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RESEARCH ARTICLE

Investigation on the Effectiveness of Botanicals and New Generation Insecticides in the Management of the Pink Bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), in the Cotton Ecosystem

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ABSTRACT

The pink bollworm, *Pectinophora gossypiella* (Saunders), is a worldwide important emerging insect pest that is causing major yield loss among the bollworms in the cotton ecosystem. A field study evaluated the bio-efficacy of newer insecticides and botanicals against pink bollworm during *Kharif* and *Rabi*, 2021-22, under Randomised Block Design (RBD). The observations on percent boll damage, percent locule damage, percent reduction over control, and yield were recorded and analyzed. The results showed that applying emamectin benzoate 5SG was superior to other treatments, followed by chlorantraniliprole 18.5 SC, spinosad 45 SC and flunbendiamide 39.5 SC. The emamectin benzoate 5 SG treated plot had the greatest reduction in boll damage (89.25%) and the highest yield (1955 kg/ ha). Among the botanicals, 5 % NSKE was found to be effective with a damage reduction over control of 58.06 % followed by 5 % neem formulation 1500 ppm (50.54 %) against pink bollworm in cotton.

Keywords: *Cotton; Pink Bollworm; Management; Botanicals; Insecticides*

INTRODUCTION

Cotton production in India uses 75–80 percent of insecticides to control bollworms and the remaining 20–25 percent of pesticides are used to control other pests in cotton. To resolve this overuse of insecticides, insecticidal proteins from the *Bacillus thuringiensis* (*Bt*) were expressed in the genetically modified cotton crop expressing *cry1Ac* and *cry2Ab* genes that were commercialized in India in March 2002 for the control of lepidopteran bollworms. In India, the only genetically modified crop approved for commercial cultivation is cotton (Kranthi *et al*. 2021). Despite initial control, the pink bollworm populations were reported to have developed resistance to the *cry1Ac* gene and were found to survive on *Bt*-I cotton fields in 2009 in Gujarat state in India (Dhurua and Gujar 2011).

Later, another cotton transgenic plant, Bollgard II (*cry1Ac* and *cry2Ab* gene) was introduced, to combat cotton bollworms but it also failed to manage the pink bollworm. It experienced high levels of pink bollworm infestation and crop damage in the fields of Gujarat, Madhya Pradesh, Maharashtra, Karnataka, and Andhra Pradesh during the Kharif season of 2015–2016. Pink bollworm, adapted itself to *cry* toxins resulting in field control failures in 2016 and 2017 (Naik et al. 2021). These incidences caused great concerns in the cotton trade chain because of the impact on cotton output and the reduced market price of pink bollworm damaged cotton and equally among the scientific fraternity, because it indicated that pink bollworm had been well managed by Bt traits in cotton in the past, but now pink bollworm was capable of feeding on Bollgard II crop (Mohan et al. 2016). In China, laboratory bioassay data from 51 field-derived strains showed that the susceptibility to the *cry1Ac* gene was significantly lower from 2008 to 2010 than

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from 2005 to 2007 (Wan et al. 2012). This shows that this problem is unique to India because the pest has developed multi-fold resistance to cry toxins in many Indian populations but not in most other countries. Most Indian populations have developed multi-fold resistance to *cry 1 Ac* and *cry 1Ac + cry 2 Ab* toxins. Year-round cultivation of long-duration Bt cotton hybrids on a large scale may have a pronounced impact on the incidence (Rao 2021).

Furthermore, pink bollworm is an oligophagous insect pest; a quick amalgamation of alleles with several adaptive mechanisms for resistance to *Bt* toxins could have fast-tracked *Bt* resistance populations in pink bollworm over other polyphagous bollworms (Ojha et al. 2014). Wang et al. (2019) found that the Indian pink bollworm populations had eight new mutations in the cadherin gene, which severely messed up the cadherin alleles that were responsible for *cry1Ac* resistance. Followed by the development of Insecticide Resistance Management (IRM) strategies implemented by different cotton-growing countries globally; the USA, India, and China had a significant impact on the interaction of pink bollworm on *Bt* cotton (Rao 2021).

