Full Length Article

Effects of Insecticides on the Functional Response of Spider *Oxyopes javanus* against Aphid *Sitobion avenae*

Abida Butt[*], Rabia Talib and Muhammad Xaaceph Khan
Department of Zoology, University of the Punjab, Lahore, Pakistan
[*]Corresponding author: abidajawed.zool@pu.edu.pk

Abstract

The impact of sublethal concentrations of three insecticides, lambda cyhalothrin, imidacloprid and emamectin benzoate on the predation rate of the spider, *Oxyopes javanus* Thorell (Araneae: Oxyopidae), was assessed at different densities (5, 10, 20, 40 and 80) of apterous adults of *Sitobion avenae* Fabricius (Hemiptera: Aphidoidea) under mesocosm conditions. The mesocosm was prepared by caging potted wheat plant in the laboratory at $30 \pm 3°C$, $50 \pm 5\%$ relative humidity and 12:12 h (L:D) photoperiod. Logistic regression analysis suggested a type II functional response both in the control and insecticides treated spiders. However, a lower asymptote of the predation curve was recorded for insecticide treated spiders as compared to control ones. Among the insecticide treatments, asymptote of functional response curve of Emamectin benzoate was lower than lambda cyhalothrin and imidacloprid. A significant reduction in attack rates of insecticide treated spiders was recorded as compared to control. The lowest attack rate was observed in Imidacloprid-treated spiders ($0.0062 \, h^{-1}$) followed by Lambda cyhalothrin ($0.0064 \, h^{-1}$) and Emamectin benzoate ($0.0097 \, h^{-1}$). Handling times of Imidacloprid-treated ($1.614 \, h$) and control ($1.363 \, h$) spiders were non-significantly different. Handling times in emammectin benzoate-treated spiders ($2.276 \, h$) were longer and in Lambda cyhalothrin-treated spiders ($0.781 \, h$) were shorter than in control spiders. Results of study suggested that insecticides residues that have sublethal effects on beneficial arthropods can reduce their predatory potential depending on type of insecticides and predator species. © 2019 Friends Science Publishers

Keywords: Functional response; Insecticides; Spider; Aphid; Biological control

Introduction

Sitobion avenae (Fabricius) a serious pest of cultivated cereal crops such as wheat, barley, oat, rye and rice (Wangai *et al.*, 2000), is widely distributed throughout Asia, Europe, America and South Africa. Under favorable conditions, aphids generally reproduce very rapidly on leaves, stems and inflorescence of the plants. Their infestation cause significant decrease in yield through direct feeding on sap, through transmission of viral diseases to plants (Blackman and Eastop, 2000) and indirectly by secreting honey dew to develop sooty molds (Quisenberry and Ni, 2007). Several insecticides are used at high aphids' infestation rates to bring their densities below economic injury level. However, due to effect of these insecticides and their residues on non-target organisms, biodiversity of beneficial fauna in agro-ecosystem is severely hampered (Talebi *et al.*, 2011; Bass *et al.*, 2014). To reduce the utilization of insecticides, effort has focused on maintaining or releasing naturally occurring biological control agents in the cropping systems.

In agroecosystems, aphids have three types of enemies; predators, parasitoids and pathogens. Among predators, beetles (Dixon, 2000; Hangay and Zborowski, 2010), midges

(Messelink *et al.*, 2013), and spiders (Gavish-Regev *et al.*, 2008) are able to suppress aphid populations below the economic threshold level in various agroecosystems. Spiders are one of the most abundant natural predators in different agroecosystems (Nyffeler and Benz, 1987; Wise, 1993; Marc *et al.*, 1999; Nyffeler and Sunderland, 2003). Most of them are polyphagous and feed on various insect pests of agricultural crops (Schmidt *et al.*, 2004; Takashi *et al.*, 2006). According to studies, cursorial and web building spiders are major predators of aphids in different crops (Birkhofer *et al.*, 2008; Gavish-Regev *et al.*, 2009). Spiders are generalist predators that invade the fields early in the season when the aphid population is unestablished and maintain it at a low level as the season progresses (Oelbermann and Scheu, 2009).

