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IMPACT OF DIFFERENT FORMULATIONS OF INSECT GROWTH REGULATORS ON MORTALITY AND NATALITY OF ADULT FEMALE *PHENACOCCUS SOLENOPSIS* (HEMIPTERA: PSEUDOCOCCIDAE)

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ABSTRACT

A study was conducted in the Integrated Pest Management Laboratory, Department of Entomology, University of Agriculture, Faisalabad, Pakistan, during 2014 to evaluate the effect of different formulations of some insect growth regulators (IGRs) on mortality and natality of *Phenacoccus solenopsis*. P. solenopsis was raised in the laboratory conditions and newly emerged females were exposed to five different concentrations of each of five selected IGRs i.e. Buprofezin, Lufenuron, Fenoxycarb, Pyriproxyfen and Methoxyfenozide. The experiment was carried out in completely randomized design repeated thrice. In all IGRs, maximum mortality rate was recorded in Buprofezin (32.0%). The results revealed that Buprofezin was the most toxic IGR as compared to the other IGRs. The *P. solenopsis* treated with Buprofezin laid 303.7 eggs/female, which was significantly higher as compared to other IGRs. The highest reproductive period was observed in those *P. solenopsis* which were treated with Buprofezin (30.7 days). Maximum incubation period of *P. solenopsis* was observed in the eggs treated with Buprofezin (52.1 minutes). The treated eggs of *P. solenopsis* with different IGRs showed significant difference in eggs hatchability. The highest eggs hatchability was observed in Methoxyfenozide (57.9%). Highest mortality of *P. solenopsis* (31.7%) was observed in leaf dip method. Highest reproductive period (29.9 days) and eggs hatchability (52.5%) were observed in topical application method. Maximum eggs laid by female (298.1 eggs/female) and incubation period (50.1 minutes) were observed in gourd treatment method.

KEYWORDS: *Gossypium hirsutum;* cotton; pest insects; *Phenecoccus solenopsis;* mortality; natality; reproductive period; incubation period; eggs hatchability; insect growth substances; performance; Pakistan.

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INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is main fibre crop, referred as "White Gold". It is consumed in textile industry and ranked 2nd among oilseed crops in the world (Khan *et al.,* 2002). It is one of the major crops cultivated in Pakistan which plays an important role in foreign exchange earnings of the country. Its value added share in agriculture is 7.0% and contributes 1.5% to GDP (Govt. of Pakistan, 2013). It fulfills human food requirements as edible oil, supplies seed cake for animals and sticks use as a fuel for domestic purpose. Cotton based textile industries mainly contribute over 60% to the total exports, 46% to the total manufacturing and 40 percent to labor force employment sector. It provides raw material to the textile mills as well as garment factories and is helpful in production of domestic edible oil or cotton cake which is fed to the animals (Altaf, 2008).

As compared to other advanced cotton producing countries, average per hectare yield in Pakistan is very low which is attributed to many reasons but infestation of insect/pests is the major cause of low yield (PCCC, 2006). Insect/pests spectrum of 1326 sucking or chewing on cotton crop has been reported worldwide and 130-145 species of insect/pests and mites are of prime importance from seedling to maturity (Bo, 1952).

Cotton yield of seed cotton is reduced because of severe attack of sucking insect/pests and bollworms which cause 20-40% yield losses in Pakistan approximately (Ahmad, 1999). Jassid, *Amarasca devastans* is an important sucking

insect/pest while other common sucking insect/ pests are whitefly (*Bemisia tabaci)*, cotton thrips *(Thrips tabaci)*, dusky cotton bug (*Oxycarenus hyalinipennis)*, cotton aphid *(Aphis gossypii)* and cotton mealybug *(Phenacoccus solenopsis)* (Khan *et al.,* 1987).

Phenacoccus solenopsis is a destructive pest of many profitable crops including vegetables, fruits, field crops and ornamental plants of more than 149 plant species (Afzal *et al.,* 2009). *P. solenopsis* damages the plant by feeding on food transport channel and sucking cell sap that results in leaves distortion (Aheer *et al.,* 2009). Its nymphs and adult females also secrete sticky honey dew on the plant surface on which sooty mould grows which reduces the food synthesis process (photosynthesis) in plants (Saeed *et al.,* 2007). It severely infested cotton crop and appeared as its potential pest in Pakistan during 2005 and also caused 14-30% loss to cotton crop (Hodgson *et al.,* 2008). In Pakistan, *P. solenopsis* has been tried to be controlled by application of insecticides in the form of cover spray (Saeed *et al.,* 2007).

Insect growth regulators (IGRs) are called bio-rational agents because these attack on specific biochemical systems that are unique to arthropods and these are safe to non-target organisms particularly mammals (Rosell *et al.,* 2008). In 21st century, bio-rational approaches will have the key role in reducing the risks associated with pest management tactics such as pesticides in plant protection and IPM strategies (Ishaaya *et al.,* 2005). IGRs are very diverse group of insecticides; these mainly affect the development of immature stages, disrupt metamorphosis and reproduction (Graf, 1993) i.e. becoming more important in the management of insect/pests (Grenier and Grenier, 1993).

