International Journal of Tropical Insect Science (2020) 40:855–867
https://doi.org/10.1007/s42690-020-00142-7

ORIGINAL RESEARCH ARTICLE

Impacts and evaluation of Hormoligosis of some insect growth regulators on *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae)

Muhammad Idrees[1] · Muhammad Dildar Gogi[1] · Waqar Majeed[1] · Arbab Yaseen[1] · Mubashar Iqbal[1]

Received: 11 December 2019 / Accepted: 25 March 2020 / Published online: 12 May 2020

Abstract

Insects when exposed to sublethal applications of pesticides exhibit hormoligosis in their various biological activities. The present research was conducted to evaluate the hormoligosis impacts of IGR's pesticides including pyriproxyfen (Priority 10.8 EC) and lufenuron (Ardent 5 EC) on cotton mealybug in laboratory conditions at IPM Laboratory, Department of Entomology University of Agriculture. The results revealed that concentration-dependent mortality in cotton mealybug of 1st instars and adults was observed that decrease after generations at sub-lethal dilutions of Priority ® and Ardent ® pesticide which retained development of resistance from G1 to G2. Maximum hormoligosis revealed at 3 days post treatments interval (PAI) Priority ® in fecundity at LC_{10} (0.07%) in G5 (63.17 crawlers/female) and at 7 days Priority ® in G5 (68.13 crawlers/female). At 7 days lufenuron of sub-lethal concentration of LC_{10} (0.01%) in G5 (73.18). At 3rd and 7th days post treatments interval Priority® and Ardent® demonstrated maximum hormoligosis in longevity at LC_{10} (0.07%) in G5 (57.29, 57.14 days), (54.07, 58.10 days) respectively, and hormoligosis of sex ratio was not determined against Priority® and Ardent®. We conclude that hormoligosis development is fast at sub-lethal dilutions of Ardent and Priority® at LC_{10}, LC_{20} and LC_{30} with respect to mortality, fecundity, and longevity. While hormoligosis development was fast at sub-lethal dilutions of priority® and ardent® at LC_{30}, LC_{40} and LC_{50} with respect to the mortality of adult female. In Pakistan, pesticide resistance in cotton mealybug can be achieved if the effective and different pesticides are used along with other Integrated Pest Management techniques in rotation and at the early stage of resistance improvement.

Keywords Insect pest · Cotton · Mealybug · Hormoligosis

Introduction

In Pakistan, agriculture is yet the single business which donates 21% GDP and utilizes 44% of the workforce (Govt. of Pakistan 2008). Cotton is significant being a non-nourishment money crop has a huge wellspring of outside professional yield. It is consumed in the textile industry and ranked 2nd among oilseed crops in the world (Khan et al. 2002). *Gossypium hirsutum* characterizes approximately comprised 7.5% in horticulture and 1.6% to domestic power. Its value-added share in agriculture is 7.0% and contributes 1.5% to GDP (Govt. of Pakistan 2013).

✉ Waqar Majeed
waqarchaudhry20@gmail.com

[1] University of Agriculture, Faisalabad, Pakistan

Phenacoccus solenopsis (Hemiptera: Pseudococcidae) (cotton mealybug) is proved to be a common cotton crop pest and found all over the world (Rezk et al. 2019; Mansour et al. 2017), in the year of 2005 it was reported first time from Pakistan (Arif et al. 2013), from India in 2007 (Nagrare et al. 2009) and also from China in 2004 (Wang et al. 2009) that damage different crops (Afzal et al. 2009). Cotton mealybug has been reported to cause 12 to 35% losses in Pakistan (Azeem et al. 2003; Hodgson et al. 2008) and 10 to 60% losses in North and Central zones of the India (Tanwar et al. 2011). This pest is present in hidden spots like galls grass sheaths and damaged crop plants (Saini et al. 2009). Both nymph and adult suck the cell sap from different parts of plant viz. leaves, main stems and fruiting bodies (Aheer et al. 2009). After sucking sap, plants show inhibition and bushy appearance on their shoot tips causes a major loss for farmers. The photosynthetic activity disturbed because of black sooty mould, which occurs due to the pest excreted honeydew. *P. solenopsis* spread all

around more frequently with increasing their numbers because of the short life cycle in minimum duration of time in suitable environmental conditions (Aslam et al. 2011; Saeed et al. 2007). A significant decrease in cotton yield is occurring due to the infestation of mealybug on cotton (Nagrare et al. 2011) and a lot of damage is caused by the *P. solenopsis* worldwide.

Harmful impacts of many compounds such as IGRs, herbs, and bio-pesticides have been reported toward natural enemies, as these are considered as safer to the natural environment (Cabral et al. 2008). As few studies have been reported that the commonly used insecticides induce strange abnormalities in the physiology and functioning of natural enemies such as death rate, disruption in fecundity, and in their behavior (Saber 2011; Sohrabi et al. 2013). Many insecticides were used in the past to control the attack of cotton mealybug and its repeated use pertained the resistance against pesticides. Therefore, a phenomenon is used to minimize the resistance which produces due to the repeated doses of insecticides which are called "Hormoligosis" and the term was used first time in the 1940s. Hormoligosis is a dose-reaction association categorized by misfortune in a reaction between low and high dosages of pesticides (Kendig et al. 2010; Jager et al. 2013). Hormoligosis applications directly stimulate arthropods population outbreaks and it also reported in thrips, mites, aphids and planthoppers.

Insect growth regulators (IGRs) are called bio-rational agents, they attack specific biochemical systems that are unique to insects and safe to non-target e.g. other arthropod species and as well as mammals (Fernandes et al. 2016; Rosell et al. 2008). In the twenty-first century, bio-rational approaches will have a key role in reducing the risks associated with pest management tactics such as pesticides in plant protection and IPM (Ishaaya et al. 2005). The group of pesticides known to be effective at lethal and sublethal concentrations is IGRs and these pesticides used for reasonable results on physiological parameters of exposed treatments (Alizadeh et al. 2012). These fluctuations are at pupil and larval weight (Yin et al. 2008), fecundity, developmental time (Mahmoudvand et al. 2011a), egg size, hatching (Han et al. 2012a), adult endurance (Hamedi et al. 2010; Mahmoudvand et al. 2012), pupal ratio, adult development (Sial and Brunner 2010; Han et al. 2012b) and other biological parameters (Mahmoudvand et al. 2011b; Ahmad and Ansari 2012).

For the sustainable ecosystem, it is dire need of the time to manage the toxicity level of insecticides; so that, they can target their desired pest and induce less damage to the Agro-ecosystem (Paulo et al. 2018). The purpose of present research was to estimate the hormoligosis effect of different biological parameters (mortality, fecundity, female longevity and sex ratio) against cotton mealybug (*P. solenopsis*) by IGRs pesticides (pyriproxyfen and lufenuron) up to two generations.

Materials and methods

The trial was conducted in Integrated Pest Management Laboratory of Entomology Department, UAF Faisalabad by a complete randomized design (CRD). This experiment was conducted to assess the pesticides, usually used in cotton crops due to their compatibility with cotton mealybug. Five various dilution i.e. FRD (Field Recommended Dose), 2 x FRD, 4 x FRD, 8 x FRD, 16 x FRD, ½ x FRD, of two pesticides i.e. Pyriproxyfen (10.8 EC) and Lufenuron (5 EC) were evaluated against the adults female of cotton mealybug to determine their percentage mortality at lethal concentration (LC_{10}, LC_{20}, LC_{30}, LC_{40} and LC_{50}) in the first experiment. Commercial formulation of insecticides pyriproxyfen and lufenuron was used. The hormoligosis of the above-mentioned pesticides was assessed against *P. solenopsis* by using different doses.

Rearing of cotton mealybug

Cotton mealybug population along with infected branch was sampled from cotton plant (*Gossypium)* and shoe-flower (*China rose*) and placed in the transparent plastic-jars. Twenty-five healthy insects were selected from the collected sample and transferred in the jars provided with fresh pumpkins as food for adult female and male individuals. The jars were maintained under laboratory conditions for the mass-culturing of mealybug. The Pumpkin infected with mature mealybug was collected from jars along with the population and transformed it into the new jars containing healthy pumpkin until the required amount of population is achieved (Arif et al. 2016).

Preparation of insecticides solutions

Different solutions of recommended doses of both insecticides were prepared in water with the help of adjustable micropipettes. Five concentrations of each insecticide such as pyriproxyfen and lufenuron and one control group along with three replications were prepared (Table 1). The standard dilution (D-1) of the maximum dose was prepared for each insecticide and the serial solutions were made by taking half of the stock solution and diluting it with distilled water to the original volume in another measuring cylinder to make D-2. Successive solutions were made by this method.

