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Toxicity and bioefficacy of individual and combination of diversified insecticides against jute hairy caterpillar, *Spilarctia obliqua*

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Abstract

Toxicity of conventional (profenofos 50 EC and λ-cyhalothrin 5 EC) and non-conventional (flubendiamide 480 SC, chlorantraniliprole 18.5 SC, emamectin benzoate 5 SG) insecticides was determined on the basis of median lethal concentration (LC_{50}) values on third instar larvae of jute hairy caterpillar, *Spilarctia obliqua* under laboratory conditions. Further, the promising binary insecticides combinations with lesser LC_{50} values and adequate synergistic activity were evaluated under field conditions. The LC_{50} values calculated for insecticides *viz*., chlorantraniliprole, flubendiamide emamectin benzoate, λ-cyhalothrin and profenophos were 0.212, 0.232, 0.511, 0.985 and 3.263 ppm, respectively. Likewise, the LC_{50} values for flubendiamide with λ-cyhalothrin in 3:1 proportion was most toxic (0.103 ppm) amongst all the other binary combinations with λ-cyhalothrin. Chlorantraniliprole in combination with λ-cyhalothrin at 1:1 proportion (0.209 ppm) was most toxic followed by 3:1 proportion (0.345 ppm). Similarly, emamectin benzoate in combination with λ-cyhalothrin at 1:1 proportion was more toxic (0.271 ppm) than 3:1 ratio (0.333 ppm). Toxicity index of flubendiamide + λ-cyhalothrin (3:1 ratio) was highest (970.87). Bioefficacy of synergistic binary combinations along with individual insecticides established the superiority of profenophos + λ-cyhalothrin (3:1) with 89.12% reduction in infestation and recorded maximum fibre yield 38.67qha^{-1} under field condition. Moreover, combination of diverse insecticides group might sustain toxicity against the target insect for longer period with least probability of resistance development.

Key words

Bio-efficacy, Insecticides, Median lethal concentration, *Spilarctia obliqua,* Toxicity index

Introduction

Spilarctia (=*Spilosoma*) *obliqua* walker (Lepidoptera : Arctiidae), vernacularly known as jute hairy caterpillar, is a highly polyphagous and sporadic pest infesting approximately 126 plants species distributed in 24 families (Singh and Varatharajan, 1999). This pest causes extensive damage to crops such as groundnut, sunflower, cowpea, soybean, cabbage, cauliflower including several bast fibre crops like jute, mesta, ramie and sunnhemp (Gupta and Bhattacharya, 2008). This pest often infests jute (*Corchorus olitorius* and *C. capsularis*), and is one of the most important pest of natural fibres in India causing extensive damage through recurrent outbreaks. In recent years, the elevated pest status of *S. obliqua* is evident from few outbreaks noticed during 2011 in jute and 2012 in sunnhemp crop, causing substantial loss to the fibre yield (Satpathy *et al.,* 2014). The female moths lay eggs in clusters on lower surface of the leaves and single female may lay up to 1000 eggs. Upon hatching, the first instar larva scrape the chlorophyll content of the lower leaf, whereas late instar larvae are voracious feeder and in severe case causes complete defoliation of plants which is inevitable.

Timely management of this pest is very important as delay may even lead to complete defoliation of crop. It is customary to rely on chemical insecticides as they serve as main pillar for pest management. Chemical control of this pest through conventional insecticides is difficult due to dense hair of larva and acute toxicity and relative resistance of *S. obliqua* (Dhingra *et al.*, 2007). The embedded problem of pest resistance and resurgence encouraged in the backdrop of chemical insecticides based management can be eliminated or reduced to some extent through continuous evaluation of new insecticides belonging to diverse groups capable of causing toxicity in low volume. To