Keeping in view above-mentioned facts, present study was designed to evaluate the effect of various formulations of five insect growth regulators including two chitin synthesis inhibitors (Leufenuron and Buprofezin), two juvenile hormone mimics (Fenoxycarb and Pyriproxyfen**)** and one moulting hormone agonist **(**Methoxyfenozide) on mortality and natality of *P. solenopsis* so that highly effective IGRs could be screened out against *P. solenopsis*.

MATERIALS AND METHODS

This study was carried out in the Integrated Pest Management Laboratory, Department of Entomology, University of Agriculture, Faisalabad, Pakistan during year 2014. The experiment was laid out in completely randomized design under factorial analysis and each treatment was repeated thrice. For this study, following materials and methods were used.

Rearing and collection of *P. solenopsis*

A population of *P. solenopsis* was collected from unsprayed infested cotton fields of the experimental area of the Department. Twigs of cotton plants infested with reproducing adult females of *P. solenopsis* were brought to the laboratory. Then the individual females were separated and fed on fresh tender cotton leaves in petri plates. These leaves were collected from unsprayed cotton fields and washed thoroughly with distilled water before offering. The petioles of the leaf were wrapped with wet cotton wool to keep them turgid for longer period. Such leaves were placed individually in petri dish and *P. solenopsis* were reared on these leaves in said dish.

Insect growth regulators and preparation of their different concentrations

Five IGRs (Buprofezin, Lufenuron, Pyriproxyfen, Fenoxycarle and Methoxyfenozide) were purchased from the market. Five different concentrations of each of these IGRs were prepared by adding water (Table 1). The 100ml of stock solution of the highest concentration (0.1%) for each IGR was prepared in 250ml beaker. The next lower concentration was prepared by getting 125ml of the stock solution and making its volume to 250ml again. The rest of concentrations were prepared by taking 125ml of previous concentration and dissolving it into 125ml water to get 250ml volume. Each concentration of respective IGR was evaluated by three methods including leaf-disc, topical-application and gourd-treatment bioassay method.

Table 1. Detail of IGRs treatments.

Insecticide name/Active ingredient	Brand name	Recommended dose	Concentrations
Buprofezin	Buprofezin® 25% WP	600 g/acre	0.1, 0.05, 0.025, 0.0125 and 0.00625%
Lufenuron	Silent® 5% EC	200 ml/acre	-do-
Fenoxycarb	Fenoxycarb® 10 EC	220 ml/acre	-do-
Pyriproxyfen	Priority® 10.8 EC	500 ml/acre	-do-
Methoxyfenozide	Runner® 24% SC	120 ml/acre	-do-

Evaluation of IGRs by leaf-disc bioassay method

Five different concentrations of each IGR and water spray as control treatment were applied on cotton leaves disc (7 inch diameter) with atomizer till drift. Then the treated leaves were allowed to dry under fan at room temperature (30 ± 2 ºC). Ten newly emerged laboratory reared females of *P. solenopsis* (alongwith five males) were released on each treated leaf-disc and enforced for feeding. After three days of exposure, five female *P. solenopsis* were isolated and released on fresh untreated cotton leaves. The rest five females were forced to feed on treated leaves till death. The surviving females were kept under observation till death in both cases. The number of dead females was counted and percentage of their mortality was calculated by the formula mentioned below:-

$$\text{Mortality (\%)} = \frac{\text{Pre-treatment population of P. solenopsis}}{\text{Post-treatment population of P. solenopsis}} \times 100$$

The leaves were kept turgid for longer period as described earlier. The individual leaf was kept in glass petri dish and observed daily with microscope till eggs laying. The time of eggs laying was noted. The number of eggs laid by females of *P. solenopsis* inside the egg-sac in both cases was examined under binocular microscope. The laid eggs were counted and transferred on fresh cotton leaves. Time taken for eggs hatching was recorded to compute incubation period. The number of offsprings (1st instar nymphs) emerging from the eggs was also counted to determine the egg's hatchability (hatching percentage of eggs) by the formula mentioned below:

$$\text{Eggs hatchability (\%)} = \frac{\text{Number of eggs hatched out}}{\text{Total number of eggs kept under observation}} \times 100$$

Evaluation of IGRs by topical-application bioassay method

Five different concentrations of each IGRs and water spray as control treatment were applied on oval body of ten newly emerged female *P. solenopsis* with hand atomizer drift. The treated females were kept at room temperature (30 ± 2 ºC) and provided with untreated pumpkin as food for three days. After three days of exposure, ten newly emerged male *P. solenopsis* were isolated from the culture and released in each treatment. The surviving females were kept under observation till death. The number of dead females was counted and percentage of mortality was calculated by the above mentioned formula.

