.633±1.019	a	54	25.556±0.984	a	47	25.787±1.142	a
Daily number of offspring	54	2.205±0.041	a	50	1.760±0.022	b	42	1.616±0.029	c
Total number of offspring	54	45.481±1.516	a	50	35.560±1.148	b	42	33.071±1.210	b

* Different letters in the same line were significantly different according to Tukey (p<0.05).

Table 4. Effects of lambda-cyhalothrin on life table parameters (Mean±SE) of *Aphis fabae*, *Myzus persicae* and *Acyrthosiphon pisum*

Aphis fabae													
Treatments	N	Intrinsic rate of increase, r_m		Net reproduction rate, R_0		Mean generation time, T_0		Gross reproduction rate, ***GRR***		Doubling time, T_2		Finite rate of increase, λ	
Control	60	0.378±0.0002	a	45.289±0.041	a	10.095±0.003	c	60.343±0.030	a	1.835±0.0007	c	1.459±0.0002	a
LC_{30}	52	0.243±0.0003	b	25.810±0.055	b	13.395±0.014	b	51.390±0.022	b	2.856±0.0038	b	1.275±0.0004	b
LC_{40}	46	0.238±0.0007	c	25.581±0.066	c	13.598±0.033	a	48.952±0.041	c	2.908±0.0085	a	1.269±0.0008	c
Myzus persicae													
Treatments	N	Intrinsic rate of increase, r_m		Net reproduction rate, R_0		Mean generation time, T_0		Gross reproduction rate, ***GRR***		Doubling time, T_2		Finite rate of increase, λ	
Control	60	0.296±0.0002	a	59.922±0.053	a	13.847±0.009	c	74.788±0.031	a	2.345±0.002	c	1.344±0.0003	a
LC_{30}	49	0.202±0.0003	b	36.481±0.080	b	17.531±0.026	b	53.877±0.033	b	3.440±0.006	b	1.223±0.0004	b
LC_{40}	40	0.184±0.0002	c	34.196±0.067	c	19.588±0.015	a	53.278±0.037	c	3.775±0.004	a	1.202±0.0002	c
Acyrthosiphon pisum													
Treatments	N	Intrinsic rate of increase, r_m		Net reproduction rate, R_0		Mean generation time, T_0		Gross reproduction rate, ***GRR***		Doubling time, T_2		Finite rate of increase, λ	
Control	60	0.352±0.0012	a	44.531±0.066	a	10.806±0.040	c	60.240±0.065	a	1.973±0.008	c	1.421±0.002	a
LC_{30}	54	0.248±0.0001	b	33.767±0.032	b	14.219±0.003	b	45.160±0.033	b	2.800±0.001	b	1.281±0.001	b
LC_{40}	47	0.235±0.0001	c	31.049±0.042	c	14.620±0.006	a	41.845±0.027	c	2.950±0.002	a	1.265±0.001	c

* Different letters in the same parameters and columns were significantly different according to Tukey (p<0.05).

In this study, survival rate (l_x), fecundity (m_x, l_x*m_x), reproductive value (V_x) and expected lifetime (E_x), which are the most important parameters of life tables, were also calculated. These values were calculated and evaluated separately for each species (*A. fabae*, *M. persicae* and *A. pisum*) and for each concentration (Control, LC_{30} and LC_{40}). According to the data obtained, it was determined that the survival rates (l_x) of *A. fabae* and *M. persicae* at sublethal concentrations were longer than the control. However, the opposite was observed in *A. pisum*. According to the results, while the survival rate (l_x) of *A. fabae* showed a high decrease as of the 25th day in the control group, it was determined that this decrease started on the 5th day in sublethal concentrations of lambda-cyhalothrin (LC_{30} and LC_{40}) and decreased continuously in the following days (Figure 2). Survival rate (l_x) showed a high decrease in the control group of *M. persicae* starting on the 35th day, while this decrease at sublethal concentrations of lambda-cyhalothrin (LC_{30} and LC_{40}) started onthe 3rd day, which was yet followed by an increase in the following days (Figure 3). The same value (l_x) showed a high decrease as of the 25th day in the control group of *A. pisum*. However, this decreases at sublethal concentrations of lambda-cyhalothrin (LC_{30} and LC_{40}) started on day 5 and continued thereafter (Figure 4). It was determined that expected lifetime increased for both species at sublethal concentrations, and was shortened for *A. pisum* at these concentrations. It was determined that the fecundity (m_x, l_x*m_x) and reproductive values (V_x) of the applied concentrations (LC_{30} and LC_{40}) decreased compared to the control. It was observed that the data obtained are close when the concentrations were evaluated among themselves (Figures 2, 3, 4).

