Journal of Applied and Natural Science 8 (2): 987 - 994 (2016)

Relative toxicity of insecticides against cotton mealybug *Phenacoccus solenopsis* Tinsley (Hemiptera:Pseudococcidae) and its fortuous parasitod *Aenasius bambawalei* Hayat (Hymenoptera: Encyrtidae)

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Received: July 29, 2015; Revised received: April 7, 2016; Accepted: June 4, 2016

Abstract: Nineteen insecticidal formulations from 10 groups of insecticides were evaluated for their relative toxicity against cotton mealybug *Phenacoccus solenopsis* Tinsley and its fortuous parasitoid *Aenasius bambawalei* Hayat. Insects were exposed to cotton leaves dipped in insecticidal solutions and their mortality was recorded at 24-h intervals. Within 24 h of exposure, Quinalphos, Chlorpyriphos, Thiamethoxam and Profenophos have detrimental effect on both *P. solenospis* and *A. bambawalei* recorded more than 70% mortality. Thiodicarb was extremely toxic to *P. solenopsis* and least toxic to *A. bambawalei* where as Spinosad was less toxic to *P. solenopsis* and extremely toxic to *A. bambawalei*. Profenophos, Thiamethoxam and Chlorpyriphos results into > 90% mortality of *P. solenospsis* while 100% kill of *A. bambawalei* with Spinosad, Acephate and Chlorpyriphos up to 48 hours. More than 80% mortality of *P. solenopsis* with Chlorpyriphos, Profenophos, Monocrotophos, Thiamethoxam, Spinosad and of *A. bambawalei* with Profenophos, Monocrotophos, Flonicamid, Buprofezin, Imidacloprid, Thiamethoxam, Chlorantraniliprole, Flonicamid and Indoxacarb recorded 72 hours after exposure. While at 96 hours, cent per cent mortality of *P. solenopsis* was recorded with Monocrotophos which was equivalent to Acephate and Spinosad. Least LT_{50} values were found with Thiodicarb, Quinalphos and Thiamethoxam for *P. solenopsis* and higher in case of Thiodicarb for *A. bambawalei*. Spinosad, Chlorpyriphos and Quinalphos were found to be extremely toxic to *A. bambawalei*. Among the tested insecticides Thiodicarb was found effective against *P. solenopsis* and relatively safer to *A. bambawalei* may be used judiciously to manage *P. solenopsis* that have least implications on the environment.

Keywords: Cotton, Insecticides, Mealybugs, Parasitoid

INTRODUCTION

The cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) has been emerging as a serious invasive pest of cotton since 2006 in India (Hodgson *et al.,* 2008; Nagrare *et al.,* 2009), reducing yields up to half the potential in affected cotton fields. Prior to that the species created havoc in Pakistan (Abbas *et al.,* 2005), causing losses to the tune of 0.2 million bales (One bale = 170 kg) during 2007 (Muhammad, 2007). Since then, the species has become a pest of global importance, reported on cotton and several other economically important crops in countries Nigeria (Akintola and Ande, 2008), Thailand and Taiwan (Hodgson *et al.,* 2008), Sri Lanka (Prishanthini and Laxmi, 2009), China (Wu and Zhang, 2009), Australia (Robinson and Tapim, 2010) and Japan (Tanaka and Uesato, 2012). The species has been recorded on 194 host plants in India (Vennila *et al.,* 2011), including fields crops, fruit plants, vegetables, ornamentals, trees, spices, weeds, etc. The species poses a serious economic threat to cotton and other agricultural crops around the world, especially in tropical regions.

Farmers rely heavily on chemical insecticides as an easy and effective way of controlling this pest. It is well known that chemical pesticides are not only expensive but also affect the natural enemy fauna. Indiscriminate use of these chemicals leads to threats such as resurgence of insects (Kumar *et al.,* 2011), development of resistance in insects, environmental pollution and deleterious effects on human health.

