Journal of Nuts

Journal homepage: ijnrs.damghaniau.ac.ir

Side Effects of Spirotetramat and Imidacloprid on *Hippodamia variegata* Goezee Feeding on *Agonoscena pistaciae* Burckhardt & Lauterer

Maryam Zeinadini Meymand[1], Najmeh Sahebzadeh[1], Sultan Ravan[1], Mehdi Basirat[2]*

[1] Department of Plant Protection, Faculty of Agriculture, University of Zabol, Zabol, Iran

[2] Pistachio Research Center, Horticultural Science Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Rafsanjan, Iran

A R T I C L E I N F O

Keywords:

Demography;
Hippodamia variegate;
Life table;
Pesticide;
Pistachio

A B S T R A C T

The Adonis ladybird, *Hippodamia variegata* Goeze (Coleoptera: Coccinellidae) is known as an important predator of the Common pistachio psylla, *Agonoscena pistaciae* Burckhardt & Lauterer (Hemiptera: Psyllidae). Despite using the selective pesticides to manage the pests in the pistachio orchards, these chemicals have influenced non-target organisms like predators and parasitoids. In the present study, the effects of spirotetramat and imidacloprid (500 and 400 ml/1000 L, respectively) on some biological parameters of *H. variegata* fed on the common pistachio psylla were investigated under laboratory conditions (27.5 ± 1°C, 65 ± 5% RH and 16:8 h L: D photoperiod). To this end, the eggs of ladybird beetles were exposed to pesticides via a Dipping method. In addition, the impact of pesticides on immature and adult stages was studied. The daily number of eggs laid by a female ladybird was also recorded in laboratory conditions. The results showed that spirotetramat and imidacloprid had increased the duration of immature developmental stages (egg, larva, and pupae) and the number of daily laid eggs of female ladybirds compared to those by control (Kolmogorov-Smirnov test, $p < 0.05$). The highest and the lowest of net reproductive rates were also observed in control and imidacloprid treatments, respectively. Considering the results, the spirotetramat and imidacloprid had caused adverse effects on the demographic parameters of *H. variegata* and had also influenced the efficiency of this predator. Therefore, spirotetramat and imidacloprid were suggested to be used in IPM of *Agonoscena pistaciae* with caution.

Introduction

The Common pistachio psylla, *Agonoscena pistaciae* (Hemiptera: Psyllidae) has been introduced as one of the most important pests of pistachio in Iran, widely distributed throughout the pistachio growing areas (Iraq, Greece, Syria, Turkey, etc). In this respect, the adults and the nymphs of *A. pistaciae* can directly (sucking of leaf sap and production of a large amount of honeydew) and indirectly (plant growth reduction, defoliation, falling of fruit buds) damage the pistachio trees and finally derease the economic yields (Burckhardt and Lauterer, 1993; Mehrnejad, 2002; Samih *et al.*, 2005). Followed by the growing of pistachio buds in the early spring, this psylla emerges in pistachio orchards and stays on the trees until fall (Mehrnejad, 2001). In recent years, several natural enemies have been also reported on Common pistachio psylla (Mehrnejad, 2001, 2003, 2010; Mehrnejad and Emami, 2005; Mehrnejad *et al.*, 2011, Parish *et al.*, 2013). Accordingly, it has been well-documented that Common pistachio psylla is considered as a good host for at least eight species of ladybirds (Mehrnejad, 2010; Mehrnejad *et al.*, 2011).

*__Corresponding author__: Email address: najmeh.sahebzadeh@gmail.com, n.sahebzadeh@uoz.ac.ir

Received: 22 July 2018; Received in revised form: 10 January 2019; Accepted: 28 February 2019
DOI: 10.22034/jon.2019.664207

The eggs of this psylla are also recognized as a suitable prey for active ladybirds in pistachio orchards (Mehrnejad, 2010). So, presence and activity of ladybirds on pistachio trees are known as positive factors to use them for lowering the population of this pest on planting pistachio.

In general, the ladybirds (Coleoptera: Coccinellidae) are important predators in agro-ecosystems, which are used as biological agents and play a significant role in managing populations of aphids, psyllids, scales, and mites (Hodek, 1973; Obrycki and Kring, 1998). Among the ladybirds fed on the Common pistachio psylla, *Hippodamia variegata* (Goeze) as a polyphagous species; has been drawn to Palearctic and Nearctic ecozones (Gordon, 1987; Krafsur *et al.*, 1996; Franzmann, 2002). Studies have also reported that these ladybirds are active on the infected weeds with aphids in the early spring in pistachio orchards, and then they would be transferred on pistachio tress during spring and summer and fed on the Common pistachio psylla (Asghari, 2010). Applications of a broad range of pesticides such as oregano-chlorides, oregano-phosphors, carbamates, and pyrethroids can also influence non-target organisms such as natural enemies of pests of pistachio trees. Besides, most of the pistachio pests are assumed very sensitive to pesticides and it has been reported that the population of the pests significantly decreases following the use of only one pesticide (Mehrnejad, 2010).

