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Impact of some selected insecticides and bio-pesticides on incidence of predators, parasitoid and productivity of lac insect, *Kerria lacca*

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ABSTRACT

Two lepidopteran predators, *Eublemma amabilis* and *Pseudohypatopa pulverea* and *Aprostocetus purpureus* an endoparasitoid have emerged as a major threat to lac cultivation. The objectives of the current study were to identify some potential insecticides and bio-pesticides against major biotic stress of lac crop. Field evaluation of spinosad 2.5SC, indoxacarb 14.5SC, fipronil 5SC, ethofenprox 10EC and three commercial formulations of *Bacillus thuringiensis* var. *kurstaki* on *rangeeni* and *kusmi* lac culture reveal significant reduction in incidence of *Eublemma amabilis* and *Pseudohypatopa pulverea* attacking *Kerria lacca*. The reduction in incidence of *E. amabilis* ranged from 42.47 - 96.24% and 65.00 - 95.00% and *P. pulverea* ranged from 52.50 - 97.50% and 66.67 - 100.00% during *rangeeni* rainy and summer crop, respectively. The reduction in the incidence of *E. amabilis* and *P. pulverea* on *kusmi* winter lac crop recorded to the tune of 61.02 - 93.55% and 12.86 - 98.57%, respectively whereas, on *kusmi* summer crop it was 56.16 to 95.52% and 66.17 to 98.50%, respectively. Productivity of lac increased to the tune of 78.95 to 168.42% and 11.40 to 36.84% in *kusmi* winter and summer lac crop, respectively whereas 33.33 to 166.67% in *rangeeni* rainy lac crop. Higher fecundity and superior quality broodlac was obtained from treated crops. Insecticides, spinosad, indoxacarb, fipronil, ethofenprox and bio-pesticides therefore can be used for effective suppression of predators attacking lac culture.

Key words: *Aprostocetus purpureus, Bacillus thuringiensis, Eublemma amabilis,* Insecticides, *Kerria lacca, Pseudohypatopa pulverea*

Lac is a commercial crop produced by lac insect, *Kerria lacca* (Kerr) (Homoptera: Tachardiidae) as a protective covering on its body. Lac insects basically produced three natural products, viz. resin, dye and wax of commercial importance which finds application in many industrial sectors like food, cosmetic and jewellery, electrical and electronics, pharmaceutical, textile, adhesive, varnish, lacquer and paints etc. *Rangeeni* and *kusmi* are the two strains of lac insect each having two crops in a year. Lac insect thrives on more than 400 host plant species but *Schleichera oleosa* (*kusum*), *Butea monosperma* (*palas*), *Ziziphus mauritiana* (*ber*) and *Flemingia semialata* is the major lac host plants commercially exploited for lac cultivation. India is the world leader in best quality lac production. Other lac producing countries are Indonesia, Thailand, parts of China, Myanmar, Philippines, Vietnam and Cambodia etc. Like any other agricultural crops, lac crop is also prone to attack by number of insect pests among them, the two lepidopteran predators, viz. *Eublemma amabilis* Moore (Lepidoptera: Noctuidae) and *Pseudohypatopa pulverea* Meyr (Lepidoptera: Blastobasidae) are the key pests causing severe damage to the lac crop. It has been estimated that about 30-40% of lac crop is lost annually due to predatory ravages alone (Malhotra and Katiyar 1979, Bhattacharya *et al*. 2005). The larvae of *E. amabilis* and *P. pulverea* after hatching from the eggs on the surface of lac colonies lead a cryptic mode of life by burrowing and tunneling within the lac encrustation and feeding on the lac insects. Severe infestation of these predators has been reported to cause complete lac crop failure. Chemical control is the primary method for managing these lepidopteran predators of lac insect. In recent years, Bio-intensive Insect Pest Management Programmes (BIPM) has been promoted as alternative to traditional broad spectrum synthetic chemicals.

The chemical pesticides recommended by earlier workers for the management of lac insect's predators were endosulfan and cartap hydrochloride (Malhotra and Katiyar 1979, Bhattacharya *et al.* 2005), dichlorvos and ethofenprox (Mishra *et al.* 1995, 1996; Jaiswal *et al*. 2004). The use of endosulfan has been banned in most of the developed countries (Arora *et al*. 2009) and recently its use in India has been temporarily

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banned by the directive of Honorable Supreme Court of India. The use of dichlorvos recommended by (Mishra *et al*. 1995, 1996) for the management of lac insect predators has been categorized in highly hazardous category of pesticide by WHO (Arora *et al*. 2009). Scanning of literature clearly indicates that only few chemical pesticides are left available for the management of lac insect predators. The safety of some selected insecticides towards lac insect has been evaluated and established by Singh *et al*. (2011). Certainly it is not possible to achieve the greatest task of improving productivity without effective suppression of pests and diseases. Therefore, significance of agrochemicals in increasing sustained lac productivity cannot be denied and pesticides will continue to play major role in the production system but the question is how to achieve the best without disturbing environment by judicious use of pesticides. *Bacillus thuringiensis* var *kurstaki* is well known microbial pesticide for management of several lepidopteran pests of agricultural crops. Keeping in view it was felt desirable to evaluate some *Bacillus thuringiensis* formulations so the use of chemical pesticides in lac cultivation could be minimized. Hence, the present study was undertaken to evaluate and identify some commercially available *Bacillus thuringiensis* var *kurstaki* formulations along with some naturalyte compound and few safer molecules of chemical pesticides as an alternative to earlier recommended pesticides.