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enhance crop productivity under multiple pest situations, more than one insecticide are used in mixtures having different chemical groups. These may also be used to manage resistant field population of certain pest and delay the development of insecticide resistance (Attique *et al.,* 2006; Ahmad *et al.,* 2009). Therefore, assessing the strength and weakness of insecticide mixtures deserves utmost consideration. Moreover, it is possible to observe potentiation, synergism or antagonism against pest species simply by altering the proportion of insecticides in the mixture and hence, species-specific ratios need to be determined on the basis of their LC_{50} values. This may serve as a ready-reckoner to the farming community for scientific mixing of insecticides against target pests. Ideally, insecticides having different mode of action are mixed on the assumption that they would complement the action of each other for killing the target insect pest. However, no studies have been conducted on combination of newer insecticides with synthetic pyrethroids against *S. obliqua*. Therefore, four different groups of insecticides *i.e.*, sodium channel modulators (λ-cyhalothrin 5 EC), acetylcholine esterase inhibitors (profenofos 50 EC), chloride channel activitors (emamectin benzoate 5 SG) and ryanodine receptor modulators (flubendiamide 480 SC and chlorantraniliprole 18.5 SC) with different mode of action were selected to study potential toxicity individually, as well as, in different combinations against *S. obliqua* in jute crop.

Materials and Methods

Insect culture : *S. obliqua* egg masses were collected from insecticide free jute crop from the Research Farm of Central Research Institute for Jute and Allied Fibres (CRIJAF), Barrackpore. The newly hatched gregarious larvae were reared in the rearing container (13 cm x13 cm dia) for complete larval development on jute leaves under controlled condition with temperature 27±2°C and relative humidity about 75-80% in BOD. Fresh insecticide free leaves, as natural diet for larvae, were provided and replaced daily to avoid contamination. 3rd instar generation of first generation (F1) (10 days old) having average body weight of 98 mg was used for bioassay.

Test insecticides : Five commercial formulation of test insecticides *i.e.*, flubendiamide 480 SC (Fame®), Bayer crop science India limited, Mumbai; chlorantraniliprole 18.5 SC (Coragen®), DuPont India limited; emamectin benzoate 5 SG (Proclaim®) and profenofos 50 EC (Curacron®), Syngenta India limited, Mumbai and λ-cyhalothrin 5 EC (Command®), Tropical Agrosystem (India) limited, Chennai were used as individual and in different ratio mixtures.

Laboratory bioassay procedure : Leaf dip bioassay method was used for assessing the toxicity of individual insecticide and their combinations. Initially, stock solutions of insecticides were prepared on the basis of their active ingredients. For assessing joint toxicity parameter, individual insecticides were mixed in 1:1, 3:1 and 1:3 ratio respectively, based on LC_{50} values alone (Duraimurugan and Regupathy, 2005). From the stock solution of individual or mixtures of insecticide solutions, serial dilutions were followed to prepare six broad range concentrations that were used in bioassay using third instar larvae of *S. obliqua* and based on 20-80% larval mortality again six narrow range concentrations were prepared to determine LC_{50} of each insecticide and their mixtures. Jute leaves were dipped in water (control) or test insecticide solutions for about 20 sec and then air dried prior to exposure of leaves for feeding by larvae. Each treatment consisted of ten third instar larvae and was replicated thrice including control. Bioassays were repeated, if control mortality exceeded 20%. Larval mortality was observed at 48 hrs after treatment (HAT) for individual insecticides as well as mixtures. For preparation of insecticides combination, λ-cyhalothrin 5 EC was used at different ratios. The mortality data observed was corrected according to the Abbott formula (Abbott, 1925). LC_{50} for individual insecticides as well as, insecticide combination and fiducial limits were determined according to probit analysis (Finney, 1971) by using SPSS software. Toxicity index values and co-toxicity coefficient on LC_{50} were calculated by the method of Sun (1950) and Sun and Johnson (1960), respectively. Toxicity index (T.I.), which was relative value to express toxicity of insecticides, is defined as the ratio between LC_{50} of a standard insecticide and LC_{50} of the test sample, multiplied by 100.