Several naturally occurring predators and parasitoids of mealybugs have been identified (Nagrare *et al.,* 2011; Suroshe *et al.,* 2013) among them fortuous parasitoid, *Aenasius bambawalei* Hayat (Hymenoptera: Encyrtidae), an endophagous, nymphal solitary parasitoid of *P. solenopsis* causes average 30% parasitization (Nagrare *et al.,* 2011). *A. bambawalei* was first described and reported from India (Hayat, 2009) and is the only dominant and aggressive parasitoid responsible for the decline of the mealybug population in the north zone (Kumar *et al.,* 2009). Its parasitization on *P. solenopsis* was reported in all three cotton-growing zones of India on several hosts including cotton and weeds. Its distribution has been recorded in Pakistan

ISSN : 0974-9411 (Print), 2231-5209 (Online)

(Arif *et al.,* 2011), China (Chen *et al.,* 2010), Australia (Spargo *et al.,* 2013) and now in Iran (Fallahzadeh *et al.,* 2014).

World over numerous insecticides are being applied against *P. solenopsis* on agricultural important crops. Although insecticides are designed to kill pests, they are likely to be deleterious to the natural enemies of the pests. The knowledge of the relative toxicity of these insecticides to pest *P. solenopsis* and its natural enemies is insufficient. The objective of the present study was to understand the relative toxicity of some commonly used insecticides against *P. solenopsis* and its parasitoid *A.bambawalei*. The results would be useful to identify those insecticides that are effective against *P. solenopsis* and relatively safer to native parasitoid *A.bambawalei.*

MATERIALS AND METHODS

Experiments on relative toxicity of insecticides against *P. solenopsis* and *A. bambawalei* were carried out during April–November 2014 at the Insectary and Biocontrol Laboratory of Central Institute for Cotton Research, Nagpur, India using populations of *P. solenopsis* and *A. bambawalei* collected from location 21°2′ 18.4704″N, 79°3'36.6912"E cotton (*Gossypium hirsutum* L, var., Suraj).

Test insects: Gravid females of *P. solenopsis* were separated from field collected populations and released on the sprouted potato for generating F_1 population. Mummies of mealybug were gently removed from field collected population with camel hair brush from the plant parts and released into plastic containers (18 cm dia. × 29 cm height) (average dimensions 8–10 cm length and 4–5 cm breadth) and secured with muslin cloth. The containers were kept at 27–32°C and relative humidity (RH) of 35–60%. Ten days old nymphs of *P. solenopsis* and freshly emerged *A. bambawalei* adults from mummified mealybugs were chosen for experiment.

Insecticides: Nineteen insecticides from 10 groups of insecticides were taken up for toxicity studies against mealybug *P. solenopsis* and its parasitoid *A. bambawalei*. Details of all the insecticides and doses taken are listed in Table 1. Fresh stock of each insecticide was procured from the open market while neem seed kernel extract (NSKE) was prepared in the laboratory (Anonymous 2014). Fresh test solutions of 100 mL each were prepared as per recommended doses on cotton by taking the requisite quantity of insecticides and diluted with distilled water.

Bioassay method: IRAC method No 8 (http://www.irac-online.org/content/uploads/Method_008_v3_june09.pdf) was used for conducting bioassays against *P. solenopsis* and *A. bambawalei*. Fresh tender cotton leaves with petiole were collected from Bt cotton Jai 3028 grown in the net house without any insecticidal spray and free from insect infestation. Leaves were washed under running tap water to remove any insect infestation/dust. Washed leaves were placed on absorbent paper and shade-dried. Cut portions of petioles were wrapped with wet cotton and placed inside microcentrifuge tubes. The leaves thus prepared were dipped into the insecticidal solution and removed after 2 minutes of treatment and shade-dried.

***P. solenopsis*:** Insecticide treated leaves were placed in petri plates (9 cm diameter) and 20 Nos. of ten days old nymphs of *P. solenopsis* were released per leaf. Each treatment was replicated six times.

***A. bambawalei*:** Insecticide treated leaves were placed in transparent 1-L plastic jars. Sterile cotton swabs dipped in honey+water (1:1 ratio) were provided as a source of food for *A. bambawalei*. Fifteen freshly emerged adult parasitoids were released into each plastic jar, the mouth of which was secured with muslin cloth. Each treatment was replicated thrice.