MATERIALS AND METHODS

Response of pesticides was assessed on both *rangeeni* and *kusmi* lac crops for four consecutive years (2007-2011). The experiment was carried out at Institute Research Farm (IRF), Ranchi, Jharkhand, India (23° 19’ 48”N, 85° 22’ 20” E) and Farmers’ field at Putidih, Purulia, West Bengal, India. For conducting experiments, *rangeeni* rainy season (*katki*) lac crop (June-July to October-November) and *rangeeni* summer season (*baisakhi*) lac crop (October-November to June-July) was raised on *palas* by inoculating the broodlac during the months of June-July and October-November every year, respectively. Whereas, *kusmi* winter season (*aghani*) lac crop (June-July to January-February) was raised on *ber* and *kusmi* summer season (*jethwi*) lac crop (January-February to June-July) was raised on *kusum* by inoculating the broodlac during the month of June-July and January- February every year, respectively.

Field evaluation of eight commercially available chemical insecticides and three *Bacillus thuringiensis* var *kurstaki* formulations was carried out during experimentation. The insecticides and bio-pesticides assessed and their concentrations used on different lac crops are presented in Tables 1- 6. The commercial formulations of insecticides available in the market, viz. indoxacarb 14.5% SC (Dupont India Ltd); carbosulfan 25% EC (FMC India Pvt Ltd); spinosad 2.5% SC (Dow Agro Sciences India Ltd); fipronil 5% SC (Bayer Crop Science); lambdacyhalothrin 5% EC (Syngenta Crop Protection Pvt Ltd); alphamethrin 10% EC (Crop Chemicals India Ltd); ethofenprox 10% EC (Northern Minerals Ltd); endosulfan 35% EC (Bayer Crop Science) and commercial *Bacillus thuringiensis* formulations serovar *kurstaki* Halt® 5% WP (serotype H 3a, 3b, 3c procured from Biostadt India Ltd.), Delfin® 85% WG (serotype 3a, 3b, SA 11, and potency: 53000 SU/mg, manufactured by Certis, USA), DOR Bt 1 formulation registered provisionally as Knock WP® 0.5% procured from Directorate of Oilseeds Research, Hyderabad, India were used in the present study. The insecticide endosulfan was also used in present study for comparative efficacy with other pesticides, as it was being used in lac cultivation since 1979 for the management of lac predators.

In respect of assessment of pesticides response on incidence of predators and parasitoid of lac insect for different crops, there were twenty two treatments comprising eight chemical insecticides and one bio-pesticide for *rangeeni* rainy season lac crop. The experiment was replicated eight times whereas, for *rangeeni* summer season lac crop there were only seven treatments which includes five chemical insecticides with six replications. For the evaluation of bio-pesticides and chemical pesticides on *kusmi* winter season lac crop, there were eighteen treatments including control with eleven replications whereas for *kusmi* summer season lac crop there were eleven treatments including control which replicated ten times. Application of pesticides was carried out in the field on standing lac crops with rocking Gator sprayer. First application of pesticides was given on 30-35 day old lac crop (this period coincides with the most critical stage of the predatory caterpillars, i.e. peak period of its egg hatching) followed by second application after 60-65 days of crop inoculation. Pesticide application was targeted on lac bearing tender twigs to cover the lac encrustation with pesticidal spray and also to wash the honey dew secreted by lac insect.

For quantification of predators in lac culture, both treated and untreated lac bearing sticks of one meter shoot length from each treatment were collected 15 days after first and second spraying of pesticides as well as at the stage of crop maturity (broodlac harvesting) following the method of stratified destructive random sampling. The samples were kept inside 60-mesh nylon net bags to assess larvicidal action of the insecticides on lepidopteran predators (*E. amabilis* and *P. pulverea)* of lac insect and to trap the adult stage of predators and parasitoids emerging from collected samples for quantification. The field collected samples were kept inside the 60-mesh nylon net bags and wet cotton swab (water) was put at both the ends of lac bearing twigs to maintain the turbidity of samples and for maintain the lac insects. The mouth of net bags were tied and kept under room temperature for proper aeration and opened after a month of caging. The numbers of living and dead larvae as well as adult moths emerged from the caged samples were quantified in terms of predators per meter lac encrustation and percentage reduction in the incidence of predators was calculated subsequently. Adults of *Aprostocetus purpureus* was also emerged out from the caged samples in large number from *rangeeni* lac crop which was also quantified.

Experiment was laid down to assess the impact of four promising insecticides, viz. indoxacarb, fipronil, spinosad and ethofenprox on the larval delivery of female lac insect (fecundity). There were eight treatments including control with 10 replicates. Two concentrations of indoxacarb (0.007% and 0.014%), fipronil (0.005% and 0.01%), spinosad (0.0025% and 0.005%) and one concentration of ethofenprox (0.02%) have been evaluated on summer season *rangeeni* lac crop for their response on fecundity of lac insect. The randomly selected mature viable female cell showing yellow spots were detached from the treated lac culture, two days prior to larval emergence in the month of July. Ten mother cells collected from each treatment were kept individually in 5 ml glass vial and mouth was plugged with cotton to facilitate proper aeration. The vials were marked and left for emergence of young ones in the vial under laboratory condition. The numbers of offspring produced from each mother cell were counted 30 days after caging and average fecundity per female cell was calculated. The effect of insecticidal treatments on lac productivity was assessed on the basis of dry weight of scrap lac per meter lac encrustation at maturity. The lac was scraped from matured lac bearing twigs (lac stick) and weight of scraped lac per meter lac encrustation was recorded from each treatment. The per cent increase in lac productivity over control was calculated.