Bioefficacy under field conditions: Bio-efficacy of individual as well as insecticide mixtures, which exhibited synergistic action (with more than 100 co-toxicity factor) in laboratory, were evaluated against *S. obliqua* under field conditions during 2013 cropping season at ICAR-CRIJAF, Research Farm, Barrackpore. Jute (cv. JRO 204) seeds were sown in 4 m x 3 m plot size at 15 cm row to row and 3 cm plant to plant spacing. The experiment was conducted in randomized black design (RBD) with 10 treatments (1. Flubendiamide 480 EC @0.464 ppm, 2. Emamectin benzoate 5 SG @ 1.022 ppm, 3. Chlorantraniliprole 18.5 EC @0.424 ppm, 4. λ-cyhalothrin 5 EC @1.972 ppm, 5. Profenophos 50 EC @6.526 ppm, 6. Emamectin benzoate 5 SG+ λ-cyhalothrin 5 EC (1:1) @ 0.542 ppm, 7. Profenophos 50 EC+ λ-cyhalothrin 5 EC (1:3) @ 5.862 ppm, 8. Profenophos 50 EC+ λ-cyhalothrin 5 EC (1:1) @ 3.95 ppm, 9. Profenophos 50 EC+ λ-cyhalothrin 5 EC (3:1) @ 6.640 ppm, 10. Control) including control and each treatment was replicated thrice. Two insecticide treatments were applied to jute plants during 90 and 105 days after sowing (DAS) at 15 days' interval. Each plot was sprayed as per treatment using knapsack hand sprayer. Pre-counting of percent infested plants, a day before spraying on 10 plants/plot randomly, was done. Post-spray counting was done 2 days after treatment (DAT). The data on percent infestation was subjected to ANOVA after angular transformation. Modified Abbot's formula was used for calculation of percentage reduction of pest population over control (Abbott, 1925, Fleming and Ratnakaran, 1985).

$$P = 100 \times 1/Tb \times Ca$$

where, P = Percentage damage reduction over control, Ta =

Damage in treatment after spray, Ca = Damage in control after spray, Tb = Damage in treatment before spray, Cb = Damage in control before spray.

Results and Discussion

Bioassay studies using third instar larva of *S. obliqua* for calculating median lethal concentration (LC_{50}) for all the test insecticides were as follows: chlorantraniliprole (LC_{50} 0.212 ppm), flubendiamide (LC_{50} 0.232 ppm), emamectin benzoate (LC_{50} 0.511 ppm), λ-cyhalothrin (LC_{50} 0.985 ppm) and profenophos (LC_{50} 3.263 ppm) (Table 1). It was evident that amongst all the test insecticides, chlorantaniliprole proved to be more toxic and profenophos was least toxic at 24 HAT. Earlier, studies showed that chlorantraniliprole LC_{50} value ranged from 0.01-0.09 ppm against *Plutella xylostella, Spodoptera litura*, *Spodoptera frugiperda*, *Heliothis virescens, Heliothis zea* (Lahm *et al.,* 2007; Temple *et al*., 2009; Satish and Goud, 2013). Likewise, for flubendiamide LC_{50} ranged from 0.004-0.58 ppm against eight lepidopteran pests of cabbage, rice and tea crops (Tohnishi *et al.,* 2005); for emamectin benzoate LC_{50} value differed from 0.009 ppm against *Plutella xylostella* (Satish and Goud, 2013); 0.017 ppm against *Spodoptera littoralis* (Korrat *et al.,* 2012); 0.08 ppm against *Spodoptera litura* (Bhatti *et al.,* 2013); for λ-cyhalothrin LC_{50} value varied from 10.22 ppm and 62.25 ppm against *P. xylostella* and *S. litura,* (Satish and Goud, 2013); 71.31 ppm against *H. armigera* (Khan *et al.,* 2006). Similarly, LC_{50} values for profenophos varied from 10.9 ppm and 18.71 ppm against *S. littoralis* and *S. litura*, respectively (Rehan *et al.,* 2011; Korrat *et al.,* 2012). These results are closely in line with the request of present study. However, there are little differences that could be due to less selection pressure of insecticides among *S. obliqua* field population and other experimental factors.