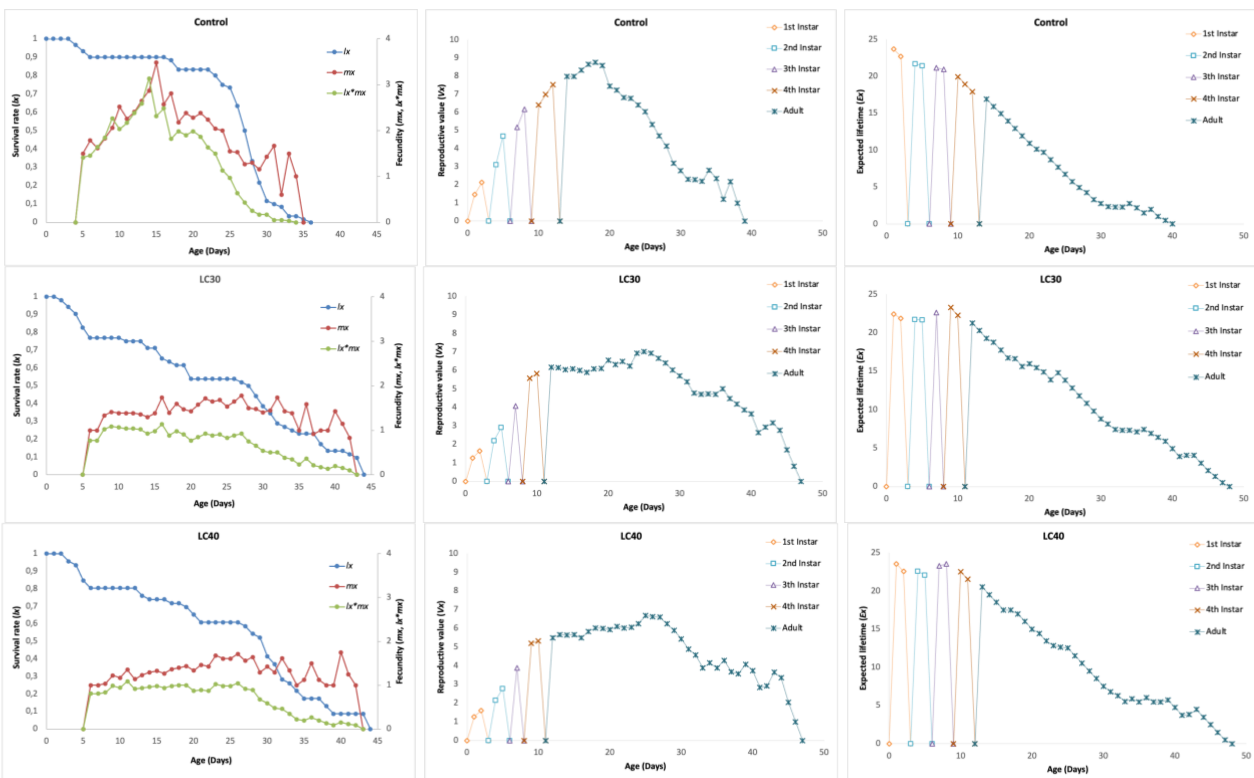

Figure 2. Survival rate (l_x), Fecundity (m_x, l_x*m_x), Reproductive value (V_x) and Expected lifetime (E_x) of *Aphis fabae* exposed to different concentrations (0.156 µl L^{-1} and 0.274 µl L^{-1}) of lambda-cyhalothrin.