In recent years, a typical pattern of progressive increase in the level of pink bollworm infestation and intensification of locule damage with the advancement of crop season was observed in India (Fand et al. 2019). The development of resistance against *Bt* leads to an increase in their incidence and the ban of the most recommended insecticides against pink bollworm management that creates the need for modulation in management practices by evaluations of newer insecticides and botanicals. These evaluations will effectively strengthen the management of the pink bollworm population in cotton.

MATERIAL AND METHODS

A field study was conducted to evaluate the bio-efficacy of selected insecticides against pink bollworm, *P. gossypiella* during *Kharif* and *Rabi*, 2021-22 under randomized block design (RBD) at the Department of Cotton, Tamil Nadu Agricultural University, Coimbatore, with nine treatments including an untreated control and were replicated thrice. The cotton variety CO17 (Gunasekaran et al. 2020) was sown during *Kharif* and *Rabi*, 2021-22 with a spacing of 90 × 60 cm in the plot size of 11 × 11 m. The standard agronomic practices recommended by Tamil Nadu Agricultural University were adopted except for the plant protection measures. The insecticides from class viz., spinosyns (spinosad), avermectins (emamectin benzoate), anthranilic diamides (chlorantraniliprole, flubendiamide) and botanicals (NSKE, neem formulation 1500 ppm, pungam and jatropha extract) were used along with untreated control. Insecticides were sprayed thrice during the investigation period. In each treatment, 20 bolls were selected randomly and pink bollworm damage incidence was recorded on the selected bolls. The pre-count observation was made one day before spray and post-treatment observations were recorded on 3, 7 and 14 days after spraying for 3 consecutive sprays. The observations on percent boll damage, percent locule damage, percent reduction over control and yield were recorded from each treatment. The yield was recorded from each plot and converted to hectares. The data from each treatment were subjected to ANOVA.

Percent green boll damage

The number of bolls, damaged by pink bollworm was counted and expressed as a percentage of tender green boll damage by using the formula.

$$\text{Green boll damage (percent)} = \frac{\text{No. of damaged green bolls}}{\text{Total no. of green bolls}} \text{X } 100$$

Before the commencement of each picking, 20 bolls were randomly sampled from the field. Then, the total number of locules and damaged locules were counted and expressed in terms of percent locule damage.

$$\text{Locule damage (percent)} = \frac{\text{Total no. of damaged locule}}{\text{Total no. of locule}} \text{X } 100$$

The percentage reduction over control was worked out with the following formula (Abbott 1987).

$$\text{Percent Reduction (PR)} = \frac{\text{Percentage damage of control - Percentage damage of treated plot}}{\text{Percentage damage of control}} \text{X } 100$$

RESULTS AND DISCUSSION

Efficacy of newer insecticides against the pink bollworm in cotton

Pink bollworm larval damage on green bolls was significantly less in all the treated plots than in the control plots. Three days after spraying (3DAS), minimum percent larval damage was recorded at emamectin benzoate 5 SG and was found superior over other treatments followed by chlorantraniliprole 18.5 SC, spinosad 45 SC and flunbendiamide 39.5 SC. Seven days after treatment and 14 days after treatment, the same trend was followed. In comparison to newer insecticides, emamectin benzoate 5 SG caused the least amount of locule damage (3.33 %), followed by chlorantraniliprole 18.5 SC (6.67-8.33 %), spinosad 45 SC (10.00 %), and flunbendiamide 39.5 SC (11.67 %) (Table 1 and 2).

Efficacy of botanicals against the pink bollworm in cotton

Significantly, the highest percentage of green boll damage was registered in control. Among the botanical insecticides, 5 % NSKE had the minimum percent green boll damage (18.89-21.67 %), followed by Neem formulation 1500 ppm (23.89 - 25.56 %), *Pongamia* extract (27.22-40.56 %) and Jatropha extract (31.67-43.89 %) (Table 3 and 4). All the above treatments were significantly superior to the control, except for the plot treated with Jatropha extract. Similar results were reported for percent locule damage. NSKE 5 % (54.67-58.06 %), neem-based formulation 1500 ppm (42.67-50.54 %), and *Pongamia* extract (21.51-34.67 %) were found to be significantly better than the control (Table 1 and 2). The Jatropha extract was found to have the least effect on the pink bollworm in the cotton ecosystem.