Median lethal concentration (LC_{50}) derived for different insecticidal mixtures in combination with λ-cyhalothrin at various proportions (1:1, 1:3, 3:1) at 24 HAT revealed that the insecticidal mixture of flubendiamide with λ-cyhalothrin in 3:1 proportion was most toxic (LC_{50} 0.103 ppm) amongst all the other insecticidal combinations with lambda cyhalothrin followed by flubendiamide + λ-cyhalothrin in 1:1 (LC_{50} 0.131 ppm). Chlorantraniliprole in combination with λ-cyhalothrin at 1:1 proportion (LC_{50} 0.209 ppm) was most toxic followed by 3:1 proportion (LC_{50} 0.345 ppm). Similarly, emamectin benzoate in combination with λ-cyhalothrin at 1:1 proportion was more toxic (LC_{50} 0.271 ppm) than 3:1 ratio (LC_{50} 0.333 ppm). Insecticidal mixture of profenophos with λ-cyhalothrin was least toxic among all the combinations with median lethal concentrations ranging from 1.975 to 3.323 (Table 1).

T.I. for insecticidal mixtures at various combinations revealed that flubendiamide + λ-cyhalothrin at 3:1 ratio recorded highest T.I. (970.87), while profenophos + λ-cyhalothrin at 3:1 ratio recorded the least (T.I. 30.09) (Table 2). Co-toxicity coefficient evaluated, based on LC_{50} using toxicity index revealed that flubendiamide, in combination with λ-cyhalothrin at all proportions proved to be antagonistic and co-toxicity coefficient was in the magnitude of 28-64. In contrary to these results, a novel insecticide formulation (AMPLIGOA® 150 ZC) in combination with chlorantraniliprole 100 g l^{-1} (10% w /v) + λ-cyhalothrin 50 g l^{-1} (5% w/v) demonstrated significant levels of toxicity to several lepidopteron targets worldwide (Regupathy and Sathyaseelan, 2011; Fanigliulo *et al.,* 2012). Combination of

Table 1 : Toxicity of insecticides and insecticide mixtures against third instar larvae of *S. obliqua*

Insecticide	Ratio of mixtures	LC_{50} (ppm)	Fiducial limits (ppm)	Chi-square
Flubendiamide 480 EC	-	0.232	0.184-0.279	1.78
Emamectin benzoate 5 SG	-	0.511	0.378-0.665	0.85
Chlorantraniliprole 18.5 EC	-	0.212	0.162-0.259	1.65
λ-cyhalothrin 5 EC	-	0.986	0.740-1.271	1.60
Profenophos 50 EC	-	3.263	2.450-4.586	0.20
Flubendiamide 480 EC + λ-cyhalothrin 5 EC	1:1	0.131	0.097-0.165	0.66
Flubendiamide 480 EC + λ-cyhalothrin 5 EC	1:3	0.437	0.323-0.580	0.57
Flubendiamide 480 EC + λ-cyhalothrin 5 EC	3:1	0.103	0.085-0.120	2.73
Emamectin benzoate 5 SG + λ-cyhalothrin 5 EC	1:1	0.271	0.190-0.366	0.94
Emamectin benzoate 5 SG + λ-cyhalothrin 5 EC	1:3	0.775	0.557-1.098	0.22
Emamectin benzoate 5 SG + λ-cyhalothrin 5 EC	3:1	0.333	0.246-0.437	0.51
Chlorantraniliprole 18.5 EC + λ-cyhalothrin 5 EC	1:1	0.209	0.172-0.253	2.29
Chlorantraniliprole 18.5 EC + λ-cyhalothrin 5 EC	1:3	0.637	0.459-0.885	0.34
Chlorantraniliprole 18.5 EC + λ-cyhalothrin 5 EC	3:1	0.345	0.264-0.443	0.86
Profenophos 50 EC+ λ-cyhalothrin 5 EC	1:1	2.931	2.158-3.919	0.04
Profenophos 50 EC+ λ-cyhalothrin 5 EC	1:3	1.975	1.425-2.612	0.26
Profenophos 50 EC+ λ-cyhalothrin 5 EC	3:1	3.323	2.306-4.745	0.06