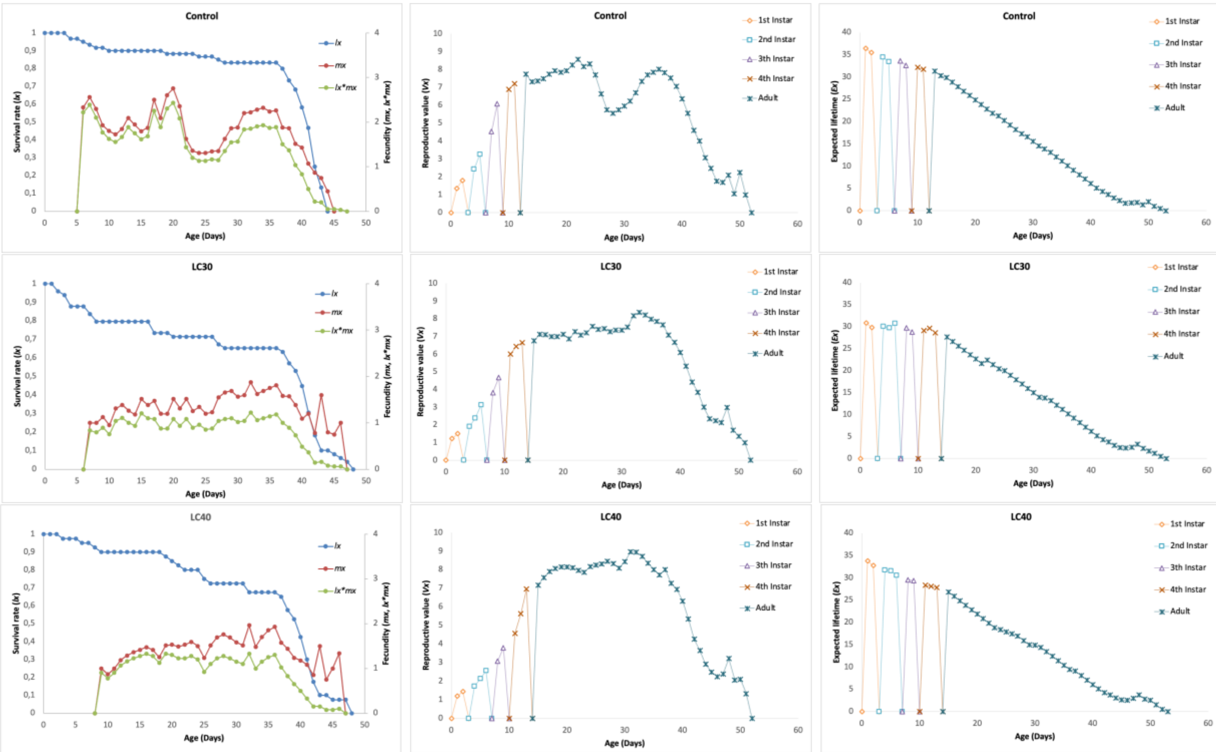

Figure 3. Survival rate (l_x), Fecundity (m_x, l_x*m_x), Reproductive value (V_x) and Expected lifetime (E_x) of *Myzus persicae* exposed to different concentrations (0.202 µl L^{-1} and 0.369 µl L^{-1}) of lambda-cyhalothrin.