The females were observed daily till egg laying. The time of eggs laying was recorded. The number of eggs laid by females of *P. solenopsis* inside the egg-sac was examined under binocular microscope. The laid eggs were counted and transferred to fresh cotton leaves. Time taken for eggs hatching was recorded to compute incubation period. The number of offsprings (1st instar nymphs) emerging from the eggs was counted to determine the egg's hatchability (hatching percentage of eggs) by the above mentioned formula.

Evaluation of IGRs by gourd-treatment bioassay method

In this method, each treatment unit was consisted of half pumpkin. The seeds and pulpy portion of the pumpkin were removed in such a way that only one inch thick top-surface of the pumpkin was left over. The solution of each concentration was filled in specially prepared one inch thick half pumpkin and kept for 24 hours i.e. one day. After 24 hours, the solution was removed from the treatment unit (one inch thick half pumpkin) that was then exposed to ten newly emerged laboratory reared f

females of *P. solenopsis* (alongwith five males) for forced feeding. After three days of exposure, five females of *P. solenopsis* were isolated and released on fresh untreated pumpkin. The rest five females were forced to feed on treated pumpkin till death. The surviving females were kept under observation till death in both cases. The number of dead females was counted and percentage of mortality was calculated by the formula mentioned earlier.

The pumpkins were observed daily till egg laying started in the form of egg-sacs. The time of eggs laying was noted. The egg-sacs produced were counted till the death of female *P. solenopsis*. The number of eggs laid by females of *P. solenopsis* inside the egg-sac in both cases were examined under binocular microscope. The laid eggs were counted and transferred to fresh cotton leaves. Time taken for eggs hatching was recorded to compute incubation period. The number of offsprings (1st instar nymphs) emerging from the eggs was counted to determine the egg's hatchability (hatching percentage of eggs) by the formula mentioned above.

Statistical analysis

Data regarding percent mortality and natality (number of ovisacs/female, nymphs/ovisac or nymphs/female) were collected and subjected to ANOVA technique for the determination of parameters of significance and mean values for different treatments. The means of significant treatments were then compared by Tukey's Honesty Significant Difference (HSD) test fitting probability value of 5% (Danho and Hanbruge, 2002). The mortality data were also subjected to Probit analysis to determine LC_{50}, chi-square and confidence interval values for each IGR (Finney, 1971).

RESULTS AND DISCUSSION

Mortality of *P. solenopsis*

Maximum (32.0%) and minimum (12.2%) mortality was observed, when adult female *P. solenopsis* was treated with Buprofezin and Fenoxycarb, respectively (Table 2). The results revealed that Buprofezin was the most toxic IGR followed by Pyriproxyfen, Methoxyfenozide, Lufenuron and Fenoxycarb. The highest mortality of *P. solenopsis* was observed in leaf dip method (31.7%) (Table 3). Regardless of IGRs, the concentrations dependent trend was observed in the mortality of *P. solenopsis*. As the concentration of IGRs increased, the mortality rate also increased and vice versa. At highest concentration (0.1%) of IGRs, mortality of *P. solenopsis* was 42.2% (Table 4). The interaction between IGRs and application methods demonstrated significant variations in the mortality of *P. solenopsis.* Buprofezin caused 45.0, 25.0 and 26.1% mortality of *P. solenopsis* in leaf dip method, topical application method and gourd treatment method, respectively (Table 5). The mortality rate increased with increasing concentration of IGRs. In Buprofezin the highest mortality (57.8%) was observed at highest concentration (0.1%) and lowest mortality (18.9%) at lowest concentration (0.00625%) (Table 6). Leaf dip method showed promising results of adult female *P. solenopsis* mortality as compared to the other methods. At highest concentration (0.1%), the leaf dip method caused 57.3% mortality while the topical application and gourd treatment method caused 30.7 and 38.7% mortality, respectively (Table 7).

These results are in line with those of Gogi *et al.* (2006) who evaluated the efficacy of two insect growth regulators i.e. Buprofezin and Lufenuron against whitefly, *Bemisia tabaci*. They noted a significant decrease in the populations of *B. tabaci* by both IGRs; higher doses gave more efficient results than lower doses. Both IGRs proved to be harmless at low doses to predator populations. However, present results are in contradiction with the results of Nasr *et al.* (2010) who studied the lethal and sublethal effects of two IGRs Buprofezin and Pyriproxyfen on newly molted second-instar larvae of *S. littoralis* through incorporation in artificial diet. They recorded mortality in Pyriproxyfen higher than Buprofezin. Pyriproxyfen had very good anti-feedant property at higher concentrations but Buprofezin showed non-significant anti-feedant property at higher concentrations.