The experiment was laid out in Randomized Block Design (RBD). The data on number of predators population obtained was transformed using square root transformation, by the formula $\sqrt{(X + 0.5)}$ to the original values. Data obtained of different crops and locations were pooled together and subjected to statistical analysis after arcsine transformation before running an analysis of variance (ANOVA). Analysis of variance and pair-wise comparison procedure for mean separation was done by using (Tukey's test). For each comparison the P = 0.05 level of significance was used.

RESULTS AND DISCUSSION

The response of biological and chemical pesticides on the incidence of predators and parasitoids as well as other productivity attributes evaluated on different crops of *kusmi* and *rangeeni* lac insect have been depicted from Tables 1 to 6. Pesticides application was found very effective in protecting the lac crop from the incidence of lac insect predators and enhancing the lac productivity in comparison to unprotected crop.

Evaluation on rangeeni rainy season lac crop

Effect on population of Eublemma amabilis

The mean value of *E. amabilis* per meter length of lac encrustation differ significantly over control ($P<0.05$) in all the treatments (Table 1). The best group of treatments includes lambdacyhalothrin (0.005%), alphamethrin (0.005%), carbosulfan (0.02%) and spinosad (0.01%) as far as reduction of incidence is concerned. But lambdacyhalothrin, alphamethrin and carbosulfan have shown long term toxic effect on lac insect culture with slight increase in doses or spray fluid on lac encrustation showed detrimental effects on lac culture (Singh *et al*. 2011). Keeping in view the technical expertise of lac growers, the applications of these pesticides are risky and not advisable during the initial stage of crop growth (first application). Amongst the safer insecticides for lac culture, spinosad (0.01%) was found to be the best treatment with mean value of 0.88/m of lac encrustation and 96.24% reduction of *E. amabilis* population over control. The next group of treatments includes fipronil (0.01%) and indoxacarb (0.02%) with mean values of 2.25 and 2.38/m lac encrustation and the reduction in population to the tune of 90.32% and 89.78%, respectively. The reduction in predator population with the treatment of spinosad (0.007%), indoxacarb (0.01%), carbosulfan (0.01%) and ethofenprox (0.02%) was recorded as 78.49%, 71.51%, 73.66% and 76.34%, respectively. The mean values of *E. amabilis* population varied from 8.0 to 13.38/m lac encrustation in the treatments of Halt *Bt*, fipronil (0.003% and 0.005%), indoxacarb (0.007%) and spinosad (0.005%) as compared to 23.25/m lac encrustation in control with the reduction in predator population ranged from 42.47 to 65.59%. The *Bt* formulation was also found to be equally effective as chemical pesticides in reducing the incidence of lac insect predators.

Effect on population of Pseudohypatopa pulverea

The mean values of all the treatments differ significantly with control ($P<0.05$) (Table 1). The best group of treatments for reducing the incidence of *P. pulverea* was found to be indoxacarb (0.02%), fipronil (0.01%), spinosad (0.01%) and spinosad (0.007%) with reduction to the tune of 97.50%, 91.25%, 86.25% and 82.50%, respectively followed by spinosad (0.005%) with 80.00% reduction in which mean population varies from 0.25 to 2.0/m lac encrustation. The next group of insecticides includes indoxacarb (0.007% and 0.01%) with population reduction to the tune of 68.75 and 71.25%, respectively.

Effect on population of Aprostocetus purpureus

The population of *A. purpureus*, a most prevalent parasitoid of lac insect, did not differ significantly in different treatments (Table 1). Though the residual effect of four chemical insecticides, viz. indoxacarb, spinosad, fipronil and ethofenprox on *A. purpureus* have been evaluated and established under laboratory conditions (unpublished). The discrepancy in efficacy might be attributed due to non-matching application time under field condition or due to short life cycle of the parasitoids.

Table 1 Effect of insecticides on incidence of predators and parasitoids of lac insect on *rangeeni* rainy season crop