In both cases, leaves treated with distilled water were used as control. The petriplates and jars were placed at room temperature 27–32 °C and 35–60% RH. Mortality was recorded at 24-h intervals by counting the dead insects and discarding them every day until 96 h. Corrected mortality was computed using Abbott's (1925) formula and data were subjected to analysis of variance under completely randomized design using the online software Web Agri Stat Package 2.0 (ICAR Research Complex for Goa, Ila Old Goa, India). A critical difference 0.05 was used to separate mean values. Probit analysis was carried with POLO-PC LeOra Software 1987.

RESULTS AND DISCUSSION

Relative toxicity of insecticide to *P. solenopsis* and *A. bambawalei* at 24 h interval: The results showed significant toxicity of test insecticides to *P. solenopsis* and *A. bambawalei* at 24 hour after treatment (Table 2).

At 24 h after treatment: More than 70 per cent mortality of *P. solenopsis* was observed with Thiodicarb and Quinalphos, Thiamethoxam, Chlorpyriphos and Profenophos and mortality of *A. bambawalei* with Quinalphos, Spinosad and Chlorpyriphos up to 24 hours after exposure. Cent per cent mortality of *P. solenopsis* was observed with Thiodicarb and Quinalphos. These were followed by Thiamethoxam, Chlorpyriphos and Profenophos and were not different from each other. Highest mortality of *A. bambawalei* was recorded with Quinalphos, Spinosad and Chlorpyriphos. Negligible mortality of *P. solenopsis* was recorded with Imidacloprid, Chlorantraniliprole, Indoxacarb and Spinosad, however they were highly toxic to *A. bambawalei.* Neem oil, NSKE, Neem oil+NSKE, Flubendiamide, Diafenthiuron, Novaluron, Buprofezin were found to be least toxic to either of the species. Monocrotophos and Profenophos were equally toxic to both the species.

At 48 h after treatment: Profenophos, Thiamethoxam and Chlorpyriphos results into >90% mortality of *P. solenospsis* while 100% kill of *A. bambawalei* with Spinosad, Acephate and Chlorpyriphos. Highest mortal-

Table 1. Details of insecticides used for toxicity study against parasitoid *A. bambawalei.*

S.N.	Group of insecticidal formulation	Name of insecticide	Trade name	Mode of action	Manufacturing company	Dose
1	Biorationals	Neem oil (1500ppm)		Antifeedent	Neem foundation	2.5 l/ha
2		NSKE 5%		Antifeedent	Neem foundation	5%
3	Neonicotinoid	Imidacloprid 30.5% SC	Confi-dor	Binds irreversibly to post-synaptic nicotinic acetyl-choline receptors	Bayer crop science ltd.	20 g a.i./ ha
4		Thiamethoxam 25% WG	Exaam	Contact, stomach and systemic activity	Coromondal Agrico Pvt Ltd	25 g a.i./ ha
5	Carbamates	Thiodicarb 75% WP	Larvin	Stomach & Contact	Bayer crop science ltd	1500 g a.i./ha
6	Anthanilic dia-mides	Chloran-traniliprole 18.5% SC	Cor-agen	Activate insect ryanodine receptors	EI Dupont India pvt Ltd	50 g a.i./ ha
7	Pyridinecarbox-amide	Flonicamid 50% WG	Ulala	Systemic and translaminar activity	United phosphorus ltd	200 gm/ha
8	Benzenedicar-boxamides	Flubendiamide 480% SC	Fame	Stomach insecticide with a new target site - Ca+ re-lease channels	Bayer	125 ml/ha
9	Insect Growth Regulators	Diafenthiuron 50% WP	Pega-sus	ATPase inhibitor	Syngenta	300 g a.i./ ha
10		Novaluron 10% EC	Rimon	IGR	Indofil	60 g a.i./ ha
11		Buprofezin 25% SC	Phy-laud	Chitin synthesis inhibitor	Phyto Chem (India) Ltd	100 g a.i./ ha
12	Organophosphate	Quinolphos 25% EC	Starlux	Translaminar stomach and contact	SWAL corporation	500 g a.i./ ha
13		Acephate 75% SP	Spit fire	Broad spectrum systemic, ovicidal, contact and stomach	Chemtura chemicals india pvt ltd	400 g a.i./ ha
14		Chlorpyriphos 20% EC	Durs-ban	Non-systemic, contact, stomach, and vapour ac-tion	Dow Agro sciences India Pvt Ltd	250 g a.i./ ha
15		Profenophos 50% EC	Cu-racron	Non-systemic, stomach and contact	Syngnta india ltd	1000 g a.i./ ha
16		Monocrotophos 36% SL	Parry-fos	cholinesterase inhibitor	Coromondal interna-tional Ltd	2ml/l
17	Oxadiazine	Indoxacarb 15.8% EC	Avaunt	Blocks sodium channel in nerve axon	EI DuPont India pvt Ltd	75 g a.i./ ha
18	Macrocyclic lactone (spinosyns)	Spinosad 45% SC	Tracer	Contact and stomach	Dow Agro sciences India Pvt Ltd	75 g a.i./ ha