As a primary concern, it is necessary to use pesticides compatible with natural enemies. In addition, there have been attempts to incorporate natural enemies such as coccinellids into integrated pest management (IPM) strategies, but ladybirds show the variable responses once are exposed to lethal or sub-lethal doses of pesticides. In response to pesticide residues on plant surfaces, patterns of prey foraging and searching have significantly altered and resulted in decreased effectiveness of coccinellids as insect predators. Moreover, negative geotactic and positive phototactic behaviors have been reported as predators that have been in pesticide exposure (Reviewed in Singh *et al.*, 2004). Application of a wide range of pesticides also controls pests in a short time although; it decreases and limits their natural enemies and pest resurgence. In addition to direct mortality caused by pesticides, non-lethal or side effects on physiology and behavior of beneficial arthropods must be considered (Desneux *et al.*, 2007). Besides, fertility is the most sensitive biological index influencing on insect physiology and it is the most important factor affecting population fluctuation. It has been also determined that pesticides often decrease fertility or infrequently increased fertility because the use of pesticides which have been observed in some insects (Croft, 1990).

Demographic studies of insects have been conducted for several purposes including the analysis of mortality, estimating and comparing the growth rate of populations, the effect of chemical control on population dynamism, efficiency and intrinsic rate of increasing population of a pest in the field conditions in different generations (Carey, 1982, 1993). Life-table tests have been also investigated through exposing insects (individual or group) with specified doses of pesticides. Insect lifetime, daily mortality, and reproduction have been also recorded and provided information valuable for estimation of an intrinsic rate of increasing population (r_m) as well as the effects of sub-lethal doses of pesticides on fecundity, growth rate, survival, and sexual ratio. In general; life table tests have been conducted to estimate toxic effects of lethal concentrations, which provide more accurate information (Forbes and Calow, 1999) such as measuring side effects of pesticides on the survival of natural enemies (Stark and Banks, 2003, Desneux *et al.*, 2007).

It has been reported that *H. variegata* is widespread all around the world. This ladybird species is known as a polyphagous predator of aphid and psylla species which is potentially able to manage economic damage in various crops (Santos *et al.*, 2017). Considering the effective dose of pesticides on insect pests and its effect on its natural enemies is also of important. Sometimes the effects are sub-lethal and they can decrease the efficiency of the predator. Spirotetramat and imidacloprid are two commonly used pesticides on pistachio orchards for controlling pistachio psylla, whose major predator is *H. variegata.* Hence, suggested concentrations of spirotetramat and imidacloprid on parameters of life table for *H. variegata* were investigated in this study. In addition, the population growth parameters and reproduction ones were estimated using Carey's method (1993).

Materials and Methods

Rearing of H. variegata

The sampling of adult coccinellids was done from the pistachio orchards in Rafsanjan region, Iran, and then transported to the laboratory. The insects were reared under laboratory conditions (27.5±1°C, 65±5% relative humidity, 16:8h L:D photoperiod) in entomology laboratory (Pistachio Research Institute, Rafsanjan, Iran). Afterwards, *H. variegata* adults were identified and separated from other species of ladybird beetles. To initially examine the stock colony of *H. variegata*, the fresh leaves of pistachio containing the psylla nymph (as preys) were collected and provided on a daily manner to the coccinellid adults for feeding. Under laboratory conditions, each pair of adults of ladybirds was kept in a plastic Petri dish (6 cm diameter). The Petri dishes were then covered with mesh organdy on the lid for ventilation. Subsequently, the adults of *H. variegata* were fed on a daily basis on the collected pistachio leaves, which were infected with pistachio psylla nymphs. To prevent mold growth, the leaves infected with psylla and the plastic boxes were replaced every three days. In addition, each larva of *H. variegata* was kept individually in the petri dish to prevent larval cannibalism. After two generations of rearing by feeding psylla, the laid eggs of the new generation were introduced to conduct the bioassay tests.

Assay of Developmental, Reproductive and life parameters of H. variegata after treatment with spirotetramat and imidacloprid

In this research, the side effects of spirotetramat (SC100%, Bayer, Germany) and imidacloprid (SC35%, Bayer, Germany) were evaluated on the laid eggs of a second generation of the reared ladybirds under laboratory conditions. For each treatment, 100 eggs of ladybirds were collected during 24 hours after oviposition. Then the eggs were placed on a fresh pistachio leaf (6 cm) using a moistened fine hairbrush and then the leaves were separately dipped for 3 seconds in the suggested concentrations of spirotetramat and imidacloprid (500 and 400 ml/1000 L, respectively). The control treatment was done only by dipping the leaves in pure water (H_2O). Then the treated eggs with these concentrations of pesticides were placed in Petri dishes (diameter 6×1.5 cm). The treated eggs were checked on a daily basis and the numbers of newly-hatched and un-hatched eggs were recorded. After hatching, the ladybird larvae were placed separately in a Petri dish to prevent larval cannibalism. The larvae were fed daily on psyllid nymphs (~150-200) that were alive on the fresh pistachio leaves as explained previously. After pupation and adult emergence, their sexes were determined. These ladybird adults were used to assess life table parameters (15 males and 15 females).