Insecticide	Conc. (%)	*Eublemma amabilis*		*Pseudohypatopa pulverea*		*Aprostocetus purpureus*	
		Average number/ meter	% reduction over control	Average number/ meter	% reduction over control	Average number/ meter	% change over control
Halt (5% WP)	0.01	8 (2.90)^{fgh}	65.59	4.25 (2.05)^{fgh}	57.5	72.2 (8.01)	–7.76
Fipronil (5% SC)	0.003	13.38 (2.88)^{h}	42.47	4.75 (2.06)^{fghi}	52.5	194.6 (11.52)	–190.45
	0.005	8 (2.83)^{fgh}	65.59	3.63 (1.86)^{defghi}	63.75	51.6 (6.33)	22.99
	0.01	2.25 (1.59)^{bcd}	90.32	0.88 (1.03)^{abc}	91.25	26.6 (4.68)	60.3
Lambdacyhalothrin (5% SC)	0.002	5.25 (2.18)^{cdef}	77.42	1.63 (1.36)^{abcde}	83.75	33.4 (5.53)	50.15
	0.005	2.38 (1.49)^{bc}	89.78	0.25 (0.84)^{ab}	97.5	72.2 (7.76)	–7.76
	0.008	1 (1.10)^{ab}	95.7	0 (0.71)^{a}	100	61.4 (7.08)	8.36
Alphamethrin (10% EC)	0.002	3.5 (1.88)^{cde}	84.95	2.75 (1.61)^{cdefgh}	72.5	77.4 (7.89)	–15.52
	0.005	2.13 (1.54)^{bcd}	90.86	2 (1.45)^{bcdef}	80	27 .0 (4.18)	59.7
	0.01	0 (0.71)^{a}	100	0 (0.71)^{a}	100	72.4 (7.96)	–8.06
Indoxacarb (14.5% SC)	0.007	11.25 (3.35)^{h}	51.61	3.13 (1.64)^{cdefgh}	68.75	74.4 (7.88)	–11.04
	0.01	6.63 (2.51)^{efg}	71.51	2.88 (1.55)^{cdefgh}	71.25	36.2 (4.97)	45.97
	0.02	2.38 (1.55)^{bcd}	89.78	0.25 (0.84)^{ab}	97.5	53 (6.75)	20.9
Carbosulfan (25% EC)	0.01	6.13 (2.35)^{efg}	73.66	6.75 (2.46)^{i}	32.5	136.6 (9.14)	–103.88
	0.02	3.38 (1.92)^{cde}	85.48	5.63 (2183)^{hi}	43.75	64.2 (7.11)	4.18
	0.05	0.75 (1.05)^{ab}	96.77	2.38 (1.50)^{bcdefg}	76.25	61.4 (6.34)	8.36
Spinosad (2.5% SC)	0.005	11.13 (3.29)^{h}	52.15	1.75 (1.42)^{bcdef}	82.5	89.8 (8.83)	–34.03
	0.007	5 (2.26)^{def}	78.49	2 (1.34)^{abcde}	80	71.2 (7.67)	–6.27
	0.01	0.88 (1.06)^{ab}	96.24	1.38 (1.21)^{abcd}	86.25	194.6 (8.01)	–190.45
Ethofenprox (10% EC)	0.02	5.5 (2.40)^{efg}	76.34	4 (1.89)^{efghi}	60	51.6 (8.83)	22.99
Endosulfan (35% EC)	0.05	9.38 (3.04)^{gh}	59.68	2.5 (1.61)^{cdefgh}	75	26.6 (7.67)	60.3
Control	Water	23.25 (4.77)^{i}	0	10 (3.18)^{ghi}	0	67 (7.33)	0
SEd ±		0.37		0.33		1.99	
F		14.15		7.99		1.47	
CD (P = 0.05)		0.74		0		NS	

Figures in parentheses are (X + 0.5) transformed values

Within columns, means followed by the same letter do not differ significantly (P<0.05)

Evaluation on rangeeni summer season lac crop

Effect on population of Eublemma amabilis

The mean value of *E. amabilis* population differ significantly in all treatments as compared to control (P<0.05) (Table 2). The maximum reduction in population (95.00%) was recorded with the treatment of indoxacarb (0.01%) followed by indoxacarb (0.007%), spinosad (0.005%), fipronil (0.005%), ethofenprox (0.02%) and endosulfan (0.05%) in which it ranged from 80.00 to 65.00%.

Effect on population of Pseudohypatopa pulverea

The mean values of *P. pulverea* population differ significantly from that of control (P<0.05) as in case of *E. amabilis.* All the treatments were found to be statistically at par and significantly superior over endosulfan (0.05%) as this insecticide was in practice for the control of *P. pulverea* since last 32 years (Table 2). The maximum population reduction (100.00%) was recorded with the treatment of fipronil (0.005%) whereas indoxacarb (0.01%) and spinosad (0.005%) causes 93.94% population reduction. The other treatment causes 81.82 to 66.67% population reduction. The mean values in different treatments varied from 0.0 to 6.05/m lac encrustation as compared to 18.15/m lac encrustation in control.

Effect on population of Aprostocetus purpureus

The result with respect to *A. purpureus* is almost similar to that of *rangeeni* rainy season lac crop as no significant differences in different treatments was observed as compared to control (Table 2).

Evaluation on kusmi winter season lac crop

Effect on population of Eublemma amabilis

The mean value of *E. amabilis* population in all treatments comprising eight insecticides differ significantly over control (P<0.05) (Table 3). The best group of treatments includes Halt® (0.01, 0.015 and 0.02%), Delfin® (0.05%), indoxacarb (0.0035% and 0.007%) and spinosad (0.01%) in which the mean values of predator population varied from 2.18 to 5.18/m of lac encrustation and per cent reduction in the incidence over control varied from 84.68 to 93.35 which were at par with each other. Spinosad (0.0025% and 0.005%) resulted in 76.35% and 77.96% population reduction with mean values of 8.00 and 7.45/m lac encrustation, respectively. Ethofenprox (0.02%) is the recommended insecticide for pest suppression on winter season *kusmi* lac crop in which reduction in *E. amabilis* incidence was recorded as 74.46%. The other insecticides and bio-pesticides which were found at par with ethofenprox (0.02%) includes Halt® (0.01%), Knock WP® (0.002%), indoxacarb (0.0035% and 0.007%), fipronil (0.005%) and spinosad (0.0025 and 0.005%). Amongst the bio-pesticides, Delfin® and Halt® have shown more pronounced effect than Knock WP®.