Efficacy of newer insecticides against the pink bollworm in cotton

The results were similar to the study conducted by Divya et al. (2020) where a higher percent reduction of larvae was recorded in chlorantraniliprole 18.5 SC treatment, which was found superior over the other treatments with a minimum larval population (6.67 larvae/ 20 bolls) followed by emamectin benzoate 5 SG and flubendiamide 39.5 SC, respectively. In Telangana, field trials were conducted for two consecutive years

Table 1. Locule damage (per cent) and yield (kg/ha) in different treatments during the *Kharif* 2021

Treatments	*Locule damage (%)	**Yield (kg/ha)	Yield Increase over control (%)
T1 - NSKE	23.33 (28.88)cd	1570.25 (39.63)d	58.33
T2 - Neem formulation 1500 ppm	26.67 (31.09)d	1404.96 (37.49)e	41.67
T3 - *Pongamia* extract	38.33 (38.25)e	1280.99 (35.80)e	29.17
T4 - *Jatropha* extract	45.00 (42.13)e	1322.31 (36.37)e	33.33
T5 - Emamectin benzoate 5 SG	10.00 (18.43)a	1955.92 (44.23)a	97.22
T6 - Flubendiamide 39.5 SC	16.67 (24.10)b	1625.34 (40.32)c	63.89
T7 - Spinosad 45 SC	20.00 (26.56)bc	1735.54 (41.66)bcd	75.00
T8 - Chlorantraniliprole 18.5 SC	21.67 (27.74)bcd	1818.18 (42.64)ab	83.33
T9 - Control	53.33 (46.91)f	991.74 (31.50)f	58.33
SEd	2.0463	0.9413	
CD (p=0.05)	4.3380	1.9956	

*Mean of three replications. The figures in the parentheses are arc-sin transformed values.

** Mean of three replications. The figures in the parentheses are square root transformed values.

In a column, means followed by different letters are significantly different (p=0.05) as per LSD.

Table 2. Locule damage (per cent) and yield (kg/ha) in different treatments during the Summer 2021

Treatments	*Locule damage (%)	**Yield (kg/ha)	Yield Increase over control (%)
T1 - NSKE	26.67 (31.09)c	1350.00 (36.75)d	42.11
T2 - Neem formulation 1500 ppm	28.33 (32.16)c	1266.67 (35.60)de	33.33
T3 - *Pongamia* extract	40.00 (39.23)d	1250.00 (35.36)de	31.58
T4 - *Jatropha* extract	41.67 (40.21)d	1200.00 (34.65)e	26.32
T5 - Emamectin benzoate 5 SG	10.00 (18.43)a	1666.67 (40.83)a	75.44
T6 - Flubendiamide 39.5 SC	20.00 (26.56)b	1516.67 (38.95)bc	59.65
T7 - Spinosad 45 SC	16.67 (24.10)b	1483.33 (38.52)c	56.14
T8 - Chlorantraniliprole 18.5 SC	20.00 (26.56)b	1633.33 (40.42)ab	71.93
T9 - Control	56.67 (48.83)e	950.00 (30.83)f	-
SEd	1.7843	0.7795	
CD (p=0.05)	5.2119	1.6525	

*Mean of three replications. The figures in the parentheses are arc-sin transformed values.

** Mean of three replications. The figures in the parentheses are square root transformed values.

In a column, means followed by different letters are significantly different (p=0.05) as per LSD.

during Kharif, 2018-20. The maximum seed cotton yield (1414 kg/ ha) was recorded in chlorpyriphos, flonicamid, emamectin benzoate, clothianidin, indoxacarb+acetamiprid sequential spray (Prasad and Ashwini 2021).