ity of *P. solenopsis* was recorded with Profenophos followed by Thiamethoxam and Chlorpyriphos and these were at par with each other. These insecticides were followed by Monocrotophos but were not statistically different from later two. Remaining insecticides indicated less toxicity to *P. solenopsis*. Complete mortality of *A. bambawalei* was noted when exposed to the insecticides Spinosad, Acephate and Chlorpyriphos; these values are comparable with those recorded with Imidacloprid, Thiamethoxam, Buprofezin and Profenophos. Similar trend on least toxicity to both species was observe at 48h of exposure in case of Neem oil, NSKE, Neem oil+NSKE, Flubendiamide, Diafenthiuron, Novaluron, Buprofezin.

At 72 h after treatment: Mortality with Chlorpyriphos and Profenophos was comparable with Monocrotophos which was at par with Thiamethoxam, Acephate and Spinosad in *P. solenopsis*. Complete kill of *A. bambawalei* was recorded for insecticides Profenophos, Monocrotophos, Flonicamid, Buprofezin and were equivalent with Imidacloprid, Thiamethoxam, Chlorantraniliprole, Flonicamid and Indoxacarb. Combination of neem oil and NSKE was moderately toxic and the rate was not significantly different from that due to Flubendiamide, Chlorantraniliprole and Indoxacarb. Individual formulations Neem oil and NSKE, Neem oil +NSKE, Diafenthiuron and Novaluron proved to be the least toxic to *A. bambawalei*.

At 96 h after treatment: At 96 hrs of exposure, cent per cent mortality of *P. solenopsis* was recorded with Monocrotophos which was equivalent to Acephate and Spinosad. Combination of Neem formulation and NSKE were found to be moderately toxic, which was not significantly different from that due to Indoxacarb,

Table 2. Relative toxicity of insecticides to *P. solenopsis* and *A. bambawalei* at 24h interval.