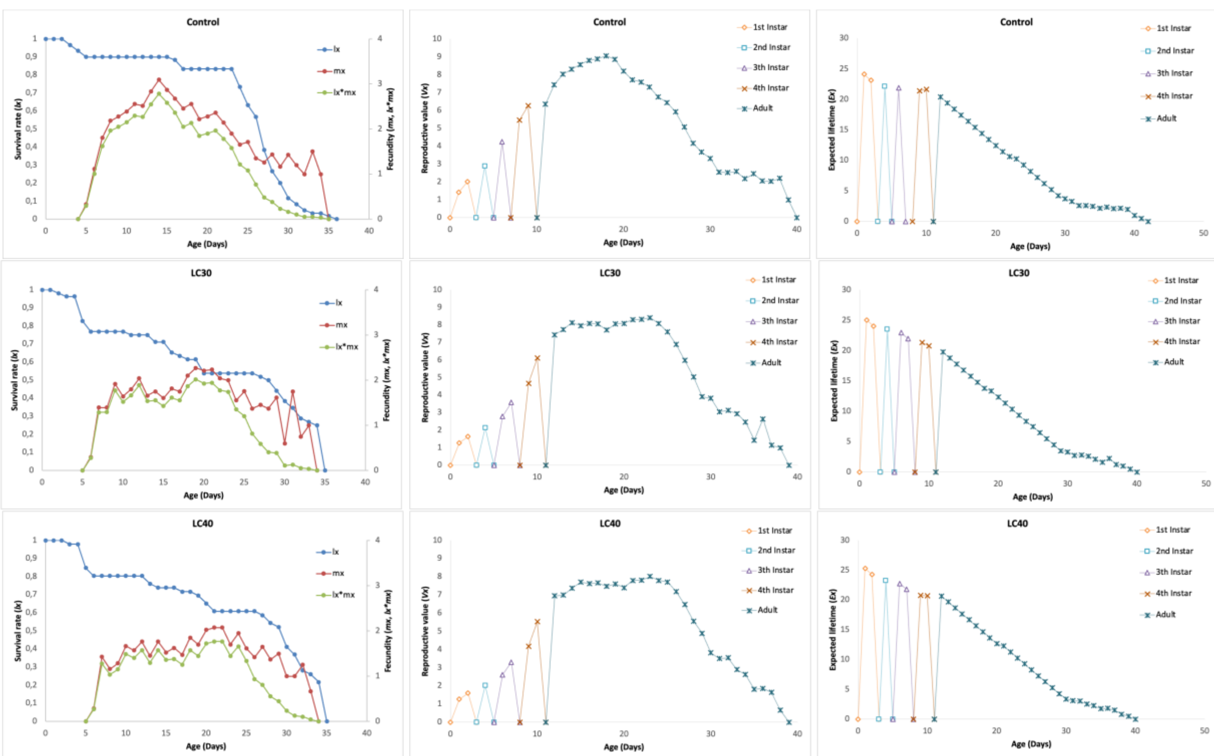

Figure 4. Survival rate (l_x), Fecundity (m_x, l_x*m_x), Reproductive value (V_x) and Expected lifetime (E_x) of *Acyrthosiphon pisum* exposed to different concentrations (0.238 µl L^{-1} and 0.474 µl L^{-1}) of lambda-cyhalothrin.

Discussion

In this study, reductions in pre- and post-emergence development times were observed in three different aphids exposed to two low-to-medium doses of lambda-cyhalothrin (LC_{30} and LC_{40}). Compared to the control group, it was found that the number of aphid progeny and related life table parameters were reduced. The full evaluation of the obtained data suggests that the application of doses below the mean dose may have effects on the physiological characteristics of aphids.

One of the most important factors in stimulating insect reproduction is the pesticides used in control. This excitation occurs when insects are exposed to these chemicals (Catae et al., 2017). This also occurs as a result of long-term control processes with the same chemical (Wang et al., 2017). The data analysis in our study revealed that all three aphid species (*A. fabae*, *M. persicae* and *A. pisum*) were affected by the chemical used and the reproduction rate decreased. For this reason, it is reasonable to use insecticides against these pests in crop rotation to prevent the species from developing resistance (Ayyanath et al., 2013; Wang et al., 2017). Some studies have shown that pyrethroid-based compounds affect reproduction of various insects and arthropods and the number of eggs/offspring laid decreases (Kidd et al., 1996; Kerns & Stewart, 2000; Fujiwara et al., 2002; Wang et al., 2008; Quan et al., 2016; Zuo et al., 2016). Ayyanath et al. (2013) reported that reproductive stimulation in insects can occur in different populations and different generations. In contrast, in our study, a decrease in reproduction was observed in all three aphids. To better understand the situation described by the researchers in *A. fabae*, *M. persicae* and *A. pisum*, it would be beneficial to conduct a similar study both in different generations and under field conditions. Ayyanath et al. (2013) and Wang et al. (2017) reported in their studies that low doses of an insecticide can prolong nymph/larval development and adult life span, thus reducing reproduction. They reported that this situation was caused by the introduction of insecticide into the embryo. In our study, these conditions were observed when low concentrations of lambda-cyhalothrin were applied. Therefore, it is reasonable to conduct molecular studies to transfer the adverse effects that occur when low doses of lambda-cyhalothrin are applied to aphids (*A. fabae*, *M. persicae* and *A. pisum*).