Spiders show functional and numerical responses against different densities of prey (Kajak, 1995; Riechert, 1999). The functional response describes the response of a predator to various densities of its prey, by killing more or fewer prey organisms (Hassell, 1978; Ives *et al.*, 1993). It is helpful to evaluate the effectiveness of a predator in regulation of prey populations at different densities (Murdoch and Oaten, 1975). Holling (1959) described three types of functional response in the organisms. Predators and

parasitoides usually exhibit type II functional response, but in some species type III was also recorded (Hassell *et al.*, 1977). Spiders like other predators also exhibit the type II functional response (Butt and Xaaceph, 2015). Factors that influence functional response of a predator includes size and density of prey and predator (Aljetlawi *et al.*, 2004), type and density of alternative prey (Tschanz *et al.*, 2007), inter and intraspecific interactions (Sih *et al.*, 1998), environmental factors (Zamani *et al.*, 2006) and pesticide exposure (Li *et al.*, 2006; Řezáč *et al.*, 2010).

Spiders show high susceptibility to different insecticides as compared to herbicides and fungicides (Mansour and Nentwig, 1988; Toft and Jensen, 1998; Marc *et al.*, 1999; Tanaka *et al.*, 2000; Ravi *et al.*, 2008). Spiders that survive the exposure of insecticides usually have decreased activity levels (Wrinn *et al.*, 2012), predatory efficiency (Griesinger *et al.*, 2011) and growth rates (Peng *et al.*, 2010).

Members of Genus *Oxyopes* form a major part of predator community in agroecosystems throughout the world (Agnew and Smith, 1989; Nyffeler *et al.*, 1992; Sebastian *et al.*, 2004; Huseynov, 2006). They are cursorial spiders which actively track their prey (Cutler *et al.*, 1977). *Oxyopes javanus* inhabit different cropping systems and prey upon many economically important insect pests including aphids (Nyffeler *et al.*, 1992). Neither, the functional response of *O. javanus* to aphids nor the effects of insecticides on the functional response of this species has to our knowledge been investigated. Objective of present study was to develop a functional response curve of *O. javanus* using different aphid densities (*Sitobion avenae*) as prey in semi field conditions. In addition, the effect of three commonly used insecticides, Lambda cyhalothrin, Imidacloprid and Emamectin benzoate on the functional response of *O. javanus* was also investigated.

Materials and Methods

Study Organisms

Specimens of *S. avenae* were collected from unsprayed wheat fields located at the University of the Punjab, Lahore and mass-cultured on leaves of 8 to 10 weeks old potted wheat plants in the laboratory at $30 \pm 3°C$, $50 \pm 5\%$ RH and L12:D12 photoperiod. The population acted as a stock and was maintained until the end of the experiment.

Adult females of *O. javanus* were collected by sweep netting and visual search from unsprayed areas of the Botanical Garden, University of the Punjab, Lahore and kept singly in plastic containers (15 cm height, 5 cm diameter). The mouth of each container was covered with muslin cloth for circulation of air. The base of each container had a 3 cm layer of wet sand covered with a few dried leaves. These containers were maintained in the laboratory at the same conditions as mentioned above. All spiders were fed with *Drosophila melanogaster* larvae *ad libitum*. Prior to the experiment, spiders were starved for 48 h due to a higher predation rate of hungry spiders than overfed ones (Haynes and Sisojević, 1966).

Bioassay Procedure

Commercial formulations of three insecticides, Lambda cyhalothrin (Karate® 2.5 EC, Syngenta), Imidacloprid (Confidor® 20 SL Bayer) and Emamectin benzoate (Proclaim® 1.9 EC, Syngenta) (Table 1) were purchased from local offices of these companies.

To assess LC_{30}, only adult specimens of *O. javanus* were exposed to different dilutions of insecticides (Table 1) by the dipping method. Stock solution of each insecticide was prepared by dissolving it in water at field rate. Further dilutions were prepared by using this stock solution. For the bioassays, single specimens were placed in a plastic vial with screen lid and dipped in insecticide solution for 10 seconds. Spiders in the control group were dipped in the water for the same time. After treatment, spiders were placed back into their individual containers with paper towel to absorb excessive moisture. The paper towel was removed after 30 minutes. Bioassays for each concentration were replicated thrice with approximately 25 individuals in each replicate. Mortality of spiders was assessed after 24 h of exposure. Mortality was considered when a spider did not move any parts of its body after being touched with a fine brush. Food was not provided to spiders during the test.