Effect on population of Pseudohypatopa pulverea

The perusal of data presented in Table 3 reveals that the mean value of all treatments except Knock WP® (0.0005%) differ significantly as compared to control (P<0.05). The most effective treatments were spinosad (0.005% and 0.01%), Halt® (0.02%), Delfin® (0.05%), and indoxacarb (0.0035% and 0.007%) in which per cent reduction in the incidence of *P. pulverea* varied from 90.00 to 98.57 with mean values in population ranged from 0.10 to 0.70/m lac encrustation. The next effective treatments include Halt® (0.015%) and Knock WP® (0.0015%) with incidence reduction as 72.86 and 65.71%, respectively followed by ethofenprox (0.02%) with 68.57% reduction. The ethofenprox (0.02%), presently in use on *kusmi* lac crop were at par with Halt® (0.01 and

Table 2 Effect of insecticides on incidence of predators and parasitoids of lac insect on *rangeeni* summer season crop

Insecticide	Conc. (%)	*Eublemma amabilis*		*Pseudohypatopa pulverea*		*Aprostocetus purpureus*	
		Average number/ meter	% reduction over control	Average number/ meter	% reduction over control	Average number/ meter	% change over control
Fipronil (5%SC)	0.005	5.50 (2.29)ᵃ	75.00	0.00 (0.71)ᵃ	100.00	127.05 (10.35)	3.35
Indoxacarb (14.5% SC)	0.007	4.40 (1.95)ᵃ	80.00	3.30(1.48)ᵃᵇ	81.82	62.70 (6.62)	52.30
	0.01	1.10 (1.03)ᵃ	95.00	1.10 (1.03)ᵃ	93.94	81.95 (9.22)	37.66
Spinosad (2.5% SC)	0.005	4.95 (2.07)ᵃ	77.50	1.10 (1.03) ᵃ	93.94	67.10 (7.76)	48.95
Ethofenprox (10% EC)	0.02	5.50 (1.71)ᵃ	75.00	3.85 (1.95)ᵃᵇ	78.79	36.85 (5.72)	71.97
Endosulfan (35% EC)	0.05	7.70 (2.34)ᵃ	65.00	6.05 (2.41)ᵇ	66.67	52.25 (6.30)	60.25
Control	Water	22.0 (4.58)ᵇ	0.00	18.15 (3.89)ᶜ	0.00	131.45 (9.54)	0.00
SEd ±		0.70		0.67		2.50	
F		4.93		5.42		1.00	
CD (P = 0.05)		1.44		1.36		NS	

Figures in parentheses are $\sqrt{(X + 0.5)}$ transformed values

Within columns, means followed by the same letter do not differ significantly (P<0.05)

Table 3 Effect of insecticides on incidence of lepidopteran predators on *kusmi* winter season lac crop

Insecticide	Conc. (%)	*Eublemma amabilis*		*Pseudohypatopa pulverea*	
		Average number/meter	% reduction over control	Average number/meter	% reduction over control
Halt (5% WP)	0.005	9.55 (0.93)fgh	71.78	4.20 (1.97)efg	40.00
	0.010	5.18 (0.69)bcdef	84.68	2.50 (1.58)de	64.29
	0.015	4.18 (0.62)abcd	87.64	1.90 (1.44)bcd	72.86
	0.020	2.18 (0.45)a	93.55	0.30 (0.82)a	95.71
Knock (0.5%)	0.0005	13.18 (1.10)h	61.02	6.10 (2.41)gh	12.86
	0.001	12.55 (1.07)h	62.91	4.40 (2.08)fg	37.14
	0.0015	11.18 (1.01)gh	66.94	2.40 (1.42)bcd	65.71
	0.002	7.55 (0.83)defgh	77.69	2.60 (1.51)d	62.86
Delfin (85% WG)	0.05	2.45 (0.48)ab	92.74	0.50 (0.95)ab	92.86
Indoxacarb (14.5% SC)	0.0035	5.18 (0.69)abcde	84.68	0.60 (1.00)abc	91.43
	0.007	4.91 (0.67)abcd	85.48	0.60 (0.97)ab	91.43
Spinosad (2.5% SC)	0.0025	8.00 (0.86)cdefg	76.35	3.20 (1.83)def	54.29
	0.005	7.45 (0.83)cdefg	77.96	0.70 (0.99)abc	90.00
	0.01	3.64 (0.58)abc	89.25	0.10 (0.76)a	98.57
Fipronil (5% SC)	0.005	8.91 (0.90)fgh	73.66	2.40 (1.51)d	65.71
Ethofenprox (10% EC)	0.02	8.64 (0.89)efgh	74.46	2.20 (1.47)cd	68.57
Endosulfan (35% EC)	0.005	11.55 (1.03)h	65.86	2.80 (1.56)de	60.00
Control	Water	33.82 (1.75)i	0.0	7.00 (2.68)h	0.0
SEd ±		0.38		0.25	
F		13.00		9.63	
CD (P = 0.05)		0.75		0.49	

Figures in parentheses are $\sqrt{(X + 0.5)}$ transformed values

Within columns, means followed by the same letter do not differ significantly (P<0.05)

0.015%), Knock WP® (0.0015%), indoxacarb (0.0035%) and spinosad (0.005%). Amongst the bio-pesticides Delfin® (0.05%) was found to be the best treatment followed by Halt® (0.02% and 0.015%) and Knock WP® (0.0015%).

Evaluation on kusmi *summer season lac crop*

Effect on population of Eublemma amabilis

All the treatments were found to be significantly effective in reducing the incidence of *E. amabilis* as the mean value of all the treatments differ significantly from control (P<0.05) (Table 4). The most effective treatment was found to be spinosad (0.01%) with 95.52% reduction in incidence followed by indoxacarb (0.01%), spinosad (0.005%), indoxacarb (0.007%) and fipronil (0.01%) with per cent reduction of 90.30, 84.51, 75.00 and 71.64, respectively and mean values of *E. amabilis* population ranged from 2.40 to 15.20/m lac encrustation. The population reduction in other treatments varied from 56.16% in fipronil (0.005%) to 70.90% in spinosad (0.0025%). All the treatments except fipronil (0.005%) were found significantly superior over earlier recommended insecticides namely ethofenprox (0.02%) and endosulfan (0.05%). *Bt* formulation, Halt® (0.01%) was found significantly more effective than endosulfan (0.05%) and equally effective as ethofenprox (0.02%).