The histological studies showed signs of intoxication had begun at the level of the midgut after lambdathrin, indoxacarb and emamectin benzoate like insecticides were treated. In insecticide-treated larvae, the epithelial columnar cells showed morphological malformation and destruction, vacuolization, and sometimes detachment of the basement membrane and peritrophic membrane (Ahmed 2020).

The result of this study also suggested that spinosad is the third most effective insecticide among the treatments, which had a 69.33 to 76.34 % pest damage reduction over the control (Table 3 and 4. Spinosad continued its supremacy by recording the minimum locule damage (14.20 %) against pink bollworm. Locule damage due to pink bollworm was significantly less in treated plots, viz., spinosad, thiodicarb and indoxacarb than in control (Shivanna et al. 2012). Similarly, in this study, locule damage was 10.00 % in the spinosad treatment plot. Also, spinosad (2,123.06 kg/ ha) produced the highest seed cotton yield, followed by thiodicarb (2,012.77 kg/ha), emamectin benzoate (1,453.52 kg/ ha), novaluron (1,908.82 kg/ ha), and indoxacarb (1,891.58 kg/ ha) (Shivanna et al. 2011). However, Sabry (2013) conducted a laboratory bioassay that showed that lambda-cyhalothrin was more effective than thiamethoxam and ibuprofen when tested against the newly hatched larvae of the pink bollworm. Pink bollworm infestation to cotton bolls was reduced by using lambda-cyhalothrin, thiamethoxam, and buprofezin by 85.7, 39.3, and 19.5 percent, respectively, in 2009 and 80.1, 64.7, and 39.1 percent, respectively, in 2010. The synthetic pyrethroids such as bifenthrin 10 EC @ 800 mL/ ha and cypermethrin 25 EC @ 500 mL/ ha were found effective over the conventional insecticides such as thiodicarb 75 WP and profenophos 40 EC and new molecules

Table 3. Bio-efficacy of insecticides against pink bollworm, *P. gossypiella* during the *Kharif* 2021