To study the life table parameters of the treated *H. variegate*; pre-oviposition, oviposition, and post-oviposition periods were recorded. In addition, the survival and fecundity of *H. variegata* females and the fertility of the laid eggs were recorded daily by a method as described by Mehrnejad *et al.* (2015). When the ladybird adults died, the experiments were terminated. Population growth parameters including intrinsic rate of increase (r_m), finite rate of increase (λ), intrinsic rate of birth (b), intrinsic rate of death (d), gross reproductive rate (GRR), net reproductive rate (R_0), mean generation time (T), and doubling time (DT) were calculated as explained by Carey (1993).

Statistical analysis

Before being subjected to analysis, data normality was checked using the Kolmogorov-Smirnov test (K-S test). The analysis results confirmed that all the data were normally distributed. The data including developmental time, survival rate adult longevity and fertility were also analyzed via one-way ANOVA (SPSS v. 16, 2007). Total developmental time as well as growth and reproductive data were used to calculate major parameters within the life table parameters including net reproductive rate ($R0$), intrinsic rate of population increase (r_m), finite rate of increase (λ) and doubling time (DT). In addition, all mentioned the parameters were estimated with mean Jackknife pseudo-values (Maia *et al.*, 2000).

Results

Developmental times, female longevity and reproduction periods (days)

The developmental times of various stages of *H. variegata* after exposure to spirotetramat and imidacloprid were presented in Table 1. The results showed that the egg incubation periods in *H. variegata* exposed to spirotetramat and imidacloprid had significantly increased in comparison with those in control (f=8.68, p <0.0001). A similar trend was also observed for larval and pupal periods in both treatments. In this respect, the larval and pupal periods in imidacloprid treatment had significantly increased (11.48 and 3.34 days, respectively). Considering spirotetramat treatment, the pupal period (3.29 days) was reported higher compared to control treatments. The total developmental time (egg to adult) in the treated *H. variegata* with spirotetramat and imidacloprid had also significantly increased compared with controls. The longest and the shortest female longevities were observed in control and imidacloprid treatments, respectively (59 and 45 days).

Table 1. Effect of imidacloprid and spirotetramat on immature developmental times, adult longevities and reproduction periods (days) of *H. variegata* fed on *Agonoscena pistaciae* (Kolmogorov-Smirnov test, *p* <0.05).

Stage	Treatment		
	Imidacloprid	Spirotetramat	Control
Egg	2.5 ± 0.087^{a}	2.32 ± 0.0791^{a}	2.09 ± 0.312^{b}
Larve I	2.30 ± 0.0727^{a}	$1.69\pm.0692^{b}$	1.18 ± 0.432^{c}
Larva II	2.67 ± 0.0773^{a}	2.72 ± 0.0726^{a}	2.10 ± 0.445^{b}
Larva III	2.82 ± 0.084^{a}	2.80 ± 0.0821^{a}	2.52 ± 0.631^{b}
Larva IV	3.69 ± 0.107^{a}	3.66 ± 0.0721^{a}	3.56 ± 0.874^{a}
larva	11.48 ± 0.341^{a}	10.93 ± 0.74^{b}	9.31 ± 0.058^{c}
Pupa	3.34 ± 0.081^{a}	3.29 ± 0.086^{a}	3.09 ± 0.56^{b}
Egg-to-adult	17.74 ± 0.0183^{a}	16.52 ± 0.162^{b}	14.91 ± 0.116^{c}
Female longevity	45 ± 0.621^{c}	52 ± 0.0154^{b}	59 ± 0.0274^{a}
Pre-oviposition period	4.8 ± 0.155^{a}	4.33 ± 0.0189^{a}	3.67 ± 0.0280^{b}
Oviposition period	30.73 ± 0.329^{b}	35.87 ± 0.347^{b}	42.07 ± 0.279^{a}
Post-oviposition period	2.47 ± 0.023^{b}	2.93 ± 0.23^{ab}	3.4 ± 0.245^{a}

Reproductive parameters of H. variegata

The reproductive parameters of *H. variegata* treated with imidacloprid and spirotetramat were presented in Table 2. Based on the fecundity (total eggs) and fertility (hatched eggs), gross fecundity and fertility rate (the average of produced offspring by females during their life cycle and the number of hatched eggs during female lifetime, respectively); a significant decrease was observed in the treatments compared to those in controls. The lowest and the highest gross fecundity rate (p<0.0001, F=17.20 df=3.56) were also observed in imidacloprid and control, respectively (125.35±7.89 and 229.57±18.98 eggs per female). Similarly, a significant decrease was detected in gross fertility rate (p<0.0001 F=30.48 df=3.56) and gross hatch rate (p=<0.0001, F=4.91, df=3.56) as *H. variegata* were treated with both pesticides in comparison to control. Net reproduction rates (net fecundity and net fertility rates) in the treatments also showed lower values (p<0.0001, F=11.69 df=3.56 and p<0.0001, F=15.94, df=3.56, respectively) than control. The daily number of eggs laid per female correspondingly decreased in spirotetramat and imidacloprid treatments compared to those controls. In addition, the daily number of fertilized eggs laid by each female insectwas the greatest in control while a significant egg reduction was observed once the ladybirds were exposed to spirotetramat and imidacloprid.