Functional Response in the Mesocosm

For experiments, arena was created using single 8 to 10 weeks old potted wheat plant en-caged in a clear plastic cylinder (40 cm high and 15 cm in diameter). The top of each cylinder was covered with white muslin cloth for ventilation. These plants were maintained in the laboratory at $30 \pm 3°C$, $50 \pm 5\%$ RH and L12:D12 photoperiod. To assess the functional response of adult *O. javanus* against apterous *S. avenea* (aphid), six densities (5, 10, 20, 40, 60 and 80) of the aphid were managed in separate arenas from the stock population. Single adult of *O. javanus* was released in each arena and number of *S. avenea* killed after 4, 8, 16, 24 and 48 h were recorded. Dead aphids were not replaced during the experiment.

To assess the effects of insecticide on predatory efficiency, *O. javanus* were exposed to the LC_{30} of each insecticide using the dip method as described above. After one hour of exposure, alive and active specimens of spiders were transferred to arenas and their predation against different densities of *S. avenea* was recorded at different time intervals. The control group was treated with water using a similar protocol.

The experiment with each prey density was replicated five times for each treatment. A minimum of 10 (for higher densities of aphid) and maximum of 15 arenas (for low densities of aphids) were used for each treatment.

Table 1: Information about insecticides used in experiment

Trade name	Insecticide	Chemical group	Active ingredient (g/L)	Field rate (ml/L)	Range of concentration tested (a.i. μg/L)	No. of concentration tested
Karate 2.5 EC	Lambda Cyhalothrin	Pyrethroid	25	2.5	2 - 100	10
Proclaim 1.9 EC	Emamectin Benzoate	Avermectin	19.2	2.0	25 - 500	10
Confidor 20 SL	Imidacloprid	Neonicotinoid	200	2.5	250 - 8000	10

a.i. Active ingredient

Table 2: Number of spiders tested against different insecticides, their sub-lethal concentration (LC$_{30}$), 95% confidence interval (C.I.) and regression slope. χ^2 is showing goodness of fit of the model

Insecticides	No. of spiders Per replicate	LC$_{30}$ (a.i. μg/L)	95% C.I.	Slope	χ^2(d.f)	P Value
Lambda Cyhalothrin	340	95.574	(83.45-107.48)	0.012	1.53 (8)	0.992
Emamectin Benzoate	300	125.14	(100.45 – 146.05)	0.008	5.67 (8)	0.689
Imidacloprid	280	2475.1	(1985.01 – 2887.9)	0.0004	4.56 (8)	0.803

Data of dead spiders in any arena during experiment was not used in the analysis. Functional response of spider was evaluated 48 h after their release in arena by counting the total number of aphids killed during this time.

Data Analysis

Mortality of spiders for all concentrations of insecticides was calculated on the basis of survived spiders after 24 h and subjected to Probit regression analysis to calculate LC$_{30}$ values and confidence interval (Finney, 1971).

Logistic regression model was used to assess the type of functional response by considering the proportion of *S. avenae* (prey) killed (*Ne/No*) as a function of the initial prey density offered (*No*) to *O. javanus* (Juliano, 2001).

$$Ne\,/No = \; exp\,(P_0 + P_1N_o + P_2N_o^2 + P_3N_o^3)\,/\,[1 + exp\,(P_0 + P_1N_o + P_2N_o^2 + P_3N_o^3)]$$

Where *Ne* is the number of prey killed by predator, No is the initial prey density available to the predator and P_0, P_1, P_2, P_3 are the intercept, linear, quadratic and cubic coefficients, respectively. A significant positive linear parameter (P_1) and negative quadratic (P_2) indicates a type III functional response and a significant negative linear parameter (P_1) indicates a type II functional response (Juliano, 2001).

After the estimation of type II functional responses (see results), searching efficiency or attack rate (α) and handling time (*Th*) were calculated using Holling's disc equation modified by non-linear regression (Livdahl and Stiven, 1983).

$$Ne = \alpha T\,No/\,(1 + \alpha Th\,No)$$

Where *T* is the total exposure time of the predator to the prey (*T* = 2 days in this study), *Th* is the handling time of the predator and α is the attack rate of the predator. The values of α and Th were determined using a modified equation (Ali *et al.*, 2011).

$$1/\,Ne = (Th/T) + (1/\,\alpha \times 1/\,Th\,No)$$

1/ *Ne* represents Y, 1/ α represents the slope parameter and *Th/T* represents the intercept parameter.