Treatment	Percent green boll damage																	
	I Spray						II Spray						III Spray					
	DBS	3 DAS	7 DAS	14 DAS	Mean	PROC	DBS	3 DAS	7 DAS	14 DAS	Mean	PROC	DBS	3 DAS	7 DAS	14 DAS	Mean	PROC
T1 - NSKE	31.67 (34.24)	21.67 (27.74)d	25.00 (30.00)d	31.67 (30.00)d	26.11	29.85	31.67 (30.00d	20.00 (26.56) d	23.33 (28.88) de	25.00 (30.00) d	22.78	45.33	25.00 (30.00) d	20.00 (26.56) d	18.33 (25.35) d	26.67 (31.09) d	21.67	58.06
T2 - Neem formulation 1500 ppm	28.33 (32.16)	23.33 (28.88) de	26.67 (31.09) de	35.00 (31.09) de	28.33	23.88	35.00 (31.09) de	28.33 (32.16) e	26.67 (31.09) ef	30.00 (33.21) e	28.33	32.00	30.00 (33.21) e	23.33 (31.09) d	21.67 (28.88) d	31.67 (34.25) de	25.56	50.54
T3 - Pongamia extract	26.67 (31.09)	25.00 (30.00) de	33.33 (35.26) def	36.67 (35.26) def	31.67	14.93	36.67 (35.26) def	28.33 (32.16) e	33.33 (35.26) efg	38.33 (38.25)f	33.33	20.00	38.33 (38.25)f	41.67 (40.21) e	38.33 (38.25) e	41.67 (40.21) e	40.56	21.51
T4 - Jatropha extract	30.00 (33.21)	30.00 (33.21) ef	35.00 (36.27)ef	38.33 (36.27)ef	34.44	7.46	38.33 (36.27)ef	38.33 (38.25)f	38.33 (38.25) fg	40.00 (39.23)f	38.89	6.67	40.00 (39.23)f	43.33 (41.17) ef	40.00 (39.23) e	48.33 (44.04) ef	43.89	15.05
T5 - Emamectin benzoate 5 SG	28.33 (32.16)	6.67 (14.96)a	3.33 (10.51)a	8.33 (10.51)a	6.11	83.58	8.33 (10.51)a	3.33 (10.51) a	5.00 (12.92) a	10.00 (18.43) a	6.11	85.33	10.00 (18.43) a	3.33 (7.42)a	6.67 (12.92) a	6.67 (14.97) a	5.56	89.25
T6 - Flubendiamide 39.5 SC	28.33 (32.16)	15.00 (22.79)c	16.67 (24.10)c	16.67 (24.10)c	16.11	56.72	16.67 (24.10)c	13.33 (21.41) cd	15.00 (22.79) cd	16.67 (24.10)c	15.00	64.00	16.67 (24.10)c	11.67 (19.97) c	11.67 (19.97) bc	16.67 (24.10)c	13.33	74.19
T7 - Spinosad 45 SC	30.00 (33.21)	15.00 (22.79)c	15.00 (22.79)c	18.33 (22.79)c	16.11	56.72	18.33 (22.79)c	11.67 (19.97) bc	11.67 (19.97) bc	16.67 (24.10)c	13.33	68.00	16.67 (24.10)c	10.00 (18.43) bc	13.33 (21.41)c	13.33 (21.41) bc	12.22	76.34
T8 -Chlorantrani-liprole 18.5 SC	36.67 (37.27)	10.00 (18.43)b	6.67 (14.97)b	10.00 (14.97)b	8.89	76.12	10.00 (14.97)b	6.67 (14.97) b	6.67 (14.97) ab	13.33 (21.41) b	8.89	78.67	13.33 (21.41) b	5.00 (12.92) ab	8.33 (16.77) b	8.33 (16.77) ab	7.22	86.02
T9 - Control	30.00 (33.21)	31.67 (34.25)f	38.33 (38.25)f	41.67 (38.25)f	37.22		41.67 (38.25)f	41.67 (40.21)f	41.67 (40.21) g	41.67 (40.21)f	41.67		41.67 (40.21)f	53.33 (46.91)f	43.33 (41.17)e	58.33 (49.80)f	51.67	
SEd	NS	1.5521	2.5886	1.3868			1.3868	2.5918	3.7289	1.2502			1.2502	2.8673	1.6872	2.9646		
CD(.05)	NS	3.2903	5.4876	2.9398			2.9398	5.4944	7.9051	2.6502			2.6502	6.0786	3.5768	6.2847		

PROC - percent reduction over control; DBS – Day before Spraying; DAS - Day after Spraying, Mean of three replications. The figures in the parentheses are arc-sin transformed values.In a column, means followed by different letters are significantly different (p=0.05) as per LSD.

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Table 4. Bio-efficacy of insecticides against pink bollworm, *P. gossypiella* during the Summer 2021