Layout of experiment-I

In this experiment, pumpkin was brought to the IPM laboratory, rinsed with water and kept in the laboratory for complete evaporation. This was done to make the pumpkin free of any kind of contamination. The contamination-free pumpkin was sprayed with each test solution of each insecticide and kept on

Table 1 Concentrations of insecticides test in present experiment

Trade Name	Active Ingredient	Formulation	Company	Concentrations
Priority	Pyriproxyfen	10.8% EC	Orange protection cpvt). Ltd. 23-A, Wahadatroad, muslim town, Lahore Pakistan.	0.25%,0.5%, 1%, 2%, 4%
Ardent	Lufenuron	5% EC	Orange protection cpvt). Ltd. 23-A, Wahadatroad, muslim town, Lahore Pakistan.	0.25%,0.5%, 1%, 2%, 4%

Significant with at alpha = 0.05*, 0.01**, 0.001***

filter paper for drying. An experimental unit having one pumpkin treated with respective insecticides solutions were prepared. Twenty individuals for each concentration were collected from susceptible culture and shifted to insecticides treated pumpkin with the help of a camel hairbrush. The exposed individuals were shifted to petri-dish and carefully observed under a microscope or lens. The individuals showing no movement in their addition of small but repeatedly touch was considered dead. The data of mortality was collected at 3 and 7 days. The data collected of dead individuals was transformed into a percentage corrected mortality by Abbott formula. The mortality data was subjected to Probit analysis to determine the sublethal doses (LC_{10}, LC_{20}, LC_{30}, LC_{40}, LC_{50}). Experiment was repeated up to three replications to remover the error in the data.

Layout of experiment-II

In the second experiment, both nymphs and adult female (1st instar) were collected from the susceptible culture of cotton mealybug and treated them with sub-lethal doses (LC_{10}, LC_{20}, LC_{30}, LC_{40} and LC_{50}) of both insecticides for 3 and 7 days. In this method, two successive generations of an insecticide-exposed population of surviving *P. solenopsis* was treated at a sub-lethal dose of each insecticide with three replications. The data of different parameters such as longevity, mortality, fecundity and sex ratio were collected and analyzed statistically with the appropriate statistical methods.

Statistical analysis

The data on percentage mortality of the adult female was changed into corrected percentage mortality by *Abbott's formula*. The modified mortality figures were also exposed to Probit analysis to find out the lethal concentration (LC_{10}, LC_{20}, LC_{30}, LC_{40} and LC_{50}) of the pesticides (Finney 1971; Danho et al. 2002). To check the significant effect of treatments on the life span of species generalized linear model (GLM) with a binary response (dead/alive) and a binomial distribution was used. The GLM was further tested via the Tukey's test to compare the mean mortality rates among different treatments ($P < 0.01$) (Rovine and Molenaar 2001). All the analysis was done the using Statistica software.

Results

Experiment 1

Adult female of cotton mealybug at different concentrations of pyriproxyfen of post-treatments

Mortality Analysis of variance for percent mortality of adult female of cotton mealybug after 3 and 7 days, showed that whole treatment was significant with differences ($P < 0.001$) at the probability level of 0.05 (Fig. 1). Maximum mortality of cotton mealybug at 3 days was recorded at highest dilution of pyriproxyfen 4% (38.35%) followed by 2% (30.09%), 1% (28.03%), 0.5% (21.50%), 0.25% (12.65%) respectively. Maximum mortality of cotton mealybug for 7 days was recorded at highest dilution of pyriproxyfen 4% (183.37%) followed by 2% (171.66%), 1% (152.57%), 0.5% (132.02%), 0.25% (121.58%) respectively (Table 2).

Fecundity and longevity Whole treatments showed significant results ($P < 0.001$) for longevity and longevity (Fig. 1). Maximum mortality (fecundity) of cotton mealy bug was recorded at highest dilution of pyriproxyfen 4% (91.65%) followed by 2% (77.35%), 1% (65.34%), 0.5% (51.03%), 0.25% (44.95%) respectively. Maximum mortality (longevity) of cotton mealy bug was recorded at highest dilution of pyriproxyfen 4% (33.37%) followed by 2% (27.96%), 1% (24.70%), 0.5% (22.62%), 0.25% (19.56%) respectively (Table 2).

Adult female of cotton mealybug at different dilution of lufenuron after post-treatments

Mortality Mortality of adult female of cotton mealybug after 3 and 7 days, showed that whole treatment had a statistically considerable difference ($P < 0.001$) (Fig. 1). Maximum mortality of cotton mealybug for 3, 7 days was recorded at the highest dilution of lufenuron 4% (35.27%), 4% (95.63%) respectively (Table 2).

Fecundity and longevity Fecundity of adult female of cotton mealy bug showed that whole treatments had significant results ($P < 0.001$) (Fig. 1). Maximum fecundity of cotton mealy

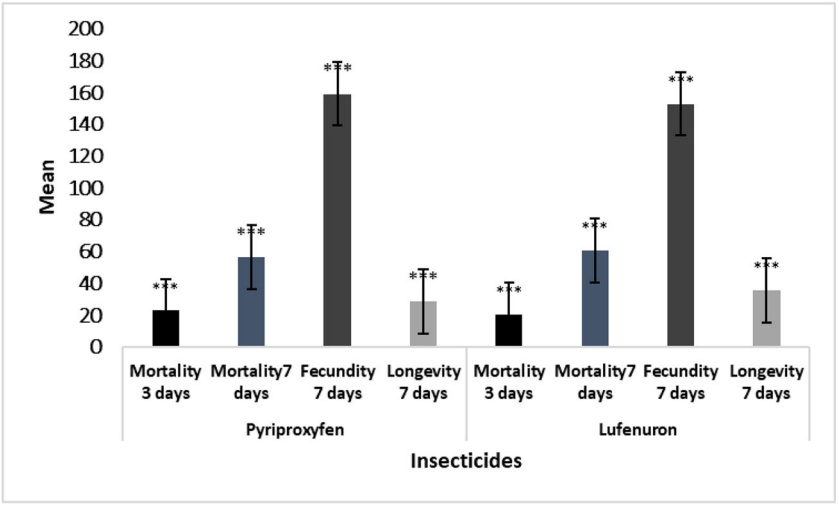

Fig. 1 ANOVA parameters regarding percent mortality of *P. solenopsis* of Pyriproxyfen after 3 and 7 days of post-treatments applications

bug was recorded at highest dilution of lufenuron 4% (170.13%) followed by 2% (158.04%), 1% (143.84%), 0.5% (131.58%), 0.25% (124.49%) respectively. Maximum longevity of cotton mealy bug was recorded at highest dilution of lufenuron 4% (45.69%) followed by 2% (38.56%), 1% (33.42%), 0.5% (26.38%), 0.25% (22.26%) respectively (Table 2).

Pyriproxyfen Laboratory bioassay revealed that after 3 days of exposure of adult female cotton mealybug to the pesticide, pyriproxyfen was the least efficient pesticides due to the highest LC_{10} (0.07 ppm) (0.00–0.19). While after the 7 days exposure of pesticide to the adult female of cotton mealybug, pesticide was the most effective due to the lowest LC_{10} (0.01 ppm) (0.00–0.03). After 3 days of exposure, pyriproxyfen was the least efficient pesticides LC_{20} (0.49 ppm) (0.16–0.82). While after the 7 days exposure, pesticide was the most effective due to the lowest LC_{20} (0.05 ppm) (0.02–0.09). From 3 days of pesticide exposure to cotton mealybug, pyriproxyfen was the least efficient pesticides due to the highest LC_{30} (1.69 ppm) (1.06–3.09). While after the 7 days exposure of pesticide to cotton mealybug, pesticide was the most effective due to the lowest LC_{30} (0.12 ppm) (0.06–0.19). LC_{40} (0.24 ppm) (0.14–0.34) was observed more effective than LC_{40} (4.38 ppm) (2.54–15.16). Pyriproxyfen LC_{50} (9.82 ppm) (4.65–67.03) was least efficient pesticides. While 7 days pesticide was most effective due to the lowest LC_{50} (0.41 ppm) (0.28–0.54) (Table 3).