Table 2. Impact of different IGRs on the mortality and natality of adult female *P. solenopsis*

IGRs	Mortality of adult female *P. solenopsis* (%)	Mean no. of eggs laid per female ± S.E	Mean of reproductive period (Days)	Incubation period (Minutes)	Eggs hatchability (%)
Buprofezin	32.0 ± 0.31 a	303.7 ± 3.15 b	30.7 ± 0.39 a	52.1 ± 0.47 a	43.1 ± 3.78 d
Lufenuron	17.6 ± 0.22 c	298.7 ± 3.03 bc	30.0 ± 0.28 ab	49.3 ± 0.39 b	49.7 ± 3.27 c
Fenoxycarb	12.2 ± 0.18 d	293.4 ± 2.19 bc	29.7 ± 0.26 ab	49.0 ± 0.51 b	57.7 ± 2.90 b
Pyriproxyfen	23.1 ± 0.28 b	301.0 ± 1.86 b	29.6 ± 0.30 ab	46.2 ± 0.20 c	43.7 ± 3.49 d
Methoxyfenozide	18.3 ± 0.22 c	290.6 ± 1.40 c	28.5 ± 0.27 ab	49.3 ± 0.52 b	57.9 ± 3.00 b
Control	0.00 ± 0.00 e	383.1 ± 1.27 a	28.4 ± 0.26 b	46.2 ± 0.19 c	90.7 ± 3.52 a

Means of mortality and natality with different alphabets are significantly different from each other at 5% probability level by Tucky's HSD test.

Table 3. Impact of different application methods on the mortality and natality of adult female *P. solenopsis.*

Application methods	Mortality of adult female *P. solenopsis* (%)	Mean no. of eggs laid per female ± S.E	Mean of reproductive period (Days)	Incubation period (Minutes)	Eggs hatchability (%)
Leaf dip method	31.7 ± 0.22 a	297.1 ± 1.90 c	29.8 ± 0.23 a	48.9 ± 0.38 b	49.3 ± 2.66 b
Topical application method	12.8 ± 0.14 c	297.1 ± 1.90 c	29.9 ± 0.24 a	48.6 ± 0.35 b	52.5 ± 2.50 c
Gourd treatment method	17.6 ± 0.17 b	298.1 ± 1.95 b	29.4 ± 0.24 a	50.1 ± 0.40 a	49.5 ± 2.70 b
Control	0.00 ± 0.00 d	396.2 ± 1.99 a	29.2 ± 0.24 a	48.5 ± 0.34 b	98.3 ± 2.84 a

Means of mortality and natality with different alphabets are significantly different from each other at 5% probability level by Tucky's HSD test.

Table 4. Impact of different concentrations on mortality and natality of adult female *P. solenopsis,* regardless of IGRs

Concentrations (%)	Mortality of adult female *P. solenopsis* (%)	Mean no. of eggs laid per female ± S.E	Mean of reproductive period (Days)	Incubation period (Minutes)	Eggs hatchability (%)
0.1	42.2 ± 0.23 a	312.2± 3.15 b	31.1 ± 0.38 a	50.7 ± 0.66 a	27.9 ± 0.84 f
0.05	33.5 ± 0.22 b	309.8± 2.34 bc	31.2 ± 0.40 a	51.0 ± 0.61 a	32.9 ± 0.95 e
0.025	24.4 ± 0.23 c	301.1± 2.03 c	30.0 ± 0.26 ab	49.6 ± 0.56 b	38.5 ± 1.05 d
0.0125	15.8 ± 0.20 d	293.4 ± 1.93 cd	29.3 ± 0.19 b	48.7 ± 0.46 bc	48.3 ± 1.58 c
0.00625	8.00 ± 0.16 e	285.4± 1.83 d	28.7 ± 0.23 bc	47.9 ± 0.39 cd	56.6 ±1.73 b
Control	0.00 ± 0.00 f	383.1± 1.07 a	27.7 ± 0.30 c	47.2 ± 0.26 d	98.3 ± 0.20 a

Means of mortality and natality with different alphabets are significantly different from each other at 5% probability level by Tucky's HSD test.

Table 5. Impact of different IGRs in interaction with application methods on the mortality and natality of adult female *P. solenopsis*