Low doses of lambda-cyhalothrin (LC_{30} and LC_{40}) used in our study, as with other insecticides, affected both the biological and physiological characteristics of the insects in our experiments. In our study, the application of lambda-cyhalothrin to aphids significantly decreased the intrinsic rate of increase (r_m), net reproduction rate (R_0), and gross reproduction rate (*GRR*) of all three aphids compared to the control. For this reason, it is suspected that the chemical used could have a negative impact on the next generations. However, as mentioned earlier, it would be beneficial to repeat a similar study both under field conditions and on different populations. There are several studies on the effects of insecticide trials on insect life cycle parameters. When examining the studies on pyrethroid-based insecticides, similar results were obtained (Kerns & Stewards, 2000; Whalen et al., 2012; Song et al., 2013; Zuo et al., 2016; Mahmoodi et al., 2020; Qu et al., 2020; Tan et al., 2021; O'Hara et al., 2022). As can be seen from the results obtained, when lambda-cyhalothrin is applied to *A. fabae*, *M. persicae* and *A. pisum* in the laboratory, development is delayed and the number of progeny decreases. This suppresses subsequent population growth in all three species. However, some researchers have reported that low doses of pyrethroid-based insecticides can have a beneficial effect on insect populations under field/greenhouse conditions (Kidd et al., 1996; Wang et al., 2008; Piiroinen et al., 2014). For this reason, it is advantageous to apply lambda-cyhalothrin, which has been tested in the laboratory on three different aphids, under field conditions.

It is unclear whether lambda-cyhalothrin has a typical effect in some aphid populations (Valmorbida et al., 2020). Similar results were obtained on different aphid species. It has been stated that the effects on the longevity and fecundity of aphids, especially for the first generations, vary according to the species and insecticide combination. For example, the adult longevity and fecundity of *M. persicae*, which was exposed to LC_{25} dose of flupyradifurone, decreased significantly (Heidel-Fischer & Vogel, 2015). In addition, there was no difference in lifespan and fertility when *A. gossypii* was exposed to LC_{25} of flupyradifurone (Liang et al., 2018) and sulfoxaflor (Chen et al., 2016). It has been reported that there was no difference in longevity in *A. gossypii* exposed to LC_{10} and LC_{50} doses of Nitenpyram, while fecundity was greatly reduced (Wang et al., 2017). In our study, there was no difference in adult and total longevity of *A. fabae* and *A. pisum* exposed to different concentrations of lambda-cyhalothrin (LC_{30} and LC_{40}) compared to the control. However, this situation differed in *M. persicae*. It was determined that this species had a lower adult and total longevity compared to the control at these doses. The effects of sublethal concentrations of lambda-cyhalothrin used differed. In addition, it was determined that fecundity and reproductive value decreased at sublethal concentrations.

The results show that the application of low concentrations of lambda-cyhalothrin to aphids (*A. fabae*, *M. persicae* and *A. pisum*) prolongs growth times and reduces fecundity. In addition, the use of this chemical on agricultural commodities is thought to have an effect not only at lethal concentrations but also at lower concentrations (Ayyanath et al., 2013; Wang et al., 2017). The emergence of insecticide-induced resistance in agricultural pests can cause distressing situations. Therefore, the emergence of resistance means that pests increase their populations in the environment and become even more harmful (Guedes et al., 2017). At the same time, it is seen that the sensitivity of pests exposed to low concentrations (sublethal doses) of insecticides decreases (Gressel, 2011). In addition, it has been stated that insects can tolerate different stress conditions (resistant host plant) indirectly in case of exposure to sublethal concentrations (Brevik et al., 2018). Valmorbida et al. (2020) reported that *A. glycines*, which are exposed to low concentrations of lambda-cyhalothrin and fed under stress conditions, may have an advantage over individuals not under stress conditions. In our study, it was determined that low concentrations of lambda-cyhalothrin had negative effects (especially on their reproductive potential) on three different aphids. Based on the data obtained here, it would be beneficial to replicate the study under different environmental and stress conditions. As is well known, resistance problems arise from intensive use of chemicals for insect control. For example, the active ingredient that we consider effective in this study may become ineffective in the future due to resistance. For this reason, it is beneficial to use different pyrethroids or different insecticides in rotation at different times, especially under field conditions. This study was conducted to determine the effects of lambda-cyhalothrin on *A. fabae*, *M. persicae* and *A. pisum* and will benefit future studies.

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