S.N.	Name of insecticide	Per cent mortality							
		At 24h after treatment		At 48h after treatment		At 72h after treatment		At 96h after treatment	
		P. solenopsis	*A. bambawalei*	*P. solenopsis*	*A. bambawalei*	*P. solenopsis*	*A. bambawalei*	*P. solenopsis*	*A. bambawalei*
1	Neem oil (1500ppm)	–	20.00 (25.82)^{f}	09.77 (16.90)^{e}	22.50 (28.28)^{e}	19.96 (26.25)^{e}	35.00 (35.78)^{de}	21.00 (26.94)^{ef}	66.66 (62.33) abc
2	NSKE 5 %	11.60 (19.67)^{e}	10.00 (18.43)^{f}	18.84 (24.36)^{cde}	-	34.77 (35.81)^{de}	33.33 (35.26)^{de}	36.40 (37.01)^{d}	58.33 (49.86) bcd
3	Neem oil+NSKE 5%	11.05 (19.39)^{e}	10.00 (18.43)^{f}	20.13 (26.27)^{cde}	20.00 (26.56)^{e}	31.08 (33.67)^{de}	58.33 (49.86)^{cd}	37.73 (37.83)^{d}	94.44 (79.97) ab
4	Imidacloprid 30.5% SC	–	68.89 (57.08)^{bcd}	30.00 (32.64)^{cde}	82.22 (69.24)^{abc}	36.88 (37.25)^{de}	92.85 (78.65)^{ab}	–	95.83 (81.32) ab
5	Thiamethoxam 25% WG	80.28 (63.89)^{b}	63.79 (54.00)^{cd}	91.25 (77.50)^{ab}	83.33 (69.93)^{abc}	92.10 (78.12)^{abc}	90.00 (78.60)^{ab}	–	100.00 (89.41) a
6	Thiodicarb 75% WP	100.00 (89.65)^{a}	11.11 (19.26)^{f}	–	31.11 (33.87)^{de}	–	-	-	-
7	Chlorantraniliprole18.5% SC	–	72.72 (58.51)^{bcd}	15.08 (22.14)^{de}	-	24.28 (29.13)^{de}	83.33 (72.12)^{abc}	34.06 (35.28)^{de}	100.00 (89.41) a
8	Flonicamid 50% WG	16.76 (23.15)^{e}	63.42 (53.03)^{cd}	–	75.23 (60.66)^{bcd}	25.05 (29.42)^{de}	91.66 (79.67)^{ab}	55.18 (47.99)^{c}	100.00 (89.41) a
9	Flubendiamide 480% SC	–	27.77 (30.63)^{ef}	10.32 (17.08)^{e}	46.03 (42.03)^{cde}	16.00 (23.26)^{e}	63.89 (53.43)^{bcd}	18.32 (25.23)^{f}	75.00 (67.20) ab
10	Diafenthiuron 50% WP	11.67 (19.88)^{e}	6.67 (14.96)^{f}	11.78 (19.28)^{e}	20.00 (26.35)^{e}	21.65 (27.63)^{de}	17.78 (20.89)^{e}	43.08 (40.83)^{cd}	20.55 (26.32)^{d}
11	Novaluron 10% EC	–	6.67 (14.96)^{f}	–	15.55 (22.69)^{e}	–	24.05 (29.33)^{de}	09.58 (17.35)^{f}	28.33 (31.79) cd
12	Buprofezin 25% S C	33.88 (34.08)^{d}		35.78 (36.42)^{cd}	91.21 (76.00)^{ab}	75.52 (66.06)^{c}	100.00 (89.51)^{a}	–	-
13	Quinalphos 25% EC	100.00 (89.65)^{a}	97.77 (84.74)^{a}	–	-	–	100.00 (89.51)^{a}	–	-
14	Acephate 75% SP	39.17 (38.53)^{d}	59.95 (50.87)^{de}	42.06 (40.25)^{c}	100.00 (89.56)^{a}	86.86 (71.03)^{bc}	-	94.85 (80.59)^{ab}	-
15	Chlorpyriphos 20% EC	73.88 (60.02)^{bc}	88.33 (73.71)^{abc}	91.23 (77.54)^{ab}	100.00 (89.56)^{a}	100.00 (89.64) a	-	–	-
16	Profenophos 50% EC	73.97 (59.70)^{bc}	62.91 (53.25)^{cd}	95.78 (82.38)^{a}	70.45 (62.63)^{abc}	100.00 (89.64)^{a}	100.00 (89.51)^{a}	–	-
17	Monocrotophos 36% SL	60.75 (51.25)^{c}	61.80 (51.93)^{de}	81.48 (65.86)^{b}	91.66 (79.70)^{ab}	96.20 (83.42)^{ab}	100.00 (89.51)^{a}	100.00 (89.60)a	-
18	Indoxacarb 15.8% EC	13.45 (21.07)^{e}	69.91 (57.40)^{bcd}	24.25 (29.33)^{cde}	94.44 (80.04)^{ab}	45.13 (42.09)^{d}	89.63 (74.49)^{abc}	56.84 (49.01)c	100.00 (89.41) a
19	Spinosad 45% SC	31.45 (33.17)^{d}	93.26 (77.52)^{ab}	39.20 (37.70)^{cd}	100.00 (89.56)^{a}	84.82 (72.68)^{bc}		85.60 (71.99)b	
	CV (%)	16.169	21.89	24.725	22.66	20.985	20.31	17.394	23.50
	CD=0.05	9.100	21.54	16.507	28.09	15.503	27.55	9.362	33.22
	Also significant at CD= 0.01	12.126	29.035	21.940	37.903	20.676	37.580	12.531	46.337

Figure in parenthesis are arcsine transformed values. Means within a column followed by same letter are not significantly different p=0.05.