Parameters	Methods	IGRs				
		Buprofezin	Lufeneuron	Fenoxycarb	Pyriproxyfen	Methoxyfenozide
Mortality	LDM	45.0 ± 0.59a	26.7 ± 0.52cd	21.1 ± 0.30def	37.2 ± 0.24b	28.3 ± 0.26c
	TAM	25.0 ± 0.42cde	10.5 ± 0.43hi	5.5 ± 0.18i	12.8 ± 0.55gh	10.0 ± 0.40hi
	GTM	26.1 ± 0.36cd	15.5 ± 0.38fgh	10.0 ± 0.32hi	19.4 ± 0.35ef	16.7 ± 0.33fg
	Control	0.00 ± 00j	0.00 ± 00j	0.00 ± 00j	0.00 ± 00j	0.00 ± 00j
Number of eggs laid by female	LDM	305.5 ± 5.23a	295.3 ± 5.22ab	286.8 ± 3.30c	305.9± 3.12a	292.2± 1.86b
	TAM	295.3 ± 5.22ab	305.5 ± 5.23a	305.9 ± 3.12a	292.2 ± 1.86b	286.8 ± 3.30c
	GTM	309.9 ± 5.64a	295.3 ± 5.22ab	287.5 ± 3.24c	304.9 ± 3.51ab	292.8 ± 1.61ab
	Control	0.00 ± 00d	0.00 ± 00d	0.00 ± 00d	0.00 ± 00d	0.00 ± 00d
Reproductive period	LDM	30.6 ± 0.74a	30.5 ± 0.47a	28.8 ± 0.41b	29.1 ± 0.42b	29.9 ± 0.42a
	TAM	30.6 ± 0.74a	30.1 ± 0.53a	30.4 ± 0.47a	29.2 ± 0.42b	29.2 ± 0.44a
	GTM	30.8 ± 0.55a	29.2 ± 0.42b	30.0 ± 0.45a	30.4 ± 0.67a	26.3 ± 0.54b
	Control	0.00 ± 0.00c	0.00 ± 0.00c	0.00 ± 0.00c	0.00 ± 0.00c	0.00 ± 0.00c
Incubation period	LDM	52.5 ± 0.89a	51.2 ± 0.76a	48.3 ± 0.54bc	46.4 ± 0.37bc	45.8 ± 0.32c
	TAM	51.2 ± 0.76a	48.3 ± 0.54bc	46.4 ± 0.37bc	45.8 ± 0.32c	51.2 ± 0.76a
	GTM	52.5 ± 0. 76a	48.5 ± 0.52b	52.3 ± 0.98a	46.3 ± 0.36c	50.8 ± 0.90a
	Control	0.00 ± 0.00d	0.00 ± 0.00d	0.00 ± 0.00d	0.00 ± 0.00d	0.00 ± 0.00d
Egg hatchability	LDM	43.3 ± 6.46g	48.1 ± 5.91de	56.0 ± 5.17b	42.1 ± 6.36g	57.0 ± 5.46h
	TAM	46.2 ± 6.08ef	51.5 ± 5.56a	59.5 ± 4.93a	45.7 ± 5.92f	59.7 ± 5.11a
	GTM	39.9 ± 7.66h	49.4 ± 5.82d	57.6 ± 5.22b	43.5 ± 6.19g	57.0 ± 5.28b
	Control	0.00 ± 0.00i	0.00 ± 0.00i	0.00 ± 0.00i	0.00 ± 0.00i	0.00 ± 0.00i

Means of mortality with different alphabets are significantly different from each other at 5% probability level by Tucky's HSD test, LDM = Leaf Dip Method; TAM = Topical Application Method; GTM = Gourd Treatment Method.

Table 6. Impact of different concentrations of IGRs on the mortality and natality of adult female *P. solenopsis*.