Lufenuron Laboratory bioassay exposed that after 3 days of pesticide exposure, lufenuron was least efficient due to the highest level LC_{10} (0.05 ppm) (0.00–0.19). While after the 7 days, the pesticide was noted most effective due to the lowest level of LC_{10} (0.01 ppm) (0.00–0.02). At LC_{20} (0.85 ppm)

Table 2 Percent means mortality, fecundity and longevity of adult female of *P. solenopsis* at different concentrations of Pyriproxyfen after 3 and 7 days of post-treatments application

Concentration (%)	Pyriproxyfen				Lufenuron			
	Mortality		Fecundity	Longevity	Mortality		Fecundity	Longevity
	3 days	Post treatments 7 days	Post treatments 7 days	Post treatments 7 days	3 days	Post treatments 7 days	Post treatments 7 days	Post treatments 7 days
	Mean ± S.E	Mean ± S.E	Mean ± S.E	Mean ± S.E	Mean ± S.E	Mean ± S.E	Mean ± S.E	Mean ± S.E
0.25	12.65 ± 0.11^{E}	121.58 ± 1.08^{F}	44.95 ± 0.23^{E}	19.56 ± 1.08^{E}	11.43 ± 0.14^{E}	48.81 ± 0.15^{E}	124.49 ± 1.08^{F}	22.26 ± 1.07^{E}
0.5	21.50 ± 0.32^{D}	132.02 ± 1.23^{E}	51.03 ± 0.37^{D}	22.62 ± 1.19^{DE}	18.13 ± 0.31^{D}	60.25 ± 0.35^{D}	131.58 ± 1.33^{E}	26.38 ± 1.15^{D}
1	28.03 ± 0.43^{C}	152.57 ± 1.37^{D}	65.34 ± 0.57^{C}	24.70 ± 1.31^{CD}	25.37 ± 0.43^{C}	69.71 ± 0.27^{C}	143.84 ± 1.47^{D}	33.42 ± 1.23^{C}
2	30.09 ± 0.23^{B}	171.66 ± 1.51^{C}	77.35 ± 0.61^{B}	27.96 ± 1.47^{C}	26.86 ± 0.34^{B}	82.14 ± 0.43^{B}	158.04 ± 1.54^{C}	38.56 ± 1.45^{B}
4	38.35 ± 0.33^{A}	183.37 ± 1.43^{B}	91.65 ± 0.70^{A}	33.37 ± 1.62^{B}	35.27 ± 0.52^{A}	95.63 ± 0.51^{A}	170.13 ± 1.62^{B}	45.69 ± 1.51^{A}
Control	5.99 ± 0.51^{F}	194.64 ± 1.65^{A}	7.95 ± 0.74^{F}	42.87 ± 1.73^{A}	6.32 ± 0.65^{F}	8.41 ± 0.64^{F}	189.93 ± 1.75^{A}	48.52 ± 1.67^{A}

Means that do not share a letter a significant ($P < 0.05$)

Table 3 LC_{10}, LC_{20}, LC_{30}, LC_{40}, LC_{50} treatments of pesticide pyriproxyfen and lufenuron after 3 and 7 days of exposure to adult female cotton mealybug

Pesticides	Treatment	Days	(ppm)	FD limit	Slope ± S.E	x^2
Pyriproxyfen	LC_{10}	3	0.07	0.00–0.19	0.38 ± 0.09	0.74
		7	0.01	0.00–0.03	0.55 ± 0.07	1.48
	LC_{20}	3	0.49	0.16–0.82	0.38 ± 0.09	0.74
		7	0.05	0.02–0.09	0.55 ± 0.07	1.48
	LC_{30}	3	1.69	0.16–1.82	0.38 ± 0.09	0.74
		7	0.12	0.06–0.19	0.55 ± 0.07	1.48
	LC_{40}	3	4.38	2.54–15.36	0.38 ± 0.09	0.74
		7	0.24	0.14–0.34	0.55 ± 0.07	1.48
	LC_{50}	3	9.82	4.65–67.03	0.38 ± 0.09	0.74
		7	0.41	0.28–0.54	0.55 ± 0.07	1.48
lufenuron	LC_{10}	3	0.21	0.03–0.29	0.38 ± 0.09	0.74
		7	0.05	0.01–0.18	0.54 ± 0.07	2.59
	LC_{20}	3	0.85	0.43–1.30	0.38 ± 0.09	0.74
		7	0.04	0.01–0.08	0.54 ± 0.07	2.59
	LC_{30}	3	2.48	1.62–4.99	0.38 ± 0.09	0.74
		7	0.16	0.04–0.19	0.54 ± 0.07	2.59
	LC_{40}	3	5.59	3.21–19.36	0.38 ± 0.09	0.74
		7	0.18	0.09–0.26	0.54 ± 0.07	2.59
	LC_{50}	3	11.18	5.39–65.19	0.38 ± 0.09	0.74
		7	0.32	0.21–0.43	0.54 ± 0.07	2.59

(0.43–1.30), after 3 days, lufenuron was noted least efficient pesticides. While, after the 7 days exposure of pesticide to the adult females of cotton mealybug, pesticide was the most effective due to the lowest LC_{20} (0.04 ppm) (0.01–0.08). After 3 days, lufenuron was the least efficient pesticides due to the highest LC_{30} (2.48 ppm) (1.62–4.99). While after the 7 days, exposure of pesticides was the most effective due to the lowest LC_{30} (0.09 ppm) (0.04–0.16). 3 days of exposure of lufenuron was the least efficient pesticides due to the highest LC_{40} (5.59 ppm) (3.21–19.36). While after the 7 days exposure of pesticide was most effective due to the lowest LC_{40} (0.18 ppm) (0.09–0.26). lufenuron LC_{50} (11.18 ppm) (5.39–65.19) was least efficient pesticides. While 7 days pesticide was most effective due to the lowest LC_{50} (0.32 ppm) (0.21–0.43) (Table 3).

Experiment 02

Comparison of different dilutions of pyriproxyfen (Priority® 10.8 EC) on different biological parameters (mortality, fecundity, longevity and sex ratio) of *P. solenopsis* after 3rd and 7th days of post-treatment in 1st and 2nd generation.

1st generation The results demonstrated that priority® dependent mortality after 3 days of 1st instar of females of *P. solenopsis,* was significantly of higher mortality (G1 = 48.17%) at higher concentration (LC_{50} = 9.82%). Means table shows that the increase of concentration the mortality of instar and adult females was increased. The maximum fecundity of adult females of *P. solenopsis,* was significantly higher (91.90) in control while minimum fecundity (24.83) was observed at higher concentrations (LC_{50} = 9.82%). Maximum longevity of *P. solenopsis,* being higher (47.85) days in control followed by (38.81 days), while minimum longevity (22.39 days) was observed at higher concentration (LC_{50} = 9.82%). The sex ratio being higher (2.54) at (LC_{10} = 0.07%) followed by others respectively. The results exposed that priority® dependent mortality after 7 days of 1st instar of females *P. solenopsis,* significantly of higher mortality (93.88%) at higher concentration (LC_{50} = 0.41%) followed by (85.45%) Similar trend was observed on the mortality of adult, being significantly higher (77.28%) at higher concentration (LC_{50} = 0.41%). Maximum fecundity was significantly higher (91.78) in control while minimum fecundity (27.67) was observed at higher concentration (LC_{50} = 0.41%). Maximum longevity was higher (38.81 days) in control. The sex ratio was higher (1.55) at (LC_{10} = 0.01%) while minimum sex ratio (1.16) was observed in the control group (Table 4).

2nd generation The results revealed that priority® demonstrated a concentration-dependent mortality after 3 days of 1st instar was significant of higher mortality (53.52%) at higher concentration (LC_{50} = 9.82%) Maximum fecundity was significantly was higher (78.85) in control while minimum (27.07) was observed at higher concentration (LC_{50} = 9.82%). Maximum longevity was higher (56.44 days) in control, while minimum longevity (17.88 days) was observed at higher concentrations (LC_{50} = 9.82%). The sex ratio was higher (2.65) at (LC_{50} = (9.82%) while the minimum sex ratio (2.17) was observed in control. After 7 days, 1st instar females were of significant higher mortality (97.77%) at higher concentrations (LC_{50} = 0.41%). Maximum fecundity was significantly higher (72.53) in control while minimum fecundity (23.57) was observed at higher concentration (LC_{50} = 0.41%). Maximum longevity was higher (35.44 days) in control while minimum longevity (17.84 days) was observed at higher concentrations (LC_{50} = 0.41%). The sex ratio was higher (1.62) at (LC_{50} = 0.41%) while the minimum sex ratio (1.16) was observed in the control group (Table 4).

Means of different concentrations of lufenuron (Ardent® 5 EC) on the different biological parameters (mortality, fecundity, longevity and sex ratio) of *P. solenopsis* after 3rd and 7th days of post-treatment in 1st and 2nd generation.