Table 3. Estimated LT_{50} for *P. solenopsis* and *A. bambawalei* exposed to different insecticides.

S. N.	Insecticide	LT_{50} (h)		LFL		UFL		Slope± SEM	
		P. solenopsis	*A. bambawalei*	*P. solenopsis*	*A. bambawalei*	*P. solenopsis*	*A. bambawalei*	*P. solenopsis*	*A. bambawalei*
1	Neem oil (1500ppm)	306.71	71.17	170.79	46.49	1851.92	98.17	1.499± 0.400	3.046±0.217
2	NSKE 5%	156.18	84.22	110.40	57.48	348.10	116.58	1.490± 0.329	3.878±0.260
3	Neem oil+NSKE 5%	152.68	69.98	109.82	48.92	317.65	70.52	1.567± 0.334	4.777±0.300
4	Imidacloprid 30.5% SC	125.97	15.89	94.48	7.31	232.55	23.61	1.508± 0.319	2.260±0.289
5	Thiamethoxam 25% WG	3.80	16.86	0.04	5.70	10.54	26.06	1.104± 0.362	2.176±0.273
6	Thiodicarb 75% WP	1.58	110.37	–	74.90	–	186.68	1.416± 0.680	2.034±0.186
7	Chlorantraniliprole 18.5% SC	204.05	13.67	132.44	0.69	614.64	26.20	1.472± 0.347	1.791±0.262
8	Flonicamid 50% WG	87.70	18.88	–	13.00	–	23.90	1.880± 0.312	2.724±0.311
9	Flubendiamide 480% SC	491.14	46.29	211.23	25.96	18748.25	63.54	1.251± 0.404	3.205±0.247
10	Diafenthiuron 50% WP	137.40	139.04	103.09	114.03	247.65	171.65	1.674± 0.332	2.249±0.160
11	Novaluron 10% EC	527.64	98.31	224.57	78.33	29512.19	121.50	1.612±0.541	3.513±0.234
12	Buprofezin 25% SC	41.79	38.65	34.30	26.61	48.71	48.96	1.940± 0.293	5.294±0.389
13	Quinalphos 25% EC	1.58	5.91	–	0.74	–	12.83	1.416± 0.680	1.462±0.273
14	Acephate 75% SP	31.15	19.34	–	11.91	–	25.48	2.678± 0.319	2.701±0.304
15	Chlorpyriphos 20% EC	15.30	3.47	10.10	0.053	19.32	10.22	3.217± 0.523	1.249±0.309
16	Profenophos 50% EC	15.49	22.99	10.41	5.69	19.36	34.52	3.411± 0.559	3.042±0.314
17	Monocrotophos 36% SL	18.37	17.96	–	12.73	–	22.48	2.966± 0.417	2.762±0.322
18	Indoxacarb 15.8% EC	84.09	20.97	72.52	6.58	103.86	32.18	2.256± 0.326	2.102±0.249
19	Spinosad 45% SC	46.19	3.39	24.21	0.01	68.85	10.66	2.256± 0.311	1.225±0.307

LFL-Upper fiducial limit, UFL-Upper fiducial limit.

Flonicamid, Diafenthiuron and Chlorantraniliprole. Formulations of Neem oil, Flubendamide, Novaluron were found to be least toxic to *P. solenopsis*. Thiamethoxam, Chlorantraniliprole, Flonicamid, Indoxacarb killed all the test insects; neem oil, Neem oil+NSKE, Imidacloprid, and Flubendiamide proved equally toxic to the parasitoid. Thiodicarb was found safe to *A. bambawalei*.

Baseline toxicity LT_{50} of test insecticides to *P. solenopsis* and *A. bambawalei*

LT_{50} *P. solenopsis*: The relative baseline toxicity of insecticides (Table 3) was determined against mealybug *P. solenopsis*, at respective doses. Least LT_{50} values were found with Thiodicarb, Quinalphos and Thiamethoxam. The slopes were steeper in Thiamethoxam, Thiodicarb and Quinalphos and were highly toxic than other insecticidal formulations. Moderate LT_{50} values were observed with Chlorpyriphos, Profenophos, Monocrotophos, Acephate, Buprofezin, Spinosad, Flonicamid and Indoxacarb. Imidacloprid, Diafenthiuron, Neem oil+NSKE, NSKE, Chlorantraniliprole, Neem oil, Flubendiamide and Novaluron required more time to kill 50 % test insects. The relative grater time for mortality was calculated over Novaluron, that showed the highest LT_{50} value.