Parameters	IGRs	Concentrations (%)					
		0.1	0.05	0.025	0.0125	0.00625	Control
Mortality	Buprofezin	57.8 ± 0.43a	50.0 ± 0.53ab	37.8±0.52de	27.8 ± 0.36gh	18.9 ± 0.40ijk	0.00 ± 0.00n
	Lufeneuron	41.1 ± 0.35cd	26.7 ± 0.33ghi	21.1±0.42hij	12.2 ± 0.36klm	04.4 ± 0.24mn	0.00 ± 0.00n
	Fenoxycarb	28.9 ± 0.42fgh	22.2 ± 0.32hi	12.2±0.36klm	06.7 ± 0.28lmn	03.3 ± 0.23n	0.00 ± 0.00n
	Pyriproxyfen	46.7 ± 0.47bc	37.8 ± 0.52de	27.8±0.52gh	18.9 ± 0.48ijk	07.8 ± 0.40lmn	0.00 ± 0.00n
	Methoxyfenozide	36.7 ± 0.47def	31.1 ± 0. 35efg	23.3±0.33ghi	13.3 ± 0.33jkl	05.5 ± 0.29lmn	0.00 ± 0.00n
Number of eggs laid by female	Buprofezin	327.4 ± 6.36a	321.8 ± 6.32ab	303.7±6.34b	299.9 ± 5.39bc	285.0 ± 5.10c	0.00 ± 0.00d
	Lufeneuron	311.8 ± 8.74ab	318.3 ± 6.20a	306.8±6.02b	294.0 ± 4.94bc	281.2 ± 4.23c	0.00 ± 0.00d
	Fenoxycarb	306.4 ± 6.25a	307.7 ± 4.01a	296.1±3.21ab	287.7 ± 3.72b	282.8 ± 4.35c	0.00 ± 0.00d
	Pyriproxyfen	302.9 ± 6.40ab	313.4 ± 4.01a	306.1±3.56b	299.0 ± 2.68bc	295.1 ± 2.71c	0.00 ± 0.00d
	Methoxyfenozide	300.2 ± 4.11a	298.9 ± 1.81ab	293.2±1.61b	286.4 ± 2.97bc	282.7 ± 2.52c	0.00 ± 0.00d
Reproductive period	Buprofezin	32.9 ± 1.12a	33.0 ± 0.90ab	31.1±0.63abcde	29.0 ± 0.44cde	28.7 ± 0.52cde	0.00 ± 0.00f
	Lufeneuron	31.5 ± 0.86abc	31.4 ± 0.91abcd	29.1±0.52cde	29.8 ± 0.48bcde	28.7 ± 0.40cde	0.00 ± 0.00f
	Fenoxycarb	29.5 ± 0.74cde	31.7 ± 0.55abc	30.3±0.88abcde	29.4 ± 0.50cde	29.0 ± 0.41cde	0.00 ± 0.00f
	Pyriproxyfen	30.3 ± 0.41abcde	31.2 ± 0.33abcde	29.8±1.12bcde	29.1 ± 0.74cde	28.2 ± 0.42e	0.00 ± 0.00f
	Methoxyfenozide	31.4 ± 0.75abcd	28.9 ± 0.76cde	29.5±0.48cde	29.3 ± 0.52cde	29.1 ± 0.52cde	0.00 ± 0.00f
Incubation period	Buprofezin	56.7 ± 0.44a	54.3 ± 0.47ab	53.1±0.71abc	51.0 ± 0.76bcdef	49.3 ± 0.62defghi	0.00 ± 0.00l
	Lufeneuron	51.4 ± 1.29bcde	51.3 ± 0.57bcde	49.7±0.62cdefgh	48.5±0.80defghijk	48.1 ± 0.84efghijk	0.00 ± 0.00l
	Fenoxycarb	48.1 ± 0.77efghijk	51.1 ± 1.82bcde	49.5±1.60cdefgh	49.2±1.24defghi	45.8 ± 0.32jk	0.00 ± 0.00l
	Pyriproxyfen	47.7 ± 0.40fghijk	46.5 ± 0.50hijk	45.5±0.55k	48.4±1.09defghijk	45.7 ± 0.28jk	0.00 ± 0.00l
	Methoxyfenozide	49.7 ± 1.68cdefg	51.8 ± 1.51bcd	50.0±1.25cdefg	49.0±1.09defghij	48.1 ± 0.99efghijk	0.00 ± 0.00l
Egg hatchability	Buprofezin	22.4 ± 0.60m	26.0 ± 0.70l	28.9±0.97kl	36.1±1.67hi	46.2 ± 2.27e	0.00 ± 0.00n
	Lufeneuron	26.0 ± 0.68l	31.8 ± 0.64jk	38.4±0.58gh	47.1±0.90e	56.8 ± 0.54d	0.00 ± 0.00n
	Fenoxycarb	34.0 ± 0.70ij	40.9 ± 0.61fg	46.2±0.72e	60.3±1.11c	67.5 ± 0.81b	0.00 ± 0.00n
	Pyriproxyfen	22.8 ± 0.57m	26.8 ± 0.66l	33.0±0.84j	38.9±1.09gh	42.7 ± 0.94f	0.00 ± 0.00n
	Methoxyfenozide	34.5 ± 0.62ij	39.0 ± 0.52gh	46.2±0.74e	59.2±0.64cd	69.8 ± 1.07b	0.00 ± 0.00n

Means of mortality with different alphabets are significantly different from each other at 5% probability level by Tucky's HSD test.

Table 7. Impact of different concentrations of IGRs in interaction with application methods on the mortality and natality of adult female *P. solenopsis*.