Table 2. Reproduction parameters of *H. Variegata* after exposure to pesticides fed on *Agonoscena pistaciae* (Kolmogorov-Smirnov test, *p* <0.05)

Parameters	Treatment		
	Imidacloprid	Spirotetramat	Control
Gross fecundity rate	125.35±7/89[c]	174.71±6.98[b]	229.57±18.98[a]
Gross fertility rate	82.73±5.20[c]	124.08±4.97[b]	188.24±15.56[a]
Gross hatch rate	0.66[c]	0.71[b]	0.82[a]
Net fecundity rate	138.97±11.44[b]	85.77±4.023[c]	146.08±16.39[a]
Net fertility rate	91.72±7.55[b]	60.903±2.85[c]	119.78±16.39[a]
Eggs/ female/ day	2.30±0.148[b]	2.53±0.0951[b]	3.35±0.210[a]
Fertile eggs/female/day	1.52±0.0981[b]	1.80±0.0675[b]	2.75±0.172[a]

Population growth parameters of *H. variegata* treated with imidacloprid and spirotetramat were illustrated in Table 3. The gross reproductive rate (*GRR*), net reproductive rate (*R0*), intrinsic rate of increase (r_m), intrinsic rate of birth, finite rate of increase (λ) and mean generation time (*T*) of *H. variegata* had significantly decreased after treatment by imidacloprid and spirotetramat. The *GRR* of this ladybird in imidacloprid treatment was reported significantly lower than that in spirotetramat and control treatments. The highest level of net reproductive rate (R_0) of *H. variegata* was also observed in control treatment which was significantly different from others. The intrinsic rate of increase (r_m) of *H. variegata* was also reported significantly higher in control than both pesticide treatments (p<0.0001, F=91.33 df = 3.56). In addition, the intrinsic rate of birth (b) of *H. variegata* in control treatment had significantly increased compared with spirotetramat and imidacloprid treatments. The highest intrinsic rate of death (d) was observed in imidacloprid treatment which was not significantly different from spirotetramat treatment. The mean generation time (*T*) increased significantly as *H. variegata* was treated with imidacloprid compared with spirotetramat and control (p<0.0001, F =19.34, df =3.56). However, the doubling time (DT) in control treatment decreased significantly in control compared with both pesticide treatments.

Table 3. Population growth parameters of *H. variegata* treated with imidacloprid and spirotetramat (Kolmogorov-Smirnov test, *p* <0.05)

Parameters	Treatment		
	Imidacloprid	Spirotetramat	Control
Gross reproductive rate (*GRR*)	62.67±3.94[c]	87.38±3.50[b]	114.78±9.49[a]
Net reproductive rate (R_0)	38.54±5.56[b]	44.40±2.07[b]	74.50/±7.99[a]
Intrinsic rate of increase (r_m) (day^{-1})	0.122±0.0026[b]	0.127±0.0022[b]	0.156±0.0023[a]
Intrinsic rate of birth (b) (day^{-1})	0.154±0.0034[b]	0.154±0.0018[b]	0.162±0.0024[a]
Intrinsic rate of death (d) (day^{-1})	0.0286±0.00066[a]	0.0272±0.00010[a]	0.0148±0.00026[b]
Finite rate of increase (λ) (day^{-1})	1.13±0.0032[b]	1.13±0.0019[b]	1.16±0.0027[a]
Mean generation time (T) (day)	33.56±0.943[a]	29.94±0.453[b]	27.56±0.728[c]
Doubling time (DT) (day)	5.49±0.144[a]	5.45±0.0739[a]	4.42±0.0734[b]

Discussion

The results of the present study confirmed that the application of either imidacloprid or spirotetramat could increase the developmental times of immature stages of *H. variegata* ladybird. Contrarily, female longevity decreased. The same findings had been also demonstrated by various researchers. For example, the effect of two pesticides on the life table of *H. variegata* showed that hexaflumuron had significantly increased the number of eggs and the first instar larval period compared with spirodaiclophen and control (Alimohammadi *et al.*, 2014) that was consistent with the findings of this study. Similarly, application of sub-lethal concentrations of carbofuran and imidacloprid enhanced the developmental time of the first and the second larval instars as well as the longevity of the female and male of *Hippodamia undecimnotata* in comparison with control (Papachristos and Milonas, 2008). In another study, Rahmani and Bandani (2013) reported that sub-lethal concentrations of thiamethoxam had no significant effects on the developmental time of instar larval, pupal and adult longevity of *H. variegata*. Cabral *et al.* (2008) also suggested that the developmental time of eggs and the first instar larvae of *Coccinella undecimpunctata* treated with boprofezine and pymetrozine had increased in comparison with control.