To compare the handling time and attack rate of the control and insecticide treated *O. javanus,* the parameters *Dα* and *DTh* were estimated that represent the difference between the treated and control spiders in the value of parameters α and *Th*, respectively. The handling time for control spiders was Th and for treated spiders it was *Th + DTh*. Similarly, the attack rate for control spiders was α and α+ *Dα* for treated spiders. A similar method was used to compare the attack rates and handling times between the two insecticides. However, α and *Th* values of one insecticide was used as control and the other as treated spiders. If the values of *DTh* or *Dα* was statistically significantly different from zero, then spiders of treatments have different handling time or attack rate (Julaino, 2001). Student t-test was used to estimate the difference in coefficient of attack rate and handling time between different treatments. An ANOVA was used to assess the difference in the predation rate of spiders in the control and treated groups at the highest density of prey. The toxicity of the studied insecticides and the functional response of control and treated spiders were compared using a general linear model (Řezáč *et al.*, 2010). For all analysis Minitab 16 was used.

Results

LC$_{30}$ value of Lambda cyhalothrin, Emamectin benzoate and Imidacloprid against *O. javanus* are presented in Table 2. These values were very low as compared to their field application rate. Lambda cyhalothrin proved more toxic (a.i. 96 μg/L) than Emamectin benzoate (a.i.125 μg/L) and Imidacloprid (a.i. 2475 μg/L) (F$_{2,84}$ = 4.77, *P* < 0.011). The estimated slope parameters indicated that the mortality of *O. javanus* treated with insecticide was dose dependent in all treatments (Table 2).

The linear regression parameters for control and all the insecticide treated (LC$_{30)}$ spiders had negative values of P$_1$, which suggest a type II functional response in all cases (Table 3). The relationship between the number of aphids offered and the number of aphids killed for all treatments are depicted in Fig. 1. Initially the number of killed aphids increased with density and then levelled to asymptote.

Table 3: Maximum likelihood estimates using logistic regression on proportion of *S. avenae* killed by *O. javanus*

Treatment	Parameters	Values	95 %C.I.	χ^2	P
Control	Intercept (p_o)	+0.7551	0.7225, 0.7859	56.24	<0.001
	Linear (p1)	-0.0118	-0.0134, -0.0101	75.56	<0.001
	Quadratic (p2)	+7.56 E-05	5.78 E-05, 9.16 E-05	46.68	<0.001
	Cubic (p3)	-2.1E-07	-2.81E-07, -1.42E-07	43.97	<0.001
Lambda cyhalothrin	Intercept (p_o)	+0.2656	0.3119, 0.2068	58.41	<0.001
	Linear (p1)	-0.0048	-0.0053, -0.0041	36.70	<0.001
	Quadratic (p2)	+12.79 E-05	13.3 E-05, 12.19 E-05	25.16	<0.001
	Cubic (p3)	-1.3E-07	-1.7E-07, -0.9E-07	27.88	<0.001
Emamectin benzoate	Intercept (p_o)	+0.4348	0.4061, 0.4628	94.64	<0.001
	Linear (p1)	-0.0058	-0.0071, -0.0044	37.4	<0.001
	Quadratic (p2)	+3.46 E-05	2.07E-05, 4.72 E-05	28.8	0.005
	Cubic (p3)	-1.1E-07	-1.2E-07, -0.8E-07	53.37	<0.001
Imidacloprid	Intercept (p_o)	+0.3136	0.2587, 0.3685	21.53	0.001
	Linear (p1)	-0.0029	-0.0033, -0.0025	23.7	<0.001
	Quadratic (p2)	+6.12 E-05	5.71E-05, 6.53 E-05	32.40	<0.001
	Cubic (p3)	-1.0E-07	-1.4E-07, -0.6E-07	36.22	<0.001

The comparison of the functional response curve of treated and control spiders revealed that the functional response curve of insecticide treated *O. javanus* was significantly lower than that of the control spiders (GLM, $F_{3,351} = 422.44$, $P < 0.001$). The lowest asymptote was recorded for Emamectin benzoate as compared to Lambda cyhalothrin and Imidacloprid. The average number of aphids killed at the highest density were significantly different among the treatments ($F_{3,36} = 76.22$, $P < 0.001$; Table 4).

The coefficient of attack rate (α) and handling time (Th) for all the treatments are presented in Table 5. A significant reduction in attack rates of insecticide treated spiders was recorded as compared to the control spiders. Spiders treated with Emamectin benzoate had significantly higher attack rates as compared to Imidacloprid and Lambda cyhalothrin treated spiders. However, no significant difference was recorded in attack rates between Imidacloprid and Lambda cyhalothrin treated spiders (Table 6). The handling time of control spiders was similar to Imidacloprid, significantly lower than Emammectin benzoate and significantly longer than Lambda cyhalothrin treated spiders. Spiders treated with Emamectin Benzoate had significantly longer handling time compared to Imidacloprid or Lambda Cyhalothrin treated spiders (Table 6).