1st generation The results revealed that ardent® demonstrated concentration-dependent mortality after 3rd days of 1st instar was of higher mortality (48.50%) at higher concentrations

Table 4 Comparison of different dilutions of pyriproxyfen (Priority® 10.8 EC) on the different biological parameters (mortality, fecundity, longevity and sex ratio) of *P. solenopsis* after 3rd and 7th days of post-treatment in 1st and 2nd generation

1st Generation						2nd Generation				
LC values	Percent of Mortality		Fecundity (Crawlers/ female)	Longevity (Days)	Sex ratio	Percent of Mortality		Fecundity (Crawlers/ female	Longevity (Days)	Sex ratio
	1st Instar	Adult female				1st Instar	Adult female			
3 days										
LC_{50} = (9.82%)	48.17 ± 2.44^{A}	38.91 ± 1.03^{A}	24.83 ± 1.85^{F}	22.39 ± 1.09^{F}	2.37 ± 0.66^{E}	53.52 ± 1.94^{A}	43.72 ± 2.14^{A}	27.07 ± 1.64^{D}	17.88 ± 0.84^{F}	2.65 ± 1.21^{A}
LC_{40} = (4.38%)	45.67 ± 1.05^{A}	36.85 ± 0.95^{A}	31.19 ± 2.21^{E}	25.50 ± 2.07^{E}	2.38 ± 1.35^{D}	51.69 ± 1.77^{A}	39.57 ± 1.47^{B}	29.30 ± 0.77^{D}	21.30 ± 0.67^{E}	2.63 ± 1.33^{B}
LC_{30} = (1.69%)	41.39 ± 2.07^{B}	34.50 ± 1.05^{B}	37.41 ± 0.73^{D}	29.69 ± 1.83^{D}	2.39 ± 2.76^{C}	48.58 ± 0.92^{B}	34.81 ± 1.63^{C}	32.70 ± 1.82^{C}	25.51 ± 2.52^{D}	2.60 ± 0.98^{C}
LC_{20} = (0.49%)	37.93 ± 1.81^{C}	28.63 ± 1.64^{C}	43.52 ± 2.31^{C}	34.91 ± 2.43^{C}	2.45 ± 2.55^{B}	45.30 ± 1.63^{C}	30.28 ± 0.74^{D}	35.88 ± 2.63^{B}	29.57 ± 1.73^{C}	2.59 ± 1.42^{B}
LC_{10} = (0.07%)	33.72 ± 0.94^{D}	23.41 ± 2.03^{D}	48.71 ± 1.87^{B}	38.81 ± 1.64^{B}	2.54 ± 1.88^{A}	42.09 ± 0.95^{D}	27.63 ± 1.89^{D}	38.41 ± 0.99^{B}	33.41 ± 0.86^{B}	2.57 ± 0.66^{C}
Control	0.0	0.00	91.90 ± 0.97^{A}	47.85 ± 1.02^{A}	2.15 ± 2.45^{F}	0.0	0.00	78.85 ± 1.39^{A}	56.44 ± 1.49^{A}	2.17 ± 1.53^{D}
7 days										
LC_{50} = (0.41%)	93.88 ± 2.74^{A}	77.28 ± 2.44^{A}	27.67 ± 0.95^{F}	22.29 ± 1.03^{E}	1.43 ± 1.09^{E}	97.77 ± 2.66^{A}	87.63 ± 2.34^{A}	23.57 ± 1.94^{F}	17.84 ± 2.14^{D}	1.62 ± 0.76^{A}
LC_{40} = (0.24%)	85.45 ± 1.83^{B}	71.41 ± 1.33^{B}	33.53 ± 1.34^{E}	25.37 ± 0.98^{D}	1.47 ± 1.77^{D}	91.59 ± 1.44^{B}	82.52 ± 1.57^{B}	27.54 ± 0.97^{E}	19.41 ± 1.67^{CD}	1.57 ± 1.22^{B}
LC_{30} = (0.12%)	77.54 ± 2.18^{C}	65.67 ± 2.11^{C}	39.74 ± 2.14^{D}	27.83 ± 1.09^{CD}	1.49 ± 0.88^{C}	84.69 ± 1.66^{C}	75.40 ± 0.64^{C}	32.43 ± 1.78^{D}	21.30 ± 1.62^{C}	1.56 ± 0.88^{C}
LC_{20} = (0.05%)	70.74 ± 1.66^{D}	59.25 ± 1.93^{D}	44.28 ± 1.69^{C}	30.61 ± 1.63^{BC}	1.51 ± 2.22^{B}	79.47 ± 0.73^{D}	68.28 ± 1.63^{D}	37.49 ± 0.79^{C}	25.18 ± 0.83^{B}	1.55 ± 1.72^{B}
LC_{10} = (0.01%)	64.83 ± 2.73^{E}	53.33 ± 0.99^{E}	48.67 ± 2.43^{B}	33.41 ± 2.03^{B}	1.55 ± 0.76^{A}	73.41 ± 1.59^{E}	63.17 ± 0.83^{E}	42.30 ± 1.89^{B}	28.09 ± 2.29^{B}	1.53 ± 1.07^{C}
Control	0.00	0.00	91.78 ± 1.53^{A}	38.81 ± 0.39^{A}	1.16 ± 1.88^{F}	0.00	0.00	72.53 ± 0.39^{A}	35.44 ± 0.39^{A}	1.16 ± 1.81^{D}

(LC_{50} = 11.18%) Maximum fecundity was significantly higher (91.62) in control, while minimum fecundity (38.84) was observed at higher concentration (LC_{50} = 11.18%). Maximum longevity was higher (47.95 days) in control, while minimum longevity (32.94 days) was observed at higher concentrations (LC_{50} = 11.18%). The sex ratio was higher (2.58) in control, while the minimum sex ratio (2.33) was observed at (LC_{50} = 11.18%). After 7 days of 1st instar was significant of higher mortality (77.50%) at higher concentrations (LC_{50} = 0.32%). Maximum fecundity for adult females was significantly higher (90.69) in control and minimum fecundity (45.27) was observed at higher concentrations (LC_{50} = 0.32%). Maximum longevity was higher (48.50 days) in control, although, minimum longevity (28.39 days) was observed at higher concentrations (LC_{50} = 0.32%). The sex ratio being higher (1.61) in the control group (Table 5).

2nd generation The results revealed that ardent® demonstrated concentration-dependent mortality after 3rd days of 1st instar was significant of higher mortality (53.61%) at higher concentrations (LC_{50} = 11.18%). The maximum fecundity was significantly higher (84.34) for the control group. Maximum longevity was higher (42.47 days) in control while minimum longevity (22.52 days) was observed at higher concentrations (LC_{50} = 11.18%). The sex ratio was noted higher (2.65) in control while the minimum (2.48) was observed at (LC_{10} = 0.07%). After 7th days of 1st instar was significantly higher mortality (83.82%) at higher concentrations (LC_{50} = 0.32%). The maximum fecundity of adult females was significantly higher (87.15) in control while minimum fecundity (43.53) was observed at higher concentrations (LC_{50} = 0.32%). Maximum longevity was noted higher (39.61 days) in control while minimum longevity (22.85 days) was observed at higher concentrations (LC_{50} = 0.32%). The sex ratio was higher (1.59) in control while the minimum sex ratio (1.48) was observed at (LC_{10} = 0.01%) (Table 5).

The results of hormoligosis showed that concentration-dependent mortality of 1st instar and adult of female cotton mealybug was observed to decrease after generations at sub-lethal dilutions of priority® and ardent® pesticide that revealed the development of resistance of G1 and G2 after 3 days and increases after 7 days of interval (Table 6). At 3 day of PAI ardent®, hormoligosis was observed in fecundity at LC_{10} (0.48%) in G1 (54.78 days) and G5 (63.19 days). At 7 days of PAI ardent® at LC_{10} (0.01%) in instar G2 (67.38 days) and in adult G2 (52.17 days) respectively (Table 7). At 3 days post treatments interval (PAI) priority® and ardent® demonstrated hormoligosis was observed in longevity at LC_{10} (0.07%) in G5 (57.29 days), (57.14 days), respectively. At PAI of 7 days priority® and ardent® revealed hormoligosis in longevity at LC_{10} (0.01%) in G5 (57.14 days) and G4 (58.10 days) (Table 8).

Discussion

In the current experiment, insecticides were used to check their effects on the life span of mealybug. The results showed positive effect on the species, whereas, the treatments of insecticides proved a significant effect on all stages (Ganjisaffar et al. 2019). Lufenuron has been registered against pests of thirteen crops including brassicas, citrus, cotton, soybean, tomatoes and wheat (Agrofit 2017). Saddiq et al. (2015) concluded that the cotton mealybug is a devastating pest of cotton and many other ornamental crops and plants (El-Zahi et al. 2016). Tanwar et al. (2011) surveyed cotton mealybug in Rajasthan and Punjab. They observed that *P. solenopsis* infestation occurs mostly in North and Central areas during medium and high range temperature.

The present findings revealed that concentration-dependent percent mortality of 1st instar and adult female was observed to decrease with the decrease of concentration after 3 days of interval while after 7 days interval, the percent mortality was observed to increase when the concentration decreases throughout the generations at different dilutions of priority® and ardent® insecticide which showed that development of resistance is not developed from G1 to G2 (Abbas et al. 2014). Different IGR's insecticide like pyriproxyfen was used against the growth of whitefly, European honeybee and whitefly predators. IGR such as lufenuron was used against the cotton leafworm (Islam et al. 2015) and different genus of wasps (Sattar et al. 2011). Another IGR insecticide fenoxycarb was used against reproduction and metamorphosis of rice moth (Begum and Qamar 2016), immature stages of lacewings (Ayubi et al. 2013), physiological or behavioral activity of *diamondback moth (*Mahmoudvand and Moharramipour 2015) *at different life stages of dusky cotton bug (*Atta et al. 2015).