The results of this study revealed that the pre-oviposition period of females of *H. variegata* had significantly increased after being treated by imidacloprid and spirotetramat, while a significant decrease was observed in oviposition and post-oviposition periods when this ladybird was treated via both pesticides. Moreover, similar results were demonstrated by Smith and Krischik (1999) wherein the coccinellid predator *Coleomegilla maculate* (DeGeer) was treated using sub-lethal concentrations of imidacloprid. Papachristos and Milonas (2008) correspondingly found that sub-lethal concentrations of imidacloprid and carbofuran had increased the pre-oviposition period of females of *H. undecimnotata*. However, imidacloprid, bendiocarb, and halofenozide pesticides had no significant effects on pre-oviposition, oviposition, and post-oviposition period of *Harpalus pennsylvanicus* (Coleoptera: Carabidae) (Kunkel *et al.*, 2001).

Likewise, some research studies showed that the application of pesticides had reduced the reproductive parameters of beneficial organisms. For example, Papachristos and Milonas (2008) reported that sub-lethal concentrations of imidacloprid and carbofuran had decreased the fecundity and fertility of *H. undecimnotata*. In the same study, the numbers of the laid eggs by *Menochilus sexmaculatus* ladybird had significantly decreased after treatment with a topical sub-lethal concentration of malathion (Smith, 1966). In another study, Planes *et al.* (2013) explained the lethal and sub-lethal effects of spirotetramat, chlorpyriphos, and pyriproxyfen on the mealybug destroyer, *Cryptolaemus montrouzieri* (Coleoptera:

Coccinellidae). In this regard, they resulted that the direct application of spirotetramat on larvae and adults of *C. montrouzieri* had no significant effects on survival, longevity, fecundity, and fertility. In contrast, chlorpyriphos and pyriproxyfen significantly showed an acute effect on this coccinellid. They concluded that spirotetramat might be compatible with *C. montrouzieri* release. Also, Rahmani and Bandani (2013) observed no significant differences between the control and thiamethoxam treatment in terms of the fecundity of *H. variegata*.

The results of the present study also showed that net reproductive rate (*R0*) in the treated *H. variegata* with both pesticides had significantly decreased in comparison with control, due to reduced survival rate in the individuals treated by these pesticides. It should be noted that intrinsic rate of increase ($r=r_{max}$) is a population statistical basis for the description of population growth (Cortes, 2016); so the rate of population growth will be faster and the developmental time will become shorted as this index increases (Medeiros *et al.*, 2000).

In line with the results of the present study, the population parameters including r_m, *R0*, and λ values of *H. variegata* had decreased after treatment via thiamethoxam (Rahmani and Bandani, 2013). Moreover, Stark and Banks (2003) in the same study confirmed that imidacloprid and abamectin had decreased the intrinsic rate of increase of *H. variegata* compared with the control. Papachristos and Milonas (2008) also demonstrated that r_m, R_0 and λ values of *H. undecimnotata* after treated with the sub-lethal concentrations of imidacloprid and carbofuran were significantly decreased in comparison with control.

As the r_m values of the population decreases, its related factors were also affected followed by an increase in DT. The findings of the present study confirmed that both studied pesticides (imidacloprid and spirotetramat) had potentially decreased the efficiency of *H. variegata* while being treated with the recommended concentrations of these pesticides in pistachio orchards. Generally, doubling time (DT) had witnessed a shorter increase in predator's efficiency to control the prey. This research also confirmed that the application of imidacloprid and spirotetramat had significantly reduced the ability and the speed of increasing population of *H. variegata*. Some pesticides were also compatible with the environment and natural enemies as confirmed by Planes *et al.* (2013). However, accepting these findings under laboratory assays failed to demonstrated the acute side effect of pesticides on natural enemies such as predators, parasitoids and pollinator insects in semi-field or field experiments because of the involvement the environmental parameters.

As presented above, the risks of different pesticides for beneficial insects such as ladybirds had been investigated by some researchers. Overall, an interaction was observed between these components before incorporating pesticides and natural enemies into IPM programs (Fogel *et al.*, 2013). For example, the side effects of neonicotinoid acetamiprid on immature stages of the ladybird beetle *Eriopis connexa* were assayed and the results showed that acetamiprid had reduced egg hatching to 100 %. They also found that the second larval instar was more susceptible to acetamiprid than the fourth one. The survival reduction at larval stage had also reached by 100% at 10% of maximum field concentration. Overall, such results showed a high toxicity of acetamiprid on immature stages of *E. connexa*, indicating that the given pesticide could reduce the efficiency of *E. connexa* in IPM programs (Fogel *et al.*, 2013).