Effect on population of Pseudohypatopa pulverea

All the treatments were found significantly more effective in reducing the incidence of *P. pulverea* as the mean values of all the ten treatments differ significantly over control (P<0.05) (Table 4). The best group of treatments was spinosad (0.005% and 0.01%), indoxacarb (0.007% and 0.014 %) and fipronil (0.005% and 0.01%) which were on par with each other. The mean values varied 0.50 to 3.00/m lac encrustation and per cent reduction is population ranged from 90.98 to 98.50 over control. Data reveals that all the treatments were found to be significantly superior or at par with the earlier recommended ethofenprox (0.02%) and endosulfan (0.05%).

Effect of insecticides on fecundity and lac productivity

The application of insecticides have not shown any detrimental effect on fecundity of *rangeeni* lac insect which is evident from significantly enhanced crawler emergence in various treatment of insecticides. Out of seven treatments of insecticides, the mean number of larvae emerges from each mother cell differ significantly with control except spinosad (0.0025%). The maximum mean fecundity (447.9) was recorded with treatment of indoxacarb (0.007%) followed by ethofenprox (0.02%), fipronil (0.005%), spinosad (0.005%) and indoxacarb (0.01%) with mean values of 373.7, 368.2,

Table 4 Effect of insecticides on incidence of lepidopteran predators on *kusmi* summer season lac crop

Insecticide	Conc. (%)	*Eublemma amabilis*		*Pseudohypatopa pulverea*	
		Average number/meter	% reduction over control	Average number/meter	% reduction over control
Halt (5% WP)	0.010	16.90 (3.96)[def]	68.47	9.50 (3.04)[d]	71.43
Indoxacarb (14.5% SC)	0.007	13.40 (3.54)[cd]	75.00	3.00 (1.78)[ab]	90.98
	0.014	5.20 (2.29)[ab]	90.30	1.13 (1.30)[a]	96.62
Spinosad (2.5% SC)	0.0025	15.60 (3.92)[def]	70.90	6.75 (2.69)[bcd]	79.70
	0.005	8.30 (2.86)[bc]	84.51	2.50 (1.81)[abc]	92.48
	0.01	2.40 (1.72)[a]	95.52	0.50 (1.81)[a]	98.50
Fipronil (5% SC)	0.005	23.50 (4.76)[f]	56.16	2.88 (1.82)[abc]	91.35
	0.01	15.20 (3.71)[cde]	71.64	1.25 (1.43)[a]	96.24
Ethofenprox (10% EC)	0.02	21.30 (4.13)[def]	60.26	9.0 (2.74)[cd]	72.93
Endosulfan (35% EC)	0.005	22.30 (4.57)[ef]	58.40	11.25 (3.31)[d]	66.17
Control	Water	53.60 (7.11)[g]	0.0	33.25 (5.71)[e]	0.0
SEd ±		0.63		0.50	
F		12.23		15.02	
CD (P = 0.05)		1.25		1.00	

Figures in parentheses are $\sqrt{(X + 0.5)}$ transformed values

Within columns, means followed by the same letter do not differ significantly (P<0.05)

364.5 and 329.4 larvae per mother cell, respectively as compared to 239.9 larvae in untreated crop. Mean lowest fecundity from untreated mother cell might be attributed to the attack of natural enemies. Insecticides have not shown any long term residual effect on fecundity of mother cell rather improved the quality of broodlac by way of increased larval emergence per mother cell.

Three bio-pesticides and five chemical insecticides (safe to lac insect at recommended concentrations) comprising seventeen treatments were evaluated on *kusmi* winter crop raised on *Z. mauritiana*. All the treatments were found to be significantly effective in enhancing the productivity of lac as compared to control (P<0.05). Increase in lac productivity over control varied from 78.95 to 168.42% (Table 5). Maximum dry scrap lac weight (170 g/m lac encrustation) was recorded from treatment with indoxacarb (0.007%) and minimum (113.33 g/m lac encrustation) in Halt® formulation (0.005%) as compared to 63.33 g/m lac encrustation in control. The treatments, viz. Halt® ((0.01, 0.015 and 0.02%), Knock WP® (0.001, 0.0015 and 0.02%), Delfin (0.05%), indoxacarb (0.0035 and 0.007%), spinosad (0.005 and 0.01%), fipronil (0.005%), ethofenprox (0.02%) and endosulfan (0.05%) were found to be at par with each other as far as lac productivity/ m lac encrustation and ranged from 107.89 to 168.42%. Similarly, one bio-pesticide and five safer chemical insecticides were evaluated on *kusmi* summer crop raised on *S. oleosa* for their response on lac productivity. All the treatments were found to be effective in enhancing lac productivity over control to a significant level except spinosad (0.0025%) (Table 5).

Eight chemical insecticides were evaluated on *rangeeni* rainy crop raised on *B. monosperma*. Lac productivity (dry scrap lac) per meter lac encrustation has been increased significantly with the application of pesticides as compared to control. Maximum increase of 166.67% dry scrap lac weight/m lac encrustation was recorded with the application of indoxacarb (0.02%) followed by ethofenprox (0.02%), indoxacarb (0.01%) and fipronil (0.005%) in which the increase in productivity were 141.67%, 133.33% and 125.00%, respectively. Indoxacarb (0.007%) and spinosad (0.005%) were equally effective in terms of increased productivity (116.67%). The dry scrap lac weight/m lac encrustation varied from 20.00 g to 40.00 g in different treatments as compared to 15.00 g in control and increase in productivity ranged from 33.33 to 166.67% in different treatments (Table 6).