***A. bambawalei*:** Baseline toxicity (Table 3) against *A. bambawalei* at the respective doses showed that the parasitoid was highly susceptible to Spinosad, Chlorpyriphos and Quinalphos. The slopes were steeper in Spinosad, Chlorpyriphos and Quinalphos, as a result of higher toxicity when compared with other insecticidal formulations. Chlorantraniliprole, Imidacloprid, Thiamethoxam, Monocrotophos, Flonicamid, Acephate, Indoxacarb, Profenophos, Buprofezin, Flubendiamide were moderately toxic. Neem oil+NSKE, Neem oil, NSKE , Novaluron, Thiodicarb and Diafenthiuron were the least toxic.

Within 24 h of exposure, our data clearly demonstrates detrimental effect of insecticides Quinalphos, Chlorpyriphos, Thiamethoxam and Profenophos on the survival of both *P. solenospis* and *A. bambawalei*. However, Thiodicarb was extremely toxic to *P. solenopsis* and least toxic to *A. bambawalei* whereas Spinosad was less toxic to *P. solenopsis* and extremely toxic to *A. bambawalei*.

After 48 h, parasitoids exposed to the insecticides Spinosad, Chlorpyriphos, Acephate, Indoxacarb, Monocrotophos, Buprofezin, Thiamethoxam and Imidacloprid exhibited the highest mortality (80–100%). However, maximum mortality of *P. solenopsis* was recorded with Profenophos, Thiamethoxam, Chlorpyriphos and Monocrotophos. Spinosad, Acephate, Indoxacarb, Imidacloprid were lesser toxic to *P. solenopsis*. Hence, these can be avoided against *P. solenopsis*.

In the present investigation some of the insecticides tested were found to be toxic against the host insect *P. solenopsis.* These results were corroborating with the reported results (Kumar *et al.* 2012; Nagrare *et al.* 2011; Sahito *et al.* 2011; Huang *et al.* 2013). Spinosad was less effective against *P. solenopsis* was also reported by Sharma and Kaushik (2010), Nagrare and co-workers (2011) and Mandal and co-workers (2013), however high toxicity to *A. bambawalei* is reported herewith. Kumar *et al.* (2011) reported resurgence of *P. solenopsis* on cotton with repeated spray of Spinosad. Least toxicity of Spinosad to *P. solenopsis* and extremely toxic to *A. bambawalei* might be the reason behind resurgence of mealybug.

Studies also reported that Spinosad is highly toxic against the parasitoids *Trichogramma galloi* Zucchi. (Consoli *et al.* 2001), *T. chilonis* (Hussain *et al.,* 2012) and *Chrysoperla carnea* (Medina *et al.* 2001); the ladybird beetle, *Hippodamia convergens*; the minute pirate bug, *Orius laevigatus*; the big-eyed bug, *Geocoris punctipes*; and the damsel bug, *Nabis* sp. (Thompson *et al.,* 2000). Suma and co-workers (2009) have reported that Spinosad caused 100% mortality of the tested parasitoids *Aphytis melinus* DeBach and *Coccophagus lycimnia* Walker within 24 h of exposure, and Miles and co-workers (2000) and Williams *et al.* (2003) reported that it decreases parasitoid reproduction and longevity.