In another study, Rahmani and Bandani (2016) investigated the effects of the LC_{10} and LC_{30} of pirimicarb on demographic parameters of *H. variegata* and demonstrated that pirimicarb had no effects on the predator life parameters (such as developmental time of immature stages, adult longevity, adult pre-oviposition period, and total pre-oviposition period) while the population parameters (intrinsic rate of increase (r_m), net reproductive rate (*R0*), mean generation time (*T*), and finite rate of increase (λ)) had been affected by the mentioned concentrations of pirimicarb. They also concluded that the given pesticide, even at low concentrations, could potentially influence the predatory ladybird. In the same study by Xiao *et al.* (2016), the effects of sub-lethal concentrations (LC_5 and 10% LC_5) of imidacloprid on *Coccinella septempunctata* were evaluated and it was demonstrated that low imidacloprid concentrations had significantly affected the demographic parameters of this predator life. In another study; side effects, acute toxicity and demographic parameters of *Adalia bipunctata* treated with chlorantraniliprole, emamectin benzoate, spinosad, and spirotetramat were evaluated under laboratory conditions by Depalo *et al.* (2017). Overall, spinosad showed the best toxicological influence among the pesticides tested. Emamectin benzoate was also considered as a low-risk insecticide, while chlorantraniliprole exhibited lethal effects on early instar larvae and adults of *A. bipunctata*. Moreover, Spirotetramat had a low impact on larval and adult mortality. Demographic analysis also revealed that chlorantraniliprole and spirotetramat had caused sub-lethal effects in this predator. Correspondingly, Nawaz *et al.* (2017) evaluated the toxicity and sub-lethal effects of the insecticide chlorantraniliprole (Ryanoid class) as well as life table parameter data of *Harmonia axyridis*. Their results further showed that sub-lethal concentrations of chlorantraniliprole had impaired the population growth of *H. axyridis*, and more attention was required to be placed on the application as a component of IPM strategies. Similarly, Saedi *et al.* (2018) investigated the acute toxicity of the field recommended concentrations of diazinon, malathion, chlorpyrifos, and mineral oil on larvae (3rd and 4th instars) and adults of ladybird *Cryptolaemus montrouzieri*. Their results indicated that diazinon and malathion had the highest toxicity in the different stages of *C. montrouzieri*. In addition, their results showed that the adults of *C. montrouzieri* were more susceptible to diazinon than chlorpyrifos once when treated with LC_{50} and LC_{90}.

The impacts of six commonly insecticides were evaluated on *Hippodamia convergens* life parameters by Santos *et al.* (2017). Their results also showed that chlorpyrifos, etofenprox, phosmet, and imidacloprid had a significant effect on the *R0*, r_m, λ, and *T* of this predator. Although these compounds had reduced the demographic parameters of *H. convergens*, the positive mean values of *R0*, r_m and λ indicated that *H. convergens* population was able to increase. Their results also showed that chlorpyrifos, etofenprox, and phosmet had led to harmful effects on *H. convergens* in comparison with the control. Due to the low influence of thiamethoxam and azadirachtin on demographic parameters, it was concluded that these pesticides were less harmful to this predator than other pesticides examined (Santos *et al.* 2017). In another study, Jiang *et al.* (2018) examined the influence of the neonicotinoid clothianidin on *Coccinella septempunctata* at lethal and sub-lethal doses and found that the given pesticide was slightly harmful on *C. septempunctata* at 2.5 g a.i. ha^{-1} and at over this dose, *C. septempunctata* life cycle would be impaired at an over-dose level.

There are numerous studies regarding the side effects of chemical pesticides on natural enemies while the effects of pesticidal plant extracts (botanicals) on non-targeted insects such as predators and parasitoids are rare. In this regard, Mazhawidza *et al.* (2018) investigated the side effects of crude aqueous extracts of *Datura stramonium*, *Bobgunnia madagascariensis*, and *Solanum delagoense* against the *H. variegata*. Their results showed that 25% w/v concentration of *D. stramonium* and *S. delagoense* extracts were relatively safer to *H. variegata* than *B. madagascariensis* and these botanical can be included in IPM programs.

As a conclusion, the results of the current study in line with the mentioned researches confirmed that effective concentrations of pesticides could have deleterious impacts on the physiology of *H. variegata* as a beneficial insect even in the short term which was in contrast with the findings of Papachristos and Milonas (2008). The results of the present study also indicated that imidacloprid and spirotetramat might be incompatible with integrated pest management strategies of *H. variegata* released for the management of the Common pistachio psylla in the orchards. Therefore, much attention was needed during the application of these pesticides in pistachio orchards. As a whole, it was suggested to carry our further to assess the lethal and sub-lethal effects of these common insecticides on behavioral, biological, and demographic parameters of *H. variegata*. Additionally, semi-field and field studies were also needed to determine the impacts of the pesticides on *H. variegata* population dynamics, as well as the residual of pesticides on this predator in IPM programs in the domain of pistachio plantation.