Malhotra and Katiyar (1979) have reported the efficacy of endosulfan to the early stages of the lepidopteran predators; hence they recommended its use in lac cultivation. The present findings with respect of endosulfan are in agreement with the observation of Malhotra and Katiyar (1979). Bhattacharya *et al*. (2005) have evaluated the efficacy of cartap hydrochloride on *rangeeni* rainy season lac crop and advocated the use of cartap hydrochloride @ 0.05% for effective control of *E. amabilis*. Jaiswal *et al.* (2008) evaluated *Bacillus thuringiensis* var. *kurstaki* (Biolep®) and some commonly used insecticides against *E. amabilis* and *P. pulverea* on *kusmi* winter crop and reported the efficacy of *Bt* formulation at par with endosulfan and ethofenprox and recommended three sprays of the *Bt* formulation @ 0.05% at an interval of 30 days from the time of crop inoculation. Ramoliya *et al.* (2010) evaluated the efficacy of spinosad

Table 5 Response of insecticides on productivity of winter and summer season *kusmi* lac crops

Insecticide	Conc. (%)	*Kusmi* winter crop		*Kusmi* summer crop	
		Average weight (g) of scrap lac/meter lac stick	% increase over control	Average weight (g) of scrap lac/meter lac stick	% increase over control
Halt (5% WP)	0.005	113.33^{d}	78.95		
	0.01	140.00^{abcd}	121.05	128.33^{a}	35.09
	0.015	151.67^{abcd}	139.47		
	0.02	156.67^{abcd}	147.37		
Knock (0.05%WP®)	0.0005	116.67^{cd}	84.21		
	0.001	131.67^{abcd}	107.89		
	0.0015	153.33^{abcd}	142.11		
	0.002	165.00^{ab}	160.53		
Delfin (85% WG)	0.05	166.67^{ab}	163.16		
Indoxacarb (14.5% SC)	0.0035	141.67^{abcd}	123.68		
	0.007	170.00^{a}	168.42	130.00^{a}	36.84
	0.014			118.33^{ab}	24.56
Spinosad (2.5% SC)	0.0025	130.00^{bcd}	105.26	105.83^{bc}	11.40
	0.005	146.67^{abcd}	131.58	126.67^{a}	33.33
	0.01	140.00^{abcd}	121.05		
Fipronil (5% SC)	0.005	136.67^{abcd}	115.79	126.67^{a}	33.33
Ethofenprox (10% EC)	0.02	146.67^{abc}	131.58	116.67^{ab}	22.81
Endosulfan (35% EC)	0.005	153.33^{abcd}	142.11	126.67^{a}	33.33
Control (Water)		63.33^{e}	0.00	95.00^{c}	0.00
SEd ±		23.39		7.84	
F		2.68		3.40	
CD (P = 0.05)		47.56		15.76	

Within columns, means followed by the same letter do not differ significantly (P<0.05)

(0.007%) against *Athalia lugens proxima* and reported highly effective against target pest and recorded the highest yield of radish as compared to other treatment. Spinosad (0.005%) has been reported to be most effective against first and third instars larvae of *Earias vittella* on okra on the basis of their persistent and residual toxicity (Shinde *et al.* 2010). Significant reduction in incidence of pod borers, viz. *Helicoverpa armigera* (Hubner) and *Maruca testulalis* (L.) with significantly high seed yield of pigeonpea with the application of indoxacarb and spinosad have been reported by Ameta *et al.* (2011). Rao and Shivankar (2011) recorded the high mortality of citrus psylla, *Diaphorina citri* by residual effect of spinosad. Sharma and Ramani (2001) found reduced fecundity due to parasitization of female cells which is in conformity with our findings.

The *kusmi* winter crop, which is raised during July to January, passes through critical period of pest infestation due to favourable weather condition prevailing during the rainy season. During rainy season, there is always a risk of rain fastness of applied *Bt* formulations resulting in low bio-efficacy to target pests. Hence it is suggested that if there is indication of rain, chemical pesticides should be applied due to their relatively quicker action on the target pests. The *kusmi* winter crop is also prone to attack by *Chrysopids* and fungal attack. Hence application of chemical insecticide, viz. ethofenprox, indoxacarb, spinosad and fipronil along with fungicide (carbendazim) are being advocated for protecting the *kusmi* lac crop from *Chrysopids* attack and associated fungal infection in general.