Chlorpyriphos has a rapid and strong toxic effect on natural enemies (Toscano 2005; Carrillo *et al.* 2009). The findings of the present study are also in agreement with those of Kumar *et al.* (2011) in that application of organophosphates (Monocrotophos, Acephate, Profenophos) and Spinosad adversely affects the efficiency of *A. bambawalei* in cotton fields. Sahito and co-workers (2011) reported that activities of predators and parasitoids such as *A. bambawalei*, *Brumus saturalus*, *Menochilus sexmaculatus*, *Scymnus coccivora*, *S. saturalis*, *Chrysoperla carnea* and many species of spiders were significantly affected due to field application of Imidacloprid and Profenophos; a finding which is in agreement with that of the present study. Reports of Nalini and Manickavasagam (2011) indicated the high toxicity of Monocrotophos and Profenophos that caused 100% mortality of both *A. bambawalei* and *A. advena* within 1 h while Imidacloprid took 3 h and Nimbecidine (neem formulation) 24 h to kill all test insects. We recorded mortality at 24-h intervals; however, comparative results indicate a similar trend. Chlorpyriphos, Profenophos and Quinalphos were also found to be highly toxic to *Chrysoperla* larvae (Shinde *et al.,* 2009). Quinalphos completely inhibited the emergence of the parasitoid *Trichogramma brasiliensis* from egg (Varma and Singh 1987). Application of profenophos resulted in 100% morality of *C. marginiventris* in direct contact and residual studies (Ruberson *et al.,* 1993) while thiodicarb was found to be harmless to larval parasitoids *Carcella illota* (Chaturvedi 2014) and *C. carnea* (Nasreen *et al.,* 2005) which clearly indicating resembling results. Toscano *et al.* (2005) have also registered the higher toxicity of Buprofezin, Imidacloprid, Thiamethoxam and Chlorpyriphos against egg parasitoids, *Gonatocerus ashmeadi* and *G. triguttatus*.

In the recent past, insecticides belonging to various groups with different modes of action are being tried to control the invasive pest mealybug *P. solenopsis* infesting cotton and other crops. However, the waxy body coating of mealybugs hinders the penetration of insecticides to a greater degree and hence management approaches that reduce reliance on insecticides and promote conservation of natural enemies need to be studied (Kumar *et al.,* 2012). Some of these insecticides demonstrate poor pest control but are found to be highly deleterious to natural enemies that control the pest population. The parasitoid *A. bambawalei*, plays a significant role in the control of *P. solenopsis* in several Asian countries. Mealybugs have a skewed and clumped distribution and can be easily managed by predators and parasitoids (Afifi *et al.,* 2010). It is well known that natural enemies of insect pests play a key role in biotic balance, minimising pest population levels below economic injury level. The advantage of biocontrol is now well recognized, particularly in the context of environmental protection as well as sustainable pest management. Conservation of natural enemies by way of avoiding application of harmful insecticides is necessary. Thiodicarb is reported to be relatively safer to several natural enemies like, *Diglyphus intemedius* (Girault) and *Neochrysocharis punctiventris* (Crawford) (Schuster, 1994), *Eretmocerus tejanus* (Jones *et al.,* 1998), *Orgilus Lepidus* (Symington and Horne, 1998), *Geocoris punctipes* (Say), *Nabis capsifonnis* Germar, *Nabis roseipennis* Reuter, *Podisus maculiventris* (Say) (Boyd and Boethel, 1998), *Chrysoperla carnea* (Ayubi *et al.,* 2013; Rasheed *et al.,* 2014) and *Carcella illota*

(Chaturvedi, 2014). Minimum use of low to moderately toxic insecticides like Thiodicarb (belonging to WHO class II) can find a place in management of cotton pests like *P. solenopsis.*

Conclusion

This study provides basic information regarding the relative toxicity of various insecticides over time for pest mealybug and its fortuous parasitoid *A. bambawalei* under laboratory conditions. Thiodicarb was extremely toxic to *P. solenopsis* and least toxic to *A. bambawalei* where as Spinosad was less toxic to *P. solenopsis* and extremely toxic to *A. bambawalei*. Profenophos, Thiamethoxam and Chlorpyriphos results into > 90% mortality of *P. solenospsis* while 100% kill of *A. bambawalei* with Spinosad, Acephate and Chlorpyriphos up to 48 hours. Among the tested insecticides Thiodicarb was found effective against *P. solenopsis* and relatively safer to *A. bambawalei* may be used judiciously to manage *P. solenopsis.*

ACKNOWLEDGEMENTS

We acknowledge funding by Agriculture Department, Government of Maharashtra through Crop Pest surveillance and Advisory Project (CROPSAP) 2009-14.

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