Earlies research work has concluded that the nuisance of mealybug could be lower using herbal extract (Prishanthini and Vinobaba 2014) biological control (He et al. 2018) and synthetically insecticides (El-Zahi et al. 2016). The current results showed that application of priority® and ardent® at sublethal doses induced hormoligosis which increased significantly throughout the generations ($P < 0.05$). Similar effects were recorded by Vojoudi et al. 2011 that sublethal concentrations LC_{25} of lufenuron strongly affected the life characteristics of spider mite and consequently may influence mite population growth in future generations. Singh et al. 2018 revealed that tested sublethal doses (LC_{10} and LC_{30}) had significant effects on the second instar developmental time of *P. fuscipes* compared with that of the control in which sublethal doses of profenofos negatively affected the development and biological activities of rove beetle. Results of insecticides toxicity are the same as in the present study, Mandal et al. (2013) exposed relative toxicity and baseline data of different insecticides against cotton mealybug. Abbas et al.

Table 5 Means of different dilutions of lufenuron (Ardent® 5 EC) on the different biological parameters (mortality, fecundity, longevity and sex ratio) of *P. solenopsis* after 3rd and 7th days of post-treatment in 1st generation

1st Generation						2nd Generation				
LC values	Percent of Mortality		Fecundity (Crawlers/ female)	Longevity (Days)	Sex ratio	Percent of Mortality		Fecundity (Crawlers/ female)	Longevity (Days)	Sex ratio
	1st Instar	Adult female				1st Instar	Adult female			
3 days										
LC_{50} = (11.18%)	48.50 ± 1.24^{A}	35.57 ± 2.34^{A}	38.84 ± 1.64^{E}	32.94 ± 1.54^{C}	2.33 ± 0.66^{E}	53.61 ± 2.48^{A}	38.63 ± 2.44^{A}	27.72 ± 1.84^{E}	22.52 ± 0.99^{E}	2.62 ± 1.12^{A}
LC_{40} = (5.59%)	44.57 ± 2.37^{B}	33.63 ± 1.57^{A}	41.53 ± 0.77^{E}	35.73 ± 2.57^{C}	2.39 ± 1.35^{D}	50.50 ± 0.77^{B}	35.52 ± 1.87^{B}	30.61 ± 2.34^{E}	24.41 ± 1.37^{DE}	2.58 ± 1.25^{B}
LC_{30} = (2.48%)	39.30 ± 1.42^{C}	31.74 ± 0.82^{B}	45.31 ± 2.12^{D}	38.83 ± 0.62^{B}	2.48 ± 1.11^{C}	45.39 ± 1.67^{C}	33.41 ± 2.42^{B}	35.50 ± 1.34^{D}	27.30 ± 2.33^{CD}	2.55 ± 1.31^{C}
LC_{20} = (0.85%)	35.83 ± 0.53^{D}	28.94 ± 2.43^{C}	50.61 ± 0.76^{C}	41.72 ± 1.78^{B}	2.51 ± 1.05^{B}	40.28 ± 2.33^{D}	30.30 ± 1.53^{C}	39.38 ± 2.56^{C}	30.19 ± 1.89^{BC}	2.53 ± 1.45^{D}
LC_{10} = (0.07%)	31.61 ± 1.79^{E}	22.41 ± 1.99^{D}	53.74 ± 1.69^{B}	45.09 ± 0.87^{A}	2.55 ± 1.02^{A}	37.17 ± 1.49^{E}	27.19 ± 0.99^{D}	43.27 ± 0.97^{B}	33.08 ± 2.55^{B}	2.48 ± 0.76^{E}
Control	0.0	0.00	91.62 ± 2.98^{A}	47.95 ± 1.49^{A}	2.58 ± 1.32^{F}	0.00	0.00	84.34 ± 1.23^{A}	42.47 ± 1.39^{A}	2.65 ± 1.12^{F}
7 days										
LC_{50} = (0.32%)	77.50 ± 1.66^{A}	62.84 ± 0.88^{A}	45.27 ± 1.34^{F}	28.39 ± 1.64^{E}	1.40 ± 1.09^{E}	83.82 ± 0.99^{A}	68.61 ± 2.37^{A}	43.53 ± 2.23^{F}	22.85 ± 2.19^{D}	1.54 ± 0.96^{A}
LC_{40} = (0.18%)	72.62 ± 2.57^{B}	59.29 ± 1.22^{B}	51.37 ± 0.77^{E}	32.73 ± 2.47^{D}	1.42 ± 1.77^{D}	80.71 ± 1.46^{B}	64.50 ± 1.66^{B}	47.33 ± 1.64^{E}	26.74 ± 1.59^{C}	1.52 ± 1.22^{B}
LC_{30} = (0.09%)	68.21 ± 1.65^{C}	54.63 ± 0.66^{C}	55.57 ± 2.62^{D}	36.94 ± 0.72^{C}	1.48 ± 0.88^{C}	76.60 ± 2.45^{C}	60.39 ± 2.13^{C}	51.21 ± 2.44^{D}	29.63 ± 2.11^{C}	1.51 ± 0.78^{C}
LC_{20} = (0.04%)	63.41 ± 0.79^{D}	50.19 ± 2.33^{D}	60.28 ± 1.43^{C}	40.57 ± 1.83^{AB}	1.52 ± 2.22^{B}	71.49 ± 1.77^{D}	56.28 ± 1.45^{D}	55.02 ± 1.55^{C}	33.52 ± 1.45^{B}	1.50 ± 1.47^{D}
LC_{10} = (0.01%)	60.30 ± 1.87^{E}	47.49 ± 1.89^{D}	63.54 ± 0.99^{B}	43.49 ± 0.89^{A}	1.53 ± 0.76^{A}	67.38 ± 2.18^{E}	52.17 ± 0.86^{E}	58.13 ± 2.23^{B}	37.41 ± 2.15^{A}	1.48 ± 1.19^{E}
Control	0.00	0.00	90.69 ± 1.49^{A}	48.50 ± 2.39^{BC}	1.61 ± 1.88^{F}	0.00	0.00	87.15 ± 0.88^{A}	39.61 ± 0.46^{B}	1.59 ± 1.08^{F}

Table 6 Hormoligosis of 1st instar of female cotton mealybug treated by pyriproxyfen and lufenuron at 3 and 7 days of post-application period

Mortality (1st instar)												Mortality (Adult)
Pesticide	Pyriproxyfen (priority® C 10.8 EC)											Pesticide
LC at 3 days	G1	G2	G3	G4	G5	LC at 7 days	G1	G2	G3	G4	G5	LC at 3 days
LC_{50} = (9.82%)	48.17	53.52	38.35	38.25	28.10	LC_{50} = (0.41%)	93.88	97.77	83.50	78.41	63.41	LC_{50} = (9.82%)
LC_{40} = (4.38%)	45.67	51.69	35.83	35.15	25.30	LC_{40} = (0.24%)	85.45	91.59	75.61	73.52	59.52	LC_{40} = (4.38%)
LC_{30} = (1.69%)	41.39	48.58	32.49	32.39	22.41	LC_{30} = (0.12%)	77.54	84.69	67.72	65.59	52.63	LC_{30} = (1.69%)
LC_{20} = (0.49%)	37.93	45.30	29.57	28.85	19.58	LC_{20} = (0.05%)	70.74	79.74	60.38	59.74	48.74	LC_{20} = (0.49%)
LC_{10} = (0.07%)	33.72	42.09	27.42	27.19	17.50	LC_{10} = (0.01%)	64.83	73.41	53.94	52.85	43.85	LC_{10} = (0.07%)
CG	0.00	0.00	0.00	0.00	0.00	CG	0.00	0.00	0.00	0.00	0.00	CG
Pesticide	Lufenuron (ardent® 5 EC)											Pesticide
LC at 3 days	G1	G2	G3	G4	G5	LC at 7 days	G1	G2	G3	G4	G5	LC at 3 days
LC_{50} = (11.18%)	48.50	53.61	43.50	43.41	38.00	LC_{50} = (0.32%)	77.50	83.82	73.41	72.50	63.19	LC_{50} = (11.18%)
LC_{40} = (5.59%)	44.57	50.50	39.58	39.22	34.05	LC_{40} = (0.18%)	72.62	80.71	69.62	69.29	60.29	LC_{40} = (5.59%)
LC_{30} = (2.48%)	39.30	45.39	35.30	35.23	31.01	LC_{30} = (0.09%)	68.21	76.60	65.21	64.20	55.38	LC_{30} = (2.48%)
LC_{20} = (0.85%)	35.83	40.28	30.74	30.41	27.07	LC_{20} = (0.04%)	63.41	71.49	60.50	59.41	50.50	LC_{20} = (0.85%)
LC_{10} = (0.07%)	31.61	37.17	27.52	26.61	23.23	LC_{10} = (0.01%)	60.30	67.38	57.39	56.70	47.39	LC_{10} = (0.07%)
CG	0.00	0.00	0.00	0.00	0.00	CG	0.00	0.00	0.00	0.00	0.00	CG