Discussion

Results of present bioassays revealed that Lambda cyhalothrin was the most toxic insecticide for *O. javanus* than Emamectin benzoate and Imidacloprid. LC_{30} values of Lambda cyhalothrin, Emamectin benzoate and Imidacloprid were approximately 11,000, 300 and 200 times less than their field application rates. However, all these insecticides are extensively used in different agro-ecosystems to control various types of insect pests. When these insecticides enter into the body of arthropods, they interfere with different metabolic pathways and disrupt their survival, reproduction, movement and behavior (Pekár, 2012).

Table 4: Mean number of *S. avenae* killed by *O. javanus* at highest density (80 individuals) in 48 h

Treatments	Mortality	S.D.
Control	22.05[a]	0.836
Lambda cyhalothrin	19.67[b]	1.089
Emamectin benzoate	14.35[d]	1.021
Imidacloprid	18.14[c]	0.475
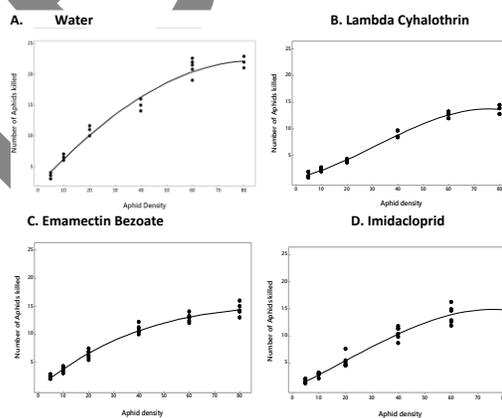
Fig. 1: Functional response of *O. javanus* when exposed to water (**A**), and sublethal doses of Lambda Cyhalothrin (**B**), Emamectin Benzoate (**C**) and Imidacloprid (**D**) while feeding on unwinged *S. avenae*. A dot represent mean observed mortality per replicate and line represent mortality calculated by model

O. javanus consumed the maximum proportion of *S. avenae* at the density of five individuals and the minimum at the density of 80 individuals. The proportion of prey consumed decreased as the density of prey increased. This shows that data can be described well by type II functional response because in type I functional response proportion of prey consumed by predator remain constant and in type III functional response it first increase with prey density and then decrease. The application of Logistic regression model on the proportion of prey consumed also estimated negative values for linear parameters and confirmed type II functional response for control and all insecticides treated *O. javanus*.

Table 5: Coefficients of attack rate (α) and handling time (Th) for insecticide treated and untreated *O. javanus* fed on *S. avenae* under microcosm conditions

Parameters	Treatments	Estimates	S.E.	95% C.I. Lower	upper
α (/h)	Control	16.13E-03[a]	3.01 E-04	14.84 E-03	17.42 E-03
	Lambda cyhalothrin	6.40 E-03[c]	1.14 E-04	5.91 E-03	6.89 E-03
	Emamectin benzoate	9.68 E-03[b]	3.68 E-04	8.45 E-03	11.01 E-03
	Imidacloprid	6.21 E-03[c]	2.14 E-04	5.28 E-03	7.12 E-03
Th (h)	Control	1.363[b]	0.0249	1.2557	1.4697
	Lambda cyhalothrin	0.781[c]	0.1660	0.0650	1.4971
	Emamectin benzoate	2.276[a]	0.0291	2.1512	2.4004
	Imidacloprid	1.614[b]	0.0848	1.2495	1.9793

Table 6: Dα and DTh values when comparing coefficient of handling times and attack rates of insecticide treated and control *O. javanus*

Coefficient Treatment	Control	Lambda cyhalothrin	Emamectin benzoate
Dα			
Lambda cyhalothrin	9.73E-03 (P= 0.002)		
Emamectin benzoate	6.45E-03 (P= 0.002)	-3.28E-03 (P= 0.011)	
Imidacloprid	9.93E-03 (P= 0.002)	-0.19E-03 (P= 0.407)	3.48E-03 (P=0.021)
DTh			
Lambda cyhalothrin	0.582 (P= 0.052)		
Emamectin benzoate	-0.913 (P= 0.001)	-1.495 (P= 0.013)	-
Imidacloprid	-0.252 (P= 0.146)	-0.834 (P= 0.080)	0.6614 (P= 0.018)

Many studies have reported type II functional response in different insects and spiders (Řezáč *et al.*, 2010; Butt and Xaaceph, 2015; Costa *et al.,*2017). However, other studies also reported that spider exhibit functional response of type I (Denno *et al.*, 2004), III (Vucic-Pestic *et al.*, 2010) and IV (Líznarová and Pekár, 2013) when exposed to variable environmental factors like presence of dangerous prey, density of alternative prey, variable temperature and arena size (Schenk and Bacher, 2002; Khan *et al*., 2016; Uiterwaal and Delong, 2018).