1:1= 50% of test insecticide (A): 50% of sample insecticide (B); 1:3= 25% of test insecticide (A): 75% of sample insecticide (B); 3:1= 75% of test insecticide (A): 25% of sample insecticide (B). A= Flubendiamide 480 EC, Emamectin benzoate 5 SG, Chlorantraniliprole 18.5 EC, Profenophos 50 EC. B= λ-cyhalothrin 5 EC.

emamectin benzoate with λ-cyhalothrin at 1:3 and 3:1 ratio showed antagonism with co-toxicity ratio of 89.15 and 52.75. However at 1:1 proportion it was synergistic in action with co-toxicity ratio of 126.94. Similar synergistic action was reported by Nasir *et al.* (2013) against *Plutella xylostella*. Insecticidal mixture of chlorantraniliprole and λ-cyhalothrin followed a similar trend of flubendiamide and λ-cyhalothrin combination, and was antagonistic in action at all proportions with co-toxicity coefficients ranging from 16.29-35.39 indicating to avoid these combinations in multiple pest situations. Co-toxicity coefficient values based on median lethal concentrations and toxicity index for insecticidal mixture of profenophos and λ-cyhalothrin were 203.16 for 3:1, 197.35 for 1:3 and 168.61 for 1:1 proportions respectively and proved to be synergistic in action (Table 2). Synergistic effect might be due to dissimilar mode of action on target pest. However, Nasir et al. (2013) found that antagonistic in action against *P. xylostella* when mixing profenophos with λ-cyhalothrin. This variation might be due to pre-exposer of the pest population to this conventional insecticidal group for many generations coupled with multiple resistance mechanisms

Table 2.: Co-toxicity coefficient of insecticidal combinations based on median lethal concentration (LC_{50}) and toxicity index

Insecticide	Ratio of mixtures	Toxicity index	Actual toxicity index of mixture	Theoretical toxicity index of mixture	Co-toxicity coefficient	Effect
Flubendiamide 480 EC + λ-cyhalothrin 5 EC	1:1	763.35	177.09	266.21	66.52	Antagonistic
Flubendiamide 480 EC + λ-cyhalothrin 5 EC	1:3	228.83	53.08	183.80	28.87	Antagonistic
Flubendiamide 480 EC + λ-cyhalothrin 5 EC	3:1	970.87	225.24	348.62	64.60	Antagonistic
Emamectin benzoate 5 SG + λ-cyhalothrin 5 EC	1:1	369.00	188.56	148.54	126.94	Synergistic
Emamectin benzoate 5 SG + λ-cyhalothrin 5 EC	1:3	129.03	65.93	124.97	52.75	Antagonistic
Emamectin benzoate 5 SG + λ-cyhalothrin 5 EC	3:1	300.33	153.45	172.11	89.15	Antagonistic
Chlorantraniliprole 18.5 EC + λ-cyhalothrin 5 EC	1:1	478.46	101.43	286.54	35.39	Antagonistic
Chlorantraniliprole 18.5 EC + λ-cyhalothrin 5 EC	1:3	156.98	33.28	193.97	17.15	Antagonistic
Chlorantraniliprole 18.5 EC + λ-cyhalothrin 5 EC	3:1	289.85	61.44	379.11	16.20	Antagonistic
Profenophos 50 EC+ λ-cyhalothrin 5 EC	1:1	34.11	111.32	66.02	168.61	Synergistic
Profenophos 50 EC+ λ-cyhalothrin 5 EC	1:3	50.63	165.21	83.71	197.35	Synergistic
Profenophos 50 EC+ λ-cyhalothrin 5 EC	3:1	30.09	98.19	48.33	203.16	Synergistic

1:1= 50% of test insecticide (A): 50% of sample insecticide (B); 1:3= 25% of test insecticide (A): 75% of sample insecticide (B); 3:1= 75% of test insecticide (A): 25% of sample insecticide (B). A= Flubendiamide 480 EC, Emamectin benzoate 5 SG, Chlorantraniliprole 18.5 EC, Profenophos 50 EC. B= λ-cyhalothrin 5 EC.