Mortality (1st instar)	Mortality (Adult)										
Pesticide	Pyriproxyfen (priority® C 10.8 EC)										
LC at 3 days	G1	G2	G3	G4	G5	LC at 7 days	G1	G2	G3	G4	G5
LC_{50} = (9.82%)	38.91	43.72	28.84	28.29	23.39	LC_{50} = (0.41%)	77.28	87.63	67.72	63.63	52.35
LC_{40} = (4.38%)	36.85	39.57	26.88	26.48	20.28	LC_{40} = (0.24%)	71.41	82.52	62.50	59.41	45.45
LC_{30} = (1.69%)	34.50	34.81	22.55	21.57	17.12	LC_{30} = (0.12%)	65.67	75.40	55.39	54.30	40.29
LC_{20} = (0.49%)	28.63	30.28	19.24	19.21	15.21	LC_{20} = (0.05%)	59.25	68.28	49.28	47.19	36.20
LC_{10} = (0.07%)	23.41	27.63	17.60	16.42	12.49	LC_{10} = (0.01%)	53.33	63.17	43.17	42.08	32.09
CG	0.00	0.00	0.00	0.00	0.00	CG	0.00	0.00	0.00	0.00	0.00
Pesticide	Lufenuron (ardent® 5 EC)										
LC at 3 days	G1	G2	G3	G4	G5	LC at 7 days	G1	G2	G3	G4	G5
LC_{50} = (11.18%)	35.57	38.63	28.17	28.08	23.51	LC_{50} = (0.32%)	62.84	68.61	58.81	57.54	52.98
LC_{40} = (5.59%)	33.63	35.52	25.31	24.49	21.60	LC_{40} = (0.18%)	59.29	64.50	54.29	53.18	50.07
LC_{30} = (2.48%)	31.74	33.41	22.74	21.83	19.69	LC_{30} = (0.09%)	54.63	60.39	50.37	49.10	46.17
LC_{20} = (0.85%)	28.94	30.30	19.58	19.94	16.78	LC_{20} = (0.04%)	50.19	56.28	45.19	44.39	41.30
LC_{10} = (0.07%)	22.41	27.19	16.50	16.41	12.87	LC_{10} = (0.01%)	47.49	52.17	42.31	42.28	38.19
CG	0.00	0.00	0.00	0.00	0.00	CG	0.00	0.00	0.00	0.00	0.00

CG Control Group + = Hormoligosis result positive

Table 7 Hormoligosis of fecundity of cotton mealybug treated with Pyriproxyfen and Lufenuron at 3rd and 7th days of post-application period

Fecundity											
Pesticide	Pyriproxyfen (priority® 10.8 EC)										
LC at 3 days	G1	G2	G3	G4	G5	LC at 7 days	G1	G2	G3	G4	G5
LC_{50} = (9.82%)	24.83	27.07	37.80	38.44	47.61	LC_{50} = (0.41%)	27.67	23.57	32.61	33.65	52.58
LC_{40} = (4.38%)	31.19	29.30	39.69	38.59	51.50	LC_{40} = (0.24%)	33.53	27.54	37.69	38.68	56.37
LC_{30} = (1.69%)	37.41	32.70	42.48	41.20	55.39	LC_{30} = (0.12%)	39.74	32.43	41.49	43.31	59.30
LC_{20} = (0.49%)	43.52	35.88	45.39	46.30	60.28	LC_{20} = (0.05%)	44.28	37.49	48.30	49.39	63.22
LC_{10} = (0.07%)	48.71	38.41	48.17	49.08	63.17	LC_{10} = (0.01%)	48.67	42.30	53.08	54.17	68.13
CG	91.90	78.85	75.80	74.40	80.21	CG	91.78	72.53	90.61	92.51	95.18
Pesticide	Lufenuron (ardent® 5 EC)										
LC at 3 days	G1	G2	G3	G4	G5	LC at 7 days	G1	G2	G3	G4	G5
LC_{50} = (11.18%)	38.84	27.72	43.47	44.11	47.78	LC_{50} = (0.32%)	45.27	43.53	52.30	53.39	57.57
LC_{40} = (5.59%)	41.53	30.61	47.33	47.69	51.69	LC_{40} = (0.18%)	51.37	47.33	55.38	56.39	59.48
LC_{30} = (2.48%)	45.31	35.50	50.59	50.62	55.60	LC_{30} = (0.09%)	55.57	51.21	60.12	60.13	63.39
LC_{20} = (0.85%)	50.61	39.38	54.52	54.61	60.52	LC_{20} = (0.04%)	60.28	55.02	64.19	64.28	69.29
LC_{10} = (0.07%)	53.74	43.27	58.19	58.28	63.19	LC_{10} = (0.01%)	63.54	58.13	68.81	69.51	73.18
CG	91.62	84.34	95.34	94.79	96.34	CG	90.69	87.15	95.66	96.11	97.01

CG Control Group + = Hormoligosis result positive

(2014) performed an experiment to check the efficacy of ten pesticides at different concentrations against the *P. solenopsis* and found that insecticides have great influence against cotton mealybug.

In a similar scenario, current research work reported that in Pakistan, the *P. solenopsis* usually developed the resistance in their body against the organophosphate and pyrethroid insecticides (Ejaz et al. 2017). Topical induction of lufenuron and pyriproxyfen have been shown to be highly harmful to first instar larvae, whereas buprofezin, methoxyfenozide and tebufenozide were only slightly harmful (Ono et al. 2017). The resistance level of insecticides has negatively affected the level of improvement on reproductive ability as less improvement was recorded for lab strains with a higher resistance level. Lower hormoligosis response with a higher resistance level could be caused by higher energy investment for

Table 8 Hormoligosis of longevity of cotton mealybug treated with pyriproxyfen and lufenuron at 3rd and 7th days of post application period

Longevity											
Pesticide	Pyriproxyfen (priority® 10.8 EC)										
LC at 3 days	G1	G2	G3	G4	G5	LC at 7 days	G1	G2	G3	G4	G5
LC_{50} = (9.82%)	22.39	17.88	32.51	32.73	46.87	LC_{50} = (0.41%)	22.29	17.84	37.81	38.54	47.47
LC_{40} = (4.38%)	25.50	21.30	35.40	35.45	48.84	LC_{40} = (0.24%)	25.37	19.41	39.70	40.43	49.39
LC_{30} = (1.69%)	29.69	25.51	38.29	37.24	50.78	LC_{30} = (0.12%)	27.83	21.30	41.59	41.77	51.30
LC_{20} = (0.49%)	34.91	29.57	41.18	41.39	54.20	LC_{20} = (0.05%)	30.61	25.18	46.48	47.20	54.17
LC_{10} = (0.07%)	38.81	33.41	43.07	43.18	57.29	LC_{10} = (0.01%)	33.41	28.09	48.37	49.10	57.14
CG	47.85	56.44	45.64	47.77	59.21	CG	38.81	35.44	40.51	40.51	63.08
Pesticide	Lufenuron (ardent® 5 EC)										
LC at 7 days	G1	G2	G3	G4	G5	LC at 7 days	G1	G2	G3	G4	G5
LC_{50} = (11.18%)	32.94	22.52	37.41	38.50	42.59	LC_{50} = (0.32%)	28.39	22.85	37.30	37.65	42.47
LC_{40} = (5.59%)	35.73	24.41	39.74	42.83	45.51	LC_{40} = (0.18%)	32.73	26.74	39.51	40.29	45.38
LC_{30} = (2.48%)	38.83	27.30	42.87	43.81	48.38	LC_{30} = (0.09%)	36.94	29.63	41.74	42.83	49.30
LC_{20} = (0.85%)	41.72	30.19	45.30	46.39	51.19	LC_{20} = (0.04%)	40.57	33.52	45.11	44.47	54.19
LC_{10} = (0.07%)	45.09	33.08	48.09	48.99	54.07	LC_{10} = (0.01%)	43.49	37.41	48.30	47.37	58.10
CG	47.95	42.47	50.84	49.73	52.40	CG	38.50	33.61	52.41	49.08	48.18

CG Control Group + = Hormoligosis result positive

insecticide detoxification (overcompensation theory). However, based on lethal and sublethal effects, pyriproxyfen could be more suitable than lufenuron for management for this pest. Ahmad et al. (2011) conducted an experiment to examine the attack of cotton mealybug with various management treatments to control it. They used to control and treatments design i.e. profenofos, neemosal and fierce in 3 treatments and concluded that profenofos revealed the greatest control than neemosal and fierce on cotton mealybug.