Acknowledgement

Authors acknowledge Pistachio Research Institute and University of Zabol for their valuable help and supplying the equipment for this research.

References

Alimohammadi N, Samih M, Izadi H, Shahidi Noghabi S (2014) Developmental and biochemical effects of hexaflumuron and spirodiclofen on the ladybird beetle, *Hippodamia variegata* Goeze (Coleoptera: Coccinellidae). Journal of Crop Protection. 3(3), 335-344.

Asghari F (2010) Biology and predation of *Hippodamia variegata* Goez (Col.: Coccinellidae) on *Agonoscena pistaciae* Burckhardt and Lauterer in laboratory condition. MSc Thesis of Entomology, College of Agriculture, Vali -e Asr University. pp. 121. (In Persian with English abstract).

Burckhardt D, Lauterer P (1993) The jumping plant lice of Iran (Homoptera, Psylloidea). Revue Suisse De Zoologie, 100(4), 829-898.

Cabral S, Garcia P, Soares AO (2008). Effects of pirimicarb, buprofezin and pymetrozine on survival, development and reproduction of *Coccinella undecimpunctata* (Coleoptera: Coccinellidae). Biocontrol Science and Technology. 18(3), 307-318.

Carey JR (1982) Demography and population Dynamics of the Mediterranean Fruit fly *Ceratitis capitata*. Ecological Entomology. 9, 261-270.

Carey JR (1993) Applied demography for biologists with special emphasis on insects. Oxford University Press New York. pp. 105.

Cortes E (2016) Perspectives on the intrinsic rate of population growth. Methods in Ecology and Evolution. 7(10), 1136-1145.

Croft BA (1990) Arthroptera Biological Control Agents and Pesticides. Wiley, New York. pp. 723.

Depalo L, Lanzoni A, Masett A, Pasqualini E, Burgio G (2017) Lethal and sub-lethal effects of four insecticides on the Aphidophagous Coccinellid *Adalia bipunctata* (Coleoptera: Coccinellidae). Journal of Economic Entomology. 110 (6, 5), 2662-2671.

Desneux N, Dcourtye A, Delpuech JM (2007) The sublethal effectsof pesticides on beneficial arthropods. Annual Review of Entomology. 52, 81-106.

Fogel MN, Schneider MI, Desneux N, González B, Ronco AE (2013). Impact of the neonicotinoid acetamiprid on immature stages of the predator *Eriopis connexa* (Coleoptera: Coccinellidae). Ecotoxicology. 22(6), 1063-1071.

Forbes VE, Calow P (1999) Is the per capita rate of increase a good measure of population-level effects in ecotoxicology? Environmental Toxicology and Chemistry. 18(7), 1544-1556.

Franzmann AB (2002) *Hippodamia variegata* (Goeze) (Coleoptera: Coccinellidae), a predacious ladybird new in Australia. Australian Journal of Entomology. 41, 375-377.

Gordon RD (1987) The first North American records of *Hippodamia variegata* (Goeze) (Col.:

Coccinellidae). Journal of New York Entomology Society. 95, 307-309.

Hodek I (1973) Biology of Coccinellidae: With Keys for Identification of Larvae. Junk, The Hague, The Netherlands. pp. 260.

Jiang J, Zhang Z, Yu X, Ma D, Yu C, Liu F, Mu W (2018) Influence of lethal and sublethal exposure to clothianidin on the seven-spotted lady beetle, *Coccinella septempunctata* L. (Coleoptera: Coccinellidae). Ecotoxicology and Environmental Safety. 16, 208-213.

Krafsur ES, Obrycki JJ, Nariboli P (1996) Gene flow in colonizing *Hippodami avariegata* ladybird beetle populations. Journal of Heredity. 87, 41-47.

Kunkel BA, Held DD, Potter A (2001) Lethal and subletal effect of bendiocarb, halofenozide, and imidacloprid on *Harpalus pennsylvanicus* (Coleoptera: Carabidae) Following different modes of exposure in Turfgrass. Journal of Economic Entomology. 94(1), 60-67.

Maia A, luiz AJB, Cameanhola C (2000) Statistical Inference on associated fertility life table parameters using Jackknife technique: Computational Aspects. Journal Economic Entomology. 93(2), 511-518.

Mazhawidza E, Mvumi BM, Mazarura U (2018) Effects of crude aqueous extracts of indigenous pesticidal plants on the ladybird beetle, *Hippodamia variegata* (Goeze) (Coleoptera: Coccinellidae). International Journal of Tropical Insect Science. 38(2), 159-167.

Medeiros RS, Ramalho FS, Lemos WP, Zanuncio JC (2000) Age dependent fecundity and life fertility tables for *Podisus nigrispinus* (Dallas) (Hest., pentatomidae). Journal Applied Entomology. 124, 319-324.