Table 3: Bio-efficacy of individual as well as insecticide combinations on *S. obliqua* damage and fibre yield under field conditions

Treatments	First spray at 90 DAS Infestation (%)			Second spray at 105 DAS Infestation (%)			
	Pre-spray	2 DAT	Reduction (%)	Pre-spray	2 DAT	Reduction (%)	Fibre Yield (q/ha)
Flubendiamide 480 EC (0.464 ppm)	26.42 (30.93)	10.83 (19.21)	62.38	29.93 (33.17)	10.14 (18.57)	65.96	31.45
Emamectin benzoate 5 SG (1.022 ppm)	25.92 (30.60)	11.14 (19.50)	60.53	32.65 (34.85)	11.59 (19.90)	64.33	30.57
Chlorantraniliprole 18.5 EC (0.424 ppm)	26.55 (31.02)	10.19 (18.62)	64.77	31.42 (34.09)	9.83 (18.27)	68.57	33.83
λ-cyhalothrin 5 EC (1.972 ppm)	27.60 (31.69)	14.25 (22.18)	52.53	31.55 (34.17)	14.12 (21.51)	57.16	28.50
Profenophos 50 EC (6.526 ppm)	25.87 (30.57)	16.81 (24.21)	40.22	30.87 (33.75)	11.92 (22.72)	51.67	26.17
Emamectin benzoate 5 SG+ λ-cyhalothrin 5 EC (1:1) (0.542 ppm)	25.72 (30.47)	8.88 (17.34)	68.25	31.57 (34.19)	8.43 (16.88)	73.17	34.50
Profenophos 50 EC+ λ-cyhalothrin 5 EC (1:3) (5.862 ppm)	27.51 (31.63)	6.29 (14.52)	78.97	29.84 (33.11)	5.02 (12.95)	83.10	36.27
Profenophos 50 EC+ λ-cyhalothrin 5 EC (1:1) (3.95 ppm)	26.51 (30.99)	11.23 (19.58)	61.03	33.51 (35.37)	11.63 (19.94)	65.13	31.07
Profenophos 50 EC+ λ-cyhalothrin 5 EC (3:1) (6.640 ppm)	25.86 (30.57)	5.44 (13.49)	80.66	30.85 (33.74)	3.34 (10.53)	89.12	38.67
Untreated control	27.37 (34.06)	29.73 (34.18)	-	31.37 (34.06)	31.55 (34.18)	-	23.33
Sem±	0.70	0.41	-	0.60	0.33	-	1.78
LSD (P=0.05)	NS	0.84	-	NS	0.69	-	4.30

DAT-Days after treatment * Figures in the parenthesis are arc sin transformed values developed by the pest.

In the present study though flubendimide and chlorantraniliprole belong to same insecticide group with similar mode of action can be attributed to the fact of proving to antagonistic with λ-cyhalothrin that targets voltage gated Na^{+} channels (IRAC, 2010). This is in accordance with co-toxicity coefficient values obtained (<100) (Sun, 1950) imparting to independent mode of action. These similar interaction with either additive or antagonistic effect might be due to selection of resistance alleles for these mechanisms in field populations. There existed variation in response to tested insecticides which might be due to variation in exposure to insecticide dose rate, frequency, location, crop and difference in insecticide choice for its control (Mohan and Gujar, 2003). Chlorantraniliprole and flubendiamide are extremely potent and have broad spectrum activity within the Lepidoptera insects and excellent selection for use in integrated pest management programme where insecticide rotations are needed to slow the resistance development as well as in regions where commercial standards are no longer effective because of resistance. In general, these insecticides provide rapid plant protection through cessation of larval feeding, regurgitation, lethargy and contractile paralysis which happens soon after consumption. The resulting mortality generally occurs after 1-3 days (Temple *et al.,* 2009; Lahm *et al*., 2009).