Hanchinal et al. (2011) reported about the occurrence of mealybug from zero scales to four grades and sub-lethal and lethal impacts of some preferred pesticides were also checked by (Nikam et al. 2010). Patel et al. (2010) carried out field experiments consisting of Bt CV cotton, Vikram-5 after randomized block design with four repetitions and six treatments to evaluate the bioefficacy of buprofezin against the cotton mealybug. It was found that the efficacy of buprofezin against *P. solenopsis* in cotton is dose dependent. An experiment was performed in the laboratory to check the biological features and preference of natural enemies of mealybug and observed that the life cycle of a female is longer as compared to males (Zain-ul-Abdin et al. 2012).

Dewer et al. (2016) conducted trial to assess the influence of sub-lethal applications of two pesticides (methomyl and chlorpyrifos) on the physiology of moth and concluded that both chlorpyrifos and methomyl have a universal effect on the insect metabolic approach. Sub-lethal dose of methomyl disturbs the behavior of *S. littoralis* larvae, while chlorpyrifos does not affect the behavior. Ayub et al. (2017) performed an experiment to check the efficacy of different concentrations of IGR's on birth rate and death rate of *P.solenopsis.* Cotton mealybug was cultured in laboratory and females that were newly come up were treated to different concentrations of IGRs e.g. methoxyfenozoid, buperofezin, fenoxycarb, lufenuron and pyriproxyfen. They concluded that pyriproxyfen and lufenuron gives higher mortality pyriproxyfen was a more toxic Insect Growth Regulator against other IGRs.

Conclusion

The use of non-selective insecticides shows a positive result on the control of natural enemies, hence, bringing serious consequences in the pest population dynamics. From the concluded results it is stated that hormoligosis development was fast at sub-lethal dilutions of priority® and ardent® at LC_{10}, LC_{20} and LC_{30} with respect to fecundity and female longevity. While hormoligosis development was fast at sub-lethal dilutions of priority® and ardent® at LC_{30}, LC_{40} and LC_{50} with respect to the mortality of adult females. Priority® has a higher hormoligosis than ardent®. Although, prior to the incorporation of any insecticide into the Integrated Pest Management (IPM) program for the control of pest, it is necessary to check its compatibility with biological control agents. Hereby, we suggest the use of rotation in use of pesticides with different modes of action and spectrums of activity, that can delay the development of resistance, additionally besides IPM strategies.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Abbas G, Hassan N, Farhan M, Haq I, Karar H (2014) Relative suitability of various insecticide for early crop management of cotton against sucking insect pest complex especially dusky cotton bug *Oxycarenus hyalinipennis* (Hemiptera: Oxycarenidae). Pak Entomol 36:129–133

Afzal M, Rahman US, Siddiqui MT (2009) Appearance and management of a new devastating pest of cotton, *Phenacoccus solenopsis* Tinsley, in Pakistan. Beltwide Cott Conf San Antonio, Texas, pp 5–8

Agrofit SAF (2017) Ministério da Agricultura, Pecuária e Abastecimento - Coordenação-Geral de Agrotóxicos e Afins/DFIA/DAS

Aheer GM, Shah Z, Saeed M (2009) Seasonal history and biology of cotton mealybug, Phenacoccus solenopsis Tinsley. J Agric Res 47: 423–431

Ahmad N, Ansari MS, Nazrussalam (2012) Effect of neemarin on life table indices of *Plutella xylostella* (L.). Crop Prot 38:7–14

Ahmad F, Akram W, Sajjad A, Imran AU (2011) Management practices against cotton mealybug, *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae). Int J Agric Biol 13:547–552

Alizadeh M, Karimzadeh J, Rassoulian GR, Farazmand H, Naveh HV, Analogue HR (2012) *Plutella xylostella* (Lepidoptera: Plutellidae): life table study. Arch Phytopathol Plant Protect 45:1741–1763

Arif MJ, Shahid MR, Gogi MD, Arshad M, Khan MA (2013) Studies on biological parameters of an invasive mealybug, *Phenacoccus solenopsis* (Tinsely) (Pseudococcidae: Hemiptera) on different host plants under laboratory conditions. Acad J Entomol 6:55–60

Arif MJ, Gogi MD, Nawaz A, Sufian M, Pasha AM (2016) Impact of male density and food sources on the progeny development of cotton mealybug, *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae). Pak Entomol 38:19–27

Aslam SF, Seni A, Sahoo AK (2011) Biology of the mealybug, *Phenacoccus solenopsis* (Tinsley) (Hemiptera: Pseudococcidae) on sprouted potato and brinjal plant. J Plant Prot Sci 3:32–36

Atta B, Gogi MD, Mustafa F, Adil M, Raza MF, Farooq MA, Abbas MW (2015) Repellency of some insect growth regulators (IGRs) against dusky cotton bug *Oxycarenus hyalinipennis* Costa (Hemiptera: Lygaeidae) under laboratory conditions. Acad J Entomol 8:52–55

Ayub MA, Ayub MM, Gogi MD, Atta B, Farooq MA, Nisar MJ (2017) Impact of different formulations of insect growth regulators on mortality and natality of adult female *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae). J Agric Res 55:651–660

Ayubi A, Moravvej G, Karimi J, Jooyandeh A (2013) Lethal effects of four insecticides on immature stages of *Chrysoper lacarnea* Stephens (Neuroptera: Chrysopidae) in laboratory conditions. Turk J Entomol 37:399–407

Azeem MK, Iqbal M, Soomor MH, Ahmad I (2003) Economic evaluation of pesticide use externalities in the cotton zone of Punjab, Pakistan. Pak Dev Rev 41:683–698

Begum R, Qamar A (2016) Fenoxycarb-a potent inhibitor of metamorphosis and reproduction in Rice moth, *Corcyra cephalonica* (Stainton). J Entomol Zool Stud 4:572–577

Cabral S, Garcia P, Soares A (2008) Effects of pirimicarb, buprofezin and pyrimetrozine in survival, development and reproduction of *Coccinella undecimpunctata* (Coleoptera: Coccinellidae). Biocont Sci Technol 18:307–318

Danho M, Caspar C, Hanbruge E (2002) The impact of grain quantity on the biology of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae): Oviposition, distribution of eggs adult emergence, body weight and sex ratio. J Stored Prod Res 38:259–266

Dewer Y, Pottier MA, Lalouette L, Maria A, Dacher M, Belzunces LP, Kairo G, Renault D, Maibeche M, Siaussat D (2016) Behavioral and metabolic effects of sublethal doses of two insecticides, chlorpyrifos and methomyl, in the Egyptian cotton leafworm, *Spodoptera littoralis* Boisduval (Lepidoptera: Noctuidae). Environ Sci Pollut Res 23:3086–3096

Ejaz M, Afzal MB, Shabbir G, Serrao JE, Shad SA, Muhammad W (2017) Laboratory selection of chlorpyrifos resistance in an invasive Pest, *Phenacoccus solenopsis* (Homoptera: Pseudococcidae): cross-resistance, stability and fitness cost. Pestic Biochem Physiol 137:8–14

El-Zahi EZS, Aref SAES, Korish SKM (2016) The cotton mealybug, *Phenacoccus solenopsis (*Tinsley) (Hemiptera: Pseudococcidae) as a new menace to cotton in Egypt and its chemical control. J Plant Prot Res 56:111–115

Fernandes ME, Alves FM, Pereira RC, Aquino LA, Fernandes FL, Zanuncio JC (2016) Lethal and sublethal effects of seven insecticides on three beneficial insects in laboratory assays and field trials. Chemosphere 156:45–55

Finney DJ (1971) Probit Analysis. Cambridge University Press, Cambridge, p 333

Ganjisaffar F, Sharon A, Andreason TMP (2019) Lethal and sub-lethal effects of insecticides on the pink Hibiscus Mealybug, *Maconellicoccus hirsutus* (Hemiptera: Pseudococcidae). Insects 10:31

Govt. of Pakistan (2008) Economic survey of Pakistan 2007–08. Ministry of Food, Agriculture and Livestock, Federal Bureau of Statistics, Islamabad, p 20

Govt. of Pakistan (2013) Economic survey of Pakistan 2012–13, finance division. Islamabad, Pakistan, pp 17–20

Hamedi N, Fathipour Y, Saber M (2010) Sublethal effects of fenpyroximate on life table parameters of the predatory mite *Phytoseius plumifer*. Biol Control 55:271–278

Han W, Zhang S, Shen F, Liu M, Ren C, Gao X (2012a) Residual toxicity and sublethal effects of chlorantranilip role on *Plutella xylostella* (Lepidoptera: Plutellidae). Pest Manag Sci 68:1184–1190

Han W, Zhang S, Shen F, Liu M, Ren C, Gao X (2012b) Residual toxicity and sublethal effects of chlorantranilip role on *Plutella xylostella* (Lepidoptera: Plutellidae). Pest Manag Sci 68:1184–1190