Parameters	Methods	Concentration (%)					
		0.1	0.05	0.025	0.0125	0.00625	Control
Mortality	LDM	57.3 ± 0.30a	47.3 ± 0.35b	38.0 ± 0.31c	28.0 ± 0.27de	19.3 ± 0.26fg	0.00 ± 0.00k
	TAM	30.7 ± 0.30d	22.0 ± 0.24ef	14.0 ± 0.28gh	07.3 ± 0.26ij	02.7 ± 0.15jk	0.00 ± 0.00k
	GTM	38.7 ± 0.27c	31.3 ± 0.23d	21.3 ± 0.33f	12.0 ± 0.30hi	02.0 ± 0.18jk	0.00 ± 0.00k
Number of eggs laid by female	LDM	318.1 ± 4.7a	309.0 ± 4.1ab	299.3 ± 3.5b	290.5 ± 3.1bc	282.8 ± 3.1c	0.00 ± 0.00d
	TAM	318.1 ± 4.1a	309.0 ± 4.1ab	299.3 ± 3.5ab	290.5 ± 3.1b	282.8 ± 3.1c	0.00 ± 0.00d
	GTM	293.0 ± 5.5ab	317.6 ± 3.8ab	305.2 ± 3.6a	299.3 ± 3.5b	290.5 ± 3.1c	0.00 ± 0.00d
Reproductive period	LDM	31.8 ± 0.77a	30.2 ± 0.50abcd	29.5 ± 0.32bcd	28.9 ± 0.35cd	28.3 ± 0.47d	0.00 ± 0.00e
	TAM	30.7 ± 0.61abc	31.8 ± 0.77a	30.2 ± 0.50abcd	29.5 ± 0.32bcd	28.9 ± 0.35cd	0.00 ± 0.00e
	GTM	31.0 ± 0.60abc	31.8 ± 0.75ab	30.2 ± 0.54abcd	29.5 ± 0.32bcd	28.9 ± 0.35cd	0.00 ± 0.00e
Incubation period	LDM	52.0 ± 1.18ab	50.0 ± 1.05bc	48.7 ± 0.97cde	48.3 ± 0.75cde	47.3 ± 0.59de	0.00 ± 0.00f
	TAM	51.6 ± 1.05ab	49.6 ± 0.90bcd	48.5 ± 0.83cde	47.9 ± 0.73cde	47.5 ± 0.61de	0.00 ± 0.00f
	GTM	48.5 ± 1.05cde	53.4 ± 1.05 a	51.7 ± 1.02ab	49.9 ± 0.85bc	49.0 ± 0.78cde	0.00 ± 0.00f
Egg hatchability	LDM	26.3 ± 1.45j	31.4 ± 1.68 i	37.3 ± 1.78g	46.7 ± 2.60e	55.7 ± 2.82c	0.00 ± 0.00k
	TAM	30.0 ± 1.44i	35.1 ± 1.60 h	41.1 ± 1.75f	51.3 ± 2.58d	59.7 ± 2.76b	0.00 ± 0.00k
	GTM	27.6 ± 1.42j	32.1 ± 1.64 i	37.2 ± 1.96gh	47.1 ± 3.06e	54.3 ± 3.40c	0.00 ± 0.00k

Means of mortality with different alphabets are significantly different from each other at 5% probability level by Tucky's HSD test, LDM = Leaf Dip Method; TAM = Topical Application Method; GTM = Gourd Treatment Method.

Number of eggs laid by female

The highest egg laying of adult female *P. solenopsis* was observed in the treatment of Buprofezin and Pyriproxyfen followed by Lufenuron, Fenoxycarb and Methoxyfenozide. All IGRs significantly decreased the egg laying of *P. solenopsis*. The *P. solenopsis* treated with Buprofezin and Pyriproxyfen laid 303.7 and 301.0 eggs per female, respectively which were significantly higher as compared to other IGRs (Table 2). The different methods had no significant difference on the eggs production of *P. solenopsis* and these methods were statistical at par with control treatment. The number of eggs laid by per female in leaf dip method and topical application method were 297.1 each and in gourd treatment method, it was 298.1. So the application method did not affect the egg laying capacity of adult female *P. solenopsis* (Table 3). At highest dose rates, egg laying was higher as compared to the lowest dose rate. The highest dose rate (0.1%) showed highest egg laying (312.2 per female) and at 0.05% dose rate the number of eggs/female was 309.8 (Table 4). Buprofezin treated *P. solenopsis*

with leaf dip method laid 305.5 eggs per female and in case of topical application method and gourd treatment method laid 295.3 and 309.9 eggs per female, respectively (Table 5). The egg laying of *P. solenopsis* increased as the dose rate increased and decreased as the concentrations decreased. At highest concentration (0.1%), Buprofezin treated *P. solenopsis* laid 327.44 eggs per female, Lufenuron (311.8 eggs per female), Fenoxycarb (306.4 eggs per female), Pyriproxyfen (302.9 eggs per female) and Methoxyfenozide (300.2 eggs per female) (Table 6). At highest concentration (0.1%) *P. solenopsis* laid 318.1 eggs in leaf dip and topical application methods while in gourd treatment method it was 293 eggs per female (Table 7).

These findings of increase in egg production of adult female *P. solenopsis* are in line with the results of Lale (1991) and Morse and Zareh (1996) who observed that use of IGRs increased egg production of different insect pests. However, the results of Cloyed (2003) are similar and also contradict with present findings. He noted that Kinoprene and Pyriproxyfen lowered the eggs production of citrus mealy bug and also stated that Buprofezin numerically increased the egg production of citrus mealybug.

Reproductive period

Buprofezin treated adult female *P. solenopsis* had highest reproductive period (30.7 days) and in case of Lufenuron treated *P. solenopsis* it was 30.0 days (Table 2). All three methods had no difference on reproductive period of *P. solenopsis* treated with different IGRs. In leaf dip method, topical application method, gourd treatment method and control treatment the reproductive period was 29.8, 29.9, 29.4 and 29.2 days, respectively (Table 3). The dose dependent trend was observed of different concentrations on the reproductive period of adult *P. solenopsis*. At highest concentration (0.1%), the reproductive period of *P. solenopsis* was 31.1 days (Table 4). Buprofezin applied through leaf dip method had 30.6 days reproductive period and topical application method and gourd treatment method had 30.6 and 30.8 days reproductive period, respectively (Table 5). At highest concentration (0.1%), Buprofezin had 32.9 days reproductive period, in Lufenuron 31.5 days, Fenoxycarb 29.5 days, Pyriproxyfen 30.3 days and in Methoxyfenozide it was 31.4 days (Table 6). At highest concentration (0.1%), leaf dip method had 31.8 days reproductive period and in topical application method and gourd treatment method it was 30.7 and 31 days, respectively (Table 7).