Emamectin benzoate and flubendiamide showed synergistic effect with bifenthrin against different insects confirming its possible use in mixture for different insects (Attique *et al.,* 2006). In the present study, emamectin benzoate, which is a microbial product of avermectin group, proved to be synergistic with lambda cyhalothrin in combination at equal proportions. Avermectin (similar to emamectin benzoate group) and cartap hydrochloride significantly caused toxicity to *S. obliqua* (Bhattacharya and Parmanik, 2005). Attique *et al.* (2006) documented synergism of chlorpyriphos and bifenthrin in binary combinations of emamectin benzoate and spinosad against diamondback moth, *Plutella xylostella*. Similarly, the most common pyrethroid, λ-cyhalothrin is still used with chlorantraniliprole, profenophos and thiamethoxam as commercial products. They have been used against many agriculturally important insect pests. In the present study, emamectin benzoate 5 SG with λ-cyhalothrin 5 EC in equal proportion (1:1) and profenophos 50 EC with λ-cyhalothrin 5 EC in all three combinations (1:1, 1:3, 3:1) proved to be synergistic in action.

The promising insecticide combinations with least LC_{50} value were evaluated for their bio-efficacy against *S. obliqua* under field conditions at concentrations twice the LC_{50} value. The initial plant damage of *S. obliqua* not varied significantly at one day before imposing treatment ranged from 25.72-27.60% which were at par each other. Post treatments, indicated that, all the treatments were found effective in reducing the infestation of *S. obliqua* significantly in comparison to control with maximum fibre yield. Sole application of flubendiamide, emamectin benzoate, chlorantraniliprole, λ-cyhalothrin and profenophos resulted in 62.38, 60.53, 64.77, 52.53, 40.22 and 65.96, 64.33, 68.57, 57.16, 51.67% reduction in *S. obliqua* infestation during first and second spray, respectively (Table 3). Likewise, insecticide combinations *i.e.,* emamectin benzoate + λ-cyhalothrin (1:1), profenophos + λ-cyhalothrin (1:3), profenophos + λ-cyhalothrin (1:1) and profenophos + λ-cyhalothrin (3:1) ratio resulted in 68.25, 78.97, 61.03, 80.66% and 73.17, 83.10, 65.13, 89.12% respectively during first and second spray, respectively. The four insecticide combinations standardized in the present study reduced *S. obliqua* infestation better than their component applied individually with significantly higher yield. However, profenophos + λ-cyhalothrin (3:1) was found superior insecticide combination with 89.12% reduction in infestation during both the sprays and resulted in maximum fibre yield (38.67q ha^{-1}). The field experiment conducted in the present study proved the impact of joint toxicity of insecticides in reducing damage, and the increased yield is in accordance with the findings of Jayanthi and Padmavathamma (2001) where binary combinations of fenvelarate (0.005%) and *Bacillus thuringiensis kurstaki* ($1x10^{7}$ spores ml^{-1}) contributed to significant reduction in larval damage by *Spodoptera litura* and increased yield of groundnut. A new molecule flubendiamide 20 WG @ 50 g a.i. ha^{-1} was found superior in reducing the incidence of fruit borers in chilli, rice stem borer, *Scirphophaga incertulas* and leaf folder, *Cnaphalocrocis medinalis*, *Helicoverpa armigera* on cotton and diamondback moth damage in cabbage with highest yield (Tatagar *et al.,* 2009; Lakshminarayana and Rajashri, 2006; Ameta and Bunker, 2007; Mallikarjunappa *et al*., 2008). Application of chlorantraniliprole @ 40 g a.i. was significantly superior in its efficacy with 95-97% reduction in percent shoot damage, 87-90% reduction in fruit damage of *Leucinodes orbonalis* (Misra, 2011). Manu *et al.* (2014) observed that flubendiamide 480 SC @ 0.2 ml l^{-1} was significantly superior in reducing *S. obliqua* and recorded highest yield (23.95 q/ha) in soybean crop. However, highest B: C ratio was recorded in λ-cyhalothrin 5 EC treatment. Based on the findings of present research it can be concluded that insecticides emamectin benzoate and profenophos possessing novel mode of action, when used in binary combinations with conventional insecticides, (λ-cyhalothrin) improved the performance to maximum level at low rates of application over a long period of time, and contribute to significant yield production with least *S. obliqua* infestation.

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