The significant decrease in the proportion of aphid killed by spiders at higher densities may be due to satiation of spider or presence of toxin which cause aversive behavior (Toft, 2005). Spiders have an elaborate midgut and elastic abdomen which can store a large quantity of food. Spiders can consume a lot of food in one sitting and then survive starvation for a long time (Foelix, 1996). Studies have reported that being generalists, spiders have low consumption capacity for aphids as compared to other specialist and aphidophagous species. However, consumption rate of aphid also varies in different species of spiders (Toft, 2005). Spiders also perform superfluous killing of prey (Riechert and Luczak, 1982). However, in the present study we did not observe whether all the killed *S. avenae* were consumed by *O. javanus* or not. The results of our study suggested that *O. javanus* is more effective against aphids when their density is low in the fields.

In predators, the type of functional response, attack rates and handling times are influenced by many factors including exposure to insecticides (Ambrose *et al.*, 2010). In our study, exposure to sublethal concentrations of insecticides reduced the predation efficiency of *O. javanus*. It causes a lower asymptote in the functional response curves of insecticide treated spiders as compared to control but did not

change the type of functional response in all treated and untreated groups. Other studies also reported a significant decrease in prey consumption by spiders exposed to different insecticide without change in the type of functional response (Řezáč *et al.*, 2010; GholamzadehChitgar *et al.*, 2014; Sharifian *et al.*, 2017).

Among insecticides, the functional response curve of Emamectin benzoate was lower than that of Lambda cyhalothrin and Imidacloprid. A lower asymptote of treated spiders represents either a decrease in attack rate or an increase in handling time of prey. Our study demonstrated that insecticide treated spiders has lower attack rates and longer handling times compared to control spiders. The exception is recorded in Lambda cyhalothrin treated spiders, which interestingly showed significantly shorter handling times. All the studied insecticides have neurotoxic mode of action and may decrease the predation activity of spiders. Poletti *et al.* (2007) reported that Imidacloprid did not change the type of functional response of predatory *phytoseiid* mites, *Neoseiulus californicus* (McGregor) and *Phytoseiulus macropilis* (Banks), but caused a conspicuous increase in handling time, and a decrease in the attack rate of the predators. Řezáč *et al.* (2010) reported that the spider *Philodromus cespitum* (family Philodromidae) treated with Acetamaprid has handling time and attack rate similar to control. Deng *et al.* (2007) reported non-significant decrease in handling time of *Hylyphantes* spiders (family Linyphiidae) when exposed to pyrethroid insecticides. The lowest handling time of Lambda cyhalothrin treated spiders may be due to hormesis (Stebbing, 1982).

Toxicity data showed that Lambda cyhalothrin is highly toxic to *O. javanus* as the LC_{30} value was 11000 times less than the field application rate. Imidacloprid and emmamecin benzoate were less toxic than Lambda cyhalotrin, but still had

a LC$_{30}$ value that was 200 to 300 times less than their field application rates. Other studies also reported higher toxicity of Lambda cyhalothrin than for other insecticides (Dinter and Poehling, 1995; Yang *et al.*, 2014). This suggested that Lambda cyhalothrin cannot be incorporated into integrated pest management programs, although it is used commonly in agroecosystems.

Conclusion

In this study, we measured the functional response of *O. javanus* in mesocosm, which does not necessarily reflect the functional response in the field. However, our results are useful for an initial assessment of the biocontrol potential of *O. javanus* in the field as well as estimating the sublethal effects of insecticides on this biocontrol potential. Our data also showed that even insecticides, which are less toxic to spiders can severely reduce their predatory efficiency. Among the studied insecticides, Lambda cyhalotrin is not suitable for integrated pest management programs. Further studies are required to investigate the sublethal effects of the studied insecticides on other species of spiders belonging to different guilds (including web-building spiders). It will help us to choose the most appropriate insecticides to incorporate into integrated pest management and to maintain beneficial spider communities in agroecosystems.

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