These findings agree to those of Smagghe *et al*. (1996); Oberlander *et al*. (1997); Elek, (1990); Parveen, (2000) and Yoon *et al*. (2008) who reported that application of insect growth inhibitors greatly affected the reproduction, development and oviposition of insect pests.

Incubation period

Maximum incubation period (52.1 minute) of adult female *P. solenopsis* was observed in the eggs treated with Buprofezin (Table 2). In gourd treatment application method, the incubation period of eggs was 50.1 minutes and in leaf dip method and topical application method, it was 48.9 and 48.6, respectively which were statistically at par with the control treatment (48.5 minutes) (Table 3). The increase in concentrations of IGRs resulted in the increase of incubation period. At maximum concentrations (0.1%), incubation period of *P. solenopsis* eggs was 50.7 minutes (Table 4). At maximum concentration (0.1%), Buprofezin had 56.66 minutes incubation period as compared with Lufenuron (51.4 minutes), Fenoxycarb (48.1 minutes), Pyriproxyfen (47.7 minutes) and Methoxyfenozide (49.7 minutes) (Table 7). In leaf dip method where the eggs were treated with Buprofezin, the incubation period was 52.5 minutes while in topical application method, it was 51.2 minutes and in gourd treatment method it was same as in leaf dip method that was 52.5 minutes (Table 5). At highest concentration (0.1%), the incubation period was 52 minutes in leaf dip method which was highest followed by topical application method (51.6 minutes) and gourd treatment method (48.5 minutes) (Table 7).

These results are comparable with the results of Kandil *et al*. (2012) who observed that IGRs (Lufenuron, Chlorfluazuron and Chromafenozide) treated *Pectionophora gossipiella* enhanced the

incubation period as compared to the control treatment. With the increase in concentrations of IGRs the incubation period increased. These results differed with the results of Liu and Stansly (2004) who observed that increase in concentration of IGR decreased the oviposition period while these matched with regards to preoviposition, as preoviposition increased with increase in dose rate of IGR. These findings are totally against to the results of Shahout *et al.* (2011) who observed the sub-lethal toxicity of Methoxyfenozide in comparison to Chlorfluazuron and β-Cypermethrin on *Spodoptera litura.* The results exposed that LC_{10} value of all experimental insecticides had no substantial effect in both pre-oviposition and oviposition duration in comparison with control. Methoxyfenozide and Chlorfluazuron minimized the oviposition duration significantly at the higher concentration of LC_{30}. It was concluded that Methoxyfenozide should be applied in controlling *S. litura* due to its sterilizing properties on vegetables crops.

Egg hatchability

The eggs of adult female *P. solenopsis* treated with different IGRs showed a large difference in eggs hatchability. The eggs treated with Methoxyfenozide showed highest hatchability (57.9%) and the least eggs hatchability was observed in Buprofezin (43%). The eggs hatchability in Lufenuron, Fenoxycarb and Pyriproxyfen was 49.7, 57.7 and 43.7%, respectively (Table 2). Three application methods of IGRs showed different percent of eggs hatchability. The highest eggs hatchability treated with IGRs was observed in topical application method (52.5%) followed by gourd treatment method (49.5%) and leaf dip method (49.3%) (Table 3). At highest dose rate (0.1%), the eggs hatchability was 27.9% which was highest mortality of eggs of *P. solenopsis* (Table 4). The Buprofezin caused 43.3% eggs hatchability in leaf dip method, 46.2% in topical application method and 39.9% in gourd treatment method (Table 5). At highest concentration (0.1%), the Buprofezin caused 22.44%, Lufenuron 26%, Fenoxycarb 34%, Pyriproxyfen 22.77% and Methoxyfenozide 34.55% eggs hatchability (Table 6). At higher concentrations 0.1%, leaf dip method caused 26.3% eggs hatchability, topical application method caused 30% and gourd treatment method showed 27.6% eggs hatchability (Table 7).

These findings are in line with those of Lee *et al.* (2002) who evaluated the toxicity of Pyriproxyfen and Thiamethoxam on sweet potato whitefly, *Bemisia tabaci*. They found that Pyriproxyfen (100 ppm) showed maximum ovicidal effect upto 94.5% in comparison to Thiamethoxam. Mortality of 3rd instar nymph was over 85% for above both insecticides. These results also coincide with the findings of Nakamura *et al.* (2007) who observed the efficacy of yellow tape formulation of Pyriproxyfen versus sweet potato whitefly, *Bemisia tabaci*. They noted high ovicidal activity of over 80% mortality for tape formulation against *B. tabaci* for four days by 30 second mandatory contact test.

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