The selected insecticides like indoxacarb, spinosad and fipronil as well as *Bt* formulations were found to be very much effective in suppressing the population of lac insect predators. The application of commercial *Bt* formulation evaluated in the present study was found equally effective as chemical insecticides in reducing the incidence of lepidopteran lac insect predators and enhancing the lac productivity. The better efficacy of bio-rational insecticide, spinosad might be due to more penetrable potential and translaminar action. The results of all the promising pesticides have been validated on farmer's field also in most of the lac growing areas of the country. These selected insecticides and bio-pesticides are gaining wider acceptance and are being used by the farmers in all the lac growing tracts of different states (Jharkhand, Chhattisgarh, West Bengal, Odisha, Madhya Pradesh, Uttar Pradesh, Maharashtra and Andhra Pradesh) of India. Application of these pesticides will not only provide ensured

Table 6 Response of insecticides on productivity of *rangeeni* rainy season lac crop

Insecticide	Conc. (%)	Average weight (g) of scrap lac/ meter lac stick	% increase over control
Fipronil (5% SC)	0.005	33.75[ab]	125.00
	0.01	30.00[abc]	100.00
Lambdacyhalothrin (5% SC)	0.005	20.00[cd]	33.33
Alphamethrin (10% EC)	0.005	25.00[bcd]	66.67
	0.01	23.75[bcd]	58.33
	0.02	23.75[bcd]	58.33
Indoxacarb (14.5% SC)	0.007	32.50[abc]	116.67
	0.01	35.00[ab]	133.33
	0.02	40.00[a]	166.67
Carbosulfan (25% EC)	0.01	20.00[cd]	33.33
	0.03	30.00[abc]	100.00
	0.05	26.25[bcd]	75.00
Spinosad (2.5% SC)	0.005	32.50[abc]	116.67
	0.01	31.25[abc]	108.33
Ethofenprox (10% EC)	0.02	36.25[ab]	141.67
Endosulfan (35% EC)	0.05	31.25[abc]	108.33
Control (Water)		15.00[d]	0.00
SEd ±		6.64	
F		1.99	
CD (P = 0.05)		13.36	

Within columns, means followed by the same letter do not differ significantly ($P<0.05$)

lac production but also yielded quality broodlac with no or very less pest infestation.

With suitably integrating bio-pesticides and chemical insecticides and alternative use of these for managing lepidopteran predators, may reduce the pesticide load in lac ecosystem as well as minimize the chances of development of resistance in insect to insecticides. In present study the endosulfan has been included only to evaluate the comparative efficacy with newer insecticides. So, any reference of endosulfan in the manuscript should be taken in that context only. Recently the use of endosulfan has been temporarily banned in India by the directive of Honorable Supreme Court of India.

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REFERENCES

Ameta O P, Sharma U S and Jeengar K L. 2011. Efficacy of flubendiamide 480 SC against pod borers, *Helicoverpa armigera* (Hubner) and *Maruca testulalis* (L.) in pigeonpea. *Indian Journal of Entomology* **73** (3): 191–5.

Arora S, Dureja P, Kanojia A K and Bambawale O M. 2009. *Pesticides, their classification based on WHO and global status of hazardous pesticides.* National Centre for Integrated Pest Management, Pusa Campus, IARI, New Delhi, pp 110.

Bhattacharya A, Jaiswal A K, Kumar S and Kumar M. 2005. Evaluation of cartap hydrochloride for management of *Eublemma amabilis* (Moore) – a serious lepidopteran predator of lac insect. *Journal of Applied Zoological Research* **16** (1): 93–4.

Jaiswal A K, Bhattacharya A, Kumar K K and Kumar S. 2004. Evaluation of ethofenprox (Nukil 10 E.C.) on lac insect culture for management of *Eublemma amabilis* Moore – a lepidopteran predator. *New Horizon of Animal Sciences*, pp 47–50. Pandey B N, Natarajan P, Armugam N and Premjith S (Eds). Zoological Society of India, Magadh University, Bodh Gaya, Bihar.

Jaiswal A K, Bhattacharya A, Kumar S and Singh J P. 2008. Evaluation of *Bacillus thuringiensis* Berliner subsp. *kurstaki* for management of lepidopteran pests of lac insect. *Entomon* **33**: 1–5.

Malhotra C P and Katiyar R N. 1979. Chemical control of the lac predator, *Eublemma amabilis* Moore – II. Relative toxicity of the various insecticides against the predatory caterpillars. *Indian Journal of Entomology* **41** (2): 187–90.

Mishra Y D, Bhattacharya A, Sushil S N, Sharma K K and Jaiswal A K. 1995. Efficacy of some insecticides against *Eublemma amabilis* Moore - a major predator of lac insect, *Kerria lacca* (Kerr). *Journal of Entomological Research* **19** (4): 351–5.

Mishra Y D, Sushil S N, Sharma K K, Bhattacharya A and Jaiswal A K. 1996. Efficacy of selected organophosphorus insecticides for control of *Chrysopa madestes* (Neuroptera: Chrysopidae) – a serious sporadic predator of Indian lac insect, *Kerria lacca* (Kerr). *New Agriculturist* **7** (1): 7–20.

Ramoliya D R, Raghvani K L, Jethwa D M and Sutaria V K. 2010. Comparative bioefficacy of insecticides against sawfly, *Athalia lugens pxoxima* (Klug) on radish. *Indian Journal of Entomology* **72** (2): 131–4.

Rao C N and Shivankar V J. 2011. Relative efficacy of certain bio-rational insecticides to citrus psylla (*Diaphorina citri*). *Indian Journal of Agricultural Sciences* **81** (7): 673–6.

Shinde S T, Shetgar S S and Pathan N M. 2010. Persistence and residual insecticidal toxicity against *Earias vittella*. *Indian Journal of Entomology* **72** (2): 135–9.

Sharma K K and Ramani R. 2001. Parasites affected reduction in fecundity and resin yield of two strains of Indian lac insect, *Kerria lacca* (Kerr). *Indian Journal of Entomology* **63** (4): 456–9.

Singh J P, Jaiswal A K and Monobrullah Md. 2011. Safety evaluation of some newer pesticides against lac insect (*Kerria lacca*) for managing predators. *Indian Journal of Agricultural Sciences* **81** (5): 465–9.