Hanchinal SG, Patil BV, Basavnagoud K, Nagnagoud A, Biradar DP, Jangudar BS (2011) Incidence of invasive mealybug *Phenacoccus solenopsis* Tinsley on cotton. Karnataka J Agric Sci 24:143–145

He LF, Li P, Xu ZF, Zhou ZS, Xu ZF (2018) Temperature dependent parasitism and development in *Aenasius arizonensis* Girault (Hymenoptera: Encyrtidae), a solitary endo parasitoid of *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae). Int J Pest Manag 64(1):45–50

Hodgson CJ, Abbas G, Arif MJ, Saeed S, Karar H (2008) Phenacoccus solenopsis Tinsley (Sternorrhyncha: Coccoidea: Pseudococcidae), a new invasive species attacking cotton in Pakistan and India, with a discussion on seasonal morphological variation. Zootaxa 1913:1–33

Ishaaya I, Svetlana K, Horowitz AR (2005) Biorational insecticides: mechanism and cross-resistance. Arch Insect Biochem Physiol 58: 192–199

Islam T, Das G, Ali M (2015) Efficacy of lufenuron, a chitin synthesis inhibitor on the mortality of *Spodoptera litura* (Fabricius) under laboratory conditions. J Entomol Zool Stud 3:480–483

Jager T, Barsi A, Ducrot V (2013) Hormesis on life-history traits: is there such a thing as a free lunch? Ecotoxicol 22:263–270

Kendig EL, Le HH, Blecher SM (2010) Defining hormesis: evaluation of a complex concentration-response phenomenon. Int J Toxicol 29: 235–246

Khan MA, Myers GO, Stewart JMD (2002) Molecular markers, genomics and cotton improvement. In: Kang MS (ed) Crop improvement: challenges in the 21st century. Food Products Press, Binghamton, pp 253–284

Mahmoudvand M, Moharramipour S (2015) Sublethal effects of fenoxycarb on the *Plutella xylostella* (Lepidoptera: Plutellidae). J Insect Sci 15:82

Mahmoudvand M, Abbasipour H, SheikhiGarjan A, Bandani AR (2011a) Sublethal effects of indoxacarb on the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae). Appl Entomol Zool 46:75–80

Mahmoudvand M, Abbasipour H, SheikhiGarjan A, Bandani AR (2011b) Sublethal effects of indoxacarb on the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae). Appl Entomol Zool 46:75–80

Mahmoudvand M, Abbasipour H, SheikhiGarjan A, Bandani AR (2012) Change in life expectancy and stable age distribution of the diamondback moth, *Plutella xylostella* (L.) after indoxacarb treatment. J Plant Prot Res 52(3):342–346

Mandal D, Bhowmik P, Halder P, Chatterjee ML (2013) Determination of relative toxicity and baseline data of different insecticides against cotton mealybug (*Phenacoccus solenopsis* Tinsley). J Plant Prot Sci 5:26–31

Mansour R, Grissa-Lebdi K, Suma P, Mazzeo G, Russo A (2017) Key scale insects (Hemiptera: Coccoidea) of high economic importance in a Mediterranean area: host plants, bio-ecological characteristics, natural enemies and pest management strategies – a review. Plant Prot Sci 53:1–14

Nagrare VS, Kranthi S, Biradar VK, Zade NN, Sangode V, Kakde G, Shukla RM, Shivare D, Khadi BM, Kranthi KR (2009) Widespread infestation of the exotic mealybug species, *Phenacoccus solenopsis* (Tinsley) (Hemiptera: Pseudococcidae) on cotton in India. Bull Entomol Res 99:537–541

Nagrare VS, Kranthi S, Dhara RK, Jothji B, Amutha M, Deshmukh AJ, Bisane KD, Kranthi KR (2011) Compendium of cotton mealybugs. Inst Cott. Res, Nagpur, India, pp. 42

Nikam ND, Patel BH, Korat DM (2010) Laboratory and field efficacy of selected insecticides against mealybug *Phenacoccus solenopsis* Tinsley infesting cotton. J Agric Sci 23:712–715

Ono EK, Zanardi OZ, Santos KFA, Yamamoto PT (2017) Susceptibility of *Ceraeochrysa cubana* larvae and adults to six insect growth-regulator insecticides. Chemosphere 168:49–57

Patel MG, Jhala RC, Vaghela NM, Chauhan VR (2010) Bio-efficacy of buprofezin against mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) an invasive pest of cotton. Karnataka J Agric Sci 23:14–18

Paulo RR, Barbosaa MD, Oliveiraa EM, Barrosa JP, Michaudb JBT (2018) Differential impacts of six insecticides on a mealybug and its coccinellid predator. Ecotoxicol Environ Saf 147:963–971

Prishanthini M, Vinobaba M (2014) Efficacy of some selected botanical extracts against the cotton mealybug *Phenacoccus solenopsis* (Tinsley) (Hemiptera: Pseudococcidae). Int J Sci Res Publ 4(3):1–6

Rezk M, Abdel-Nasser TH, Moustafa FE, Nehal S, Youssef D (2019) The impact of insecticides on the cotton mealybug, *Phenacoccus solenopsis* (Tinsley): efficacy on potato, a new record of host plant in Egypt. J Plant Prot Res 59(1):2019

Rosell G, Quero C, Coll J, Guerrero A (2008) Biorational insecticides in pest management. J Pestic Sci 33:103–121

Rovine MJ, Molenaar P (2001) A structural equations modeling approach to the general linear mixed model. J Educ Behav Stat 28:35–167

Saber M (2011) Acute and population level toxicity of imidacloprid and fenpyroximate on an important egg parasitoid, *Trichogramma cacoeciae* (Hymenoptera: Trichogrammatidae). Ecotoxicol 20: 1476–1484

Saddiq B, Shad SA, Aslam M, Ijaz M, Abbas N (2015) Monitoring resistance of *Phenacoccus solenopsis* Tinsley (Homoptera: Pseudococcidae) to new chemical insecticides in Punjab. Pakistan Crop Prot 74:24–29

Saeed S, Ahmad M, Kwon YJ (2007) Insecticidal control of mealybug *Phenacoccus gossypiphillous* (Homoptera: Pseudococcidae), a new pest of cotton in Pakistan. Entomol Res 37:76–80

Saini RK, Ram P, Sharma SS, Rohilla HR (2009) Mealybug, *Phenacoccus solenopsis* Tinsley and its survival in cotton ecosystem in Haryana. In: Proceedings of National Symposium on Bt-cotton: opportunities and prospectus, Cent Inst Cotton Res, Nagpur, pp 17–19

Sattar S, Arif M, Sattar H, Qazi JI (2011) Toxicity of some new insecticides against *Trichogramma chilonis* (Hymenoptera: Trichogrammatidae) under laboratory and extended laboratory conditions. Pak J Zool 43:1117–1125

Sial AA, Brunner JF (2010) Lethal and sublethal effects of an insect growth regulator, pyriproxyfen, on oblique banded leafroller (Lepidoptera: Tortricidae). J Econ Entomol 103:340–347

Singh S, Tiwari RK, Pandey RS (2018) Evaluation of acute toxicity of triazophosand deltamethrin and their inhibitory effect on ache activity in channa puntatus. Toxicol Rep 5:85–89

Sohrabi F, Shishehbor P, Saber M, Mosaddegh MS (2013) Lethal and sublethal effects of imidacloprid and buprofezin on the sweet potato whitefly parasitoid *Eretmocerus mundus* (Hymenoptera: Aphelinidae). Crop Prot 45:98–103

Tanwar RK, Jeyakumar P, Singh A, Jafri AA, Bambawale OM (2011) Survey for cotton mealybug, *Phenacoccus solenopsis* (Tinsley) and its natural enemies. J Environ Biol 32:381–384

Vojoudi S, Saber M, Hejazi MJ, Talaei-Hassanloui R (2011) Toxicity of chlorpyrifos, spinosad and abamectin on cotton bollworm, *Helicoverpa armigera* and their sublethal effects on fecundity and longevity. Bull Insectol 64:189–193

Wang YP, Wu SA, Zhang RZ (2009) Pest risk analysis of a new invasive pest, *Phenacoccus solenopsis* to China. Chin Bull Entomol 46:101–106

Yin XH, Wu QJ, Li XF, Zhang YJ, Xu BY (2008) Sublethal effects of spinosad on *Plutella xylostella* (Lepidoptera: Yponomeutidae). Crop Prot 27:1385–1391

Zain-ul-Abdin AMJ, Gogi MD, Arshad M, Hussain F, Abbas SK, Shaina H, Manzoor A (2012) Biological characteristics and host stage preference of mealybug parasitoid *Aenasius bambawalei* Hayat (Hymenoptera: Encyrtidae). Pak Entomol 34:47–50