Treatment	Percent green boll damage																	
	I Spray						II Spray						III Spray					
	DBS	3 DAS	7 DAS	14 DAS	Mean	PROC	DBS	3 DAS	7 DAS	14 DAS	Mean	PROC	DBS	3 DAS	7 DAS	14 DAS	Mean	PROC
T1 - NSKE	28.33 (34.55)	21.67 (27.74)d	21.67 (26.56) cd	25.00 (30.00) cd	22.78	34.92	25.00 (30.00) cd	15.00 (22.79) cd	16.67 (24.10) cd	20.00 (26.56) cd	17.22	55.71	20.00 (26.56) cd	18.33 (27.74) de	16.67 (24.10)cd	21.67 (27.74)d	18.89	54.67
T2 - Neem formulation 1500 ppm	26.67 (33.89)	26.67 (31.09)d	23.33 (28.88) de	28.33 (32.16) de	26.11	25.40	28.33 (32.16) de	16.67 (24.10) cd	20.00 (26.56) de	26.67 (31.09) de	20.00	48.57	26.67 (31.09) de	21.67 (31.09)e	20.00 (26.56)de	30.00 (33.21)e	23.89	42.67
T3 - Pongamia extract	25.00 (33.21)	26.67 (31.09) de	25.00 (30.00) de	35.00ef (36.27)	28.89	17.46	35.00 (36.27)ef	18.33 (25.35)d	26.67 (31.09)ef	28.33 (32.16) de	24.44	37.14	28.33 (32.16) de	26.67 (32.16)e	23.33 (28.88)de	31.67 (34.25)e	27.22	34.67
T4 - Jatropha extract	30.00 (35.19)	28.33 (32.16)e	26.67 (31.09)e	36.67f (37.27)	30.56	12.70	36.67 (37.27)f	21.67 (27.74)d	31.67 (34.25)fg	36.67 (37.27)ef	28.89	25.71	36.67 (37.27)ef	31.67 (38.25)f	28.33 (32.16)e	35.00 (36.27)e	31.67	24.00
T5 - Emamectin benzoate 5 SG	26.67 (33.89)	8.33 (16.77)a	6.67 (14.97)a	8.33a (16.77)	7.78	77.78	8.33 (16.77)a	3.33 (10.51)a	6.67 (14.97)a	6.67 (14.97)a	5.56	85.71	6.67 (14.97)a	3.33 (10.51)a	5.00 (12.92)a	6.67 (14.97)a	5.56	86.67
T6 Flubendia-mide 39.5 SC	31.67 (35.82)	16.67 (24.10)c	15.00 (22.79) bc	13.33b (21.41)	15.00	57.14	13.33 (21.41)b	10.00 (18.43) bc	13.33 (21.41) bcd	15.00 (22.79) bc	12.78	67.14	15.00 (22.79) bc	10.00 (21.41) bc	11.67 (19.97)bc	13.33 (21.41) bc	11.67	72.00
T7 - Spinosad 45 SC	23.33 (32.51)	13.33 (21.41)bc	13.33 (21.41)b	20.00c (26.56)	15.56	55.56	20.00 (26.56)c	10.00 (18.43) bc	11.67 (19.97) abc	13.33 (21.41) bc	12.22	68.57	13.33 (21.41) bc	13.33 (22.79)d	10.00 (18.43)bc	15.00 (22.79)c	12.78	69.33
T8 Chlorantrani liprole 18.5 SC	28.33 (34.55)	11.67 (19.97)a	11.67 (19.97)b	11.67ab (19.97)	11.67	66.67	11.67 (19.97) ab	8.33 (16.77)b	8.33 (16.77) ab	8.33 (16.77) ab	8.33	78.57	8.33 (16.77) ab	8.33 (16.77)b	8.33 (16.77)ab	10.00 (18.43)b	8.89	78.67
T9 - Control	26.67 (33.89)	31.67e (34.25)	35.00 (36.27)f	38.33f (38.25)	35.00		38.33 (38.25)f	38.33 (38.25)e	38.33 (38.25)g	40.00 (39.23)f	38.89	-	40.00 (39.23)f	41.67 (40.21)f	41.67 (40.21)f	43.33 (41.17)f	41.67	-
SEd	NS	1.7177	2.1216	1.9731			1.9731	2.6005	2.6510	3.5488			3.5488	4.2449	2.8828	1.4923		
CD(.05)	NS	3.6415	4.4976	4.1829			4.1829	5.5129	5.6200	7.5233			7.5233	8.9990	6.1113	3.1635		

PROC - percent reduction over control; DBS – Day before Spraying; DAS - Day after Spraying. Mean of three replications. The figures in the parentheses are arc-sin transformed values. In a column, means followed by different letters are significantly different (p=0.05) as per LSD.

such as spinosad 45 SC, emamectin benzoate 5 SG and chlorantraniliprole 20 SC in reducing the larval population of pink bollworm along with less boll damage (Zaki and Hegab 2015; Mahalakshmi and Prasad 2021). This suggests that lambda-cyhalothrin is the most effective pesticide against the early instars of pink bollworm larvae and the synthetic pyrethroids were found to be effective against the pink bollworm larva.

But the use of synthetic pyrethroids may cause an increase in the sucking pest population at the later stage of the cotton crop. Sole reliance on insecticides, particularly pyrethroids, has caused an imbalance in the agro-ecosystem, creating resistance and resurgence problems, warranting alternate control measures and adverse effects on the human beings