Mehrnejad MR (2001) The current status of pistachio in Iran. In: Ak B.E. (ed.). XI GREMPA Seminar on Pistachios and Almonds. Zaragoza: CIHEAM, 2001. p. 315-322. (Cahiers Options Méditerranéennes; n. 56). 11. GREMPA Seminar on Pistachios and Almonds, 1999/09/01-04, Sanliurfa (Turkey).

Mehrnejad MR (2002) Bionomics of the common pistachio psylla, *Agonoscena pistaciae*, in Iran. Acta Horticulturae. 591, 535-539.

Mehrnejad MR (2003) Influence of host species on some biological and behavioural aspects of *Dibrachchysboarmiae*, parasitoid of *Kermania pistaciella*. Biocontrol Science and Technology. 13, 219-229.

Mehrnejad MR (2010) Potential biological control agent of the common pistachio psylla, *Agonoscenapistaciae* (Hem.: Psylloidea). Entomofauna. 31, 317-340.

Mehrnejad MR, Jalali MA, Mirzaei R (2011) Abundance and biological parameters of psyllophagous coccinellids in pistachio orchards. Journal of Applied Entomology. 135, 673-681.

Mehrnejad MR, Emami SY (2005) Parasitoids associated with the common pistachio psylla, *Agonoscena pistaciae* in Iran. Biological Control. 32, 385-390.

Nawaz M, Cai W, Jing Z, Zhou X, Mabubu JI, Hua H (2017) Toxicity and sublethal effects of chlorantraniliprole on the development and fecundity of a non-specific predator, the multicolored Asian lady beetle, *Harmonia axyridis* (Pallas). Chemosphere. 178, 496-503.

Obrycki JJ, Kring TJ (1998) Predaceous Coccinellidae in biological control. Annual Review of Entomology. 43, 295-321.

Papachristos DP, Milonas PG (2008) Adverse effects of soil applied insecticides on the predatory coccinellid *Hippodamia undecimnotata* (Coleoptera: Coccinellidae). Biological Control. 47(1), 77-81.

Parish H, Mehrnejad MR, Fallahzadeh M, Basirat M (2013) Thermal requirements and population growth parameters of *Coccinula elegantula*

(Col., Coccinellidae), predator of *Agonoscena pistaciae* (Hem., Psylloidea) in laboratory condition. Journal of Applied Entomology. 7(2), 115-129.

Planes L, Catalán J, Tena A, Porcuna JL, Jacas JA, Izquierdo J, Urbaneja A (2013) Lethal and sublethal effects of spirotetramat on the mealybug destroyer, *Cryptolaemus montrouzieri*. Journal of Pest Science. 86, 321-327.

Rahmani S, Bandani AR (2016). Pirimicarb, an aphid selective insecticide, adversely affects demographic parameters of the aphid predator *Hippodamia variegata* (Goeze) (Coleoptera: Coccinellidae). Journal of Plant Protection Research. 56(4), 353-363.

Rahmani S, Bandani AR (2013) Sublethal concentrations of thiamethoxam adversely affect life table parameters of the aphid predator, *Hippodamia variegata* (Goeze)(Coleoptera: Coccinellidae). Crop Protection. 54, 168-175.

Saedi S, Damavandian MR, Dadpour Moghanloo H (2018) Laboratory evaluation of the toxicity of mineral oil, Diazinon, Malathion and Chlorpyrifos on ladybird *Cryptolaemus montrouzieri* Mulsant (Col.: Coccinellidae). Journal of Crop Protection. 7(1), 1-11.

Samih MA, Alizadeh A, Saberi Riseh R (2005) Pistachio pests and diseases in Iran and their IPM. pp. 301.

Santos KFA, Zanuzo Zanardi O, de Morais MR, Jacob CRO, de Oliveira MB, Yamamoto PT (2017) The impact of six insecticides commonly used in control of agricultural pests on the generalist predator *Hippodamia convergens* (Coleoptera: Coccinellidae). Chemosphere. 186, 218-226.

Singh SR, Walters KFA, Port GR, Northing P (2004) Consumption rate and predatory activity of adult and fourth instar larvae of the seven spot ladybird, *Coccinella septempunctata* (L.), following contact with dimethoate residue and contaminated prey in laboratory arenas. Biological Control. 30, 127-33.

Smith BC (1966) Variation in weight, size and sex ratio of Coccinellid adults (Coleoptera: Coccinellidae). The Canadian Entomology. 98(6), 639-644.

Smith SF, Krischik VA (1999) Effects of systemic imidacloprid on *Coleomegilla maculata* (Coleoptera: Coccinellidae). Environmental Entomology. 28, 1189-1195.

Stark JD, Banks JE (2003) Population-level effects of pesticides and other toxicants on arthropods. Annual Review of Entomology. 48, 505–519.

Xiao D, Zhao J, Guo X, Chen H, Qu M, Zhai W, Desneux N, Biondi A, Zhang F, Wang S (2016) Sublethal effects of imidacloprid on the predatory seven-spot ladybird beetle *Coccinella septempunctata*. Ecotoxicology. 25(10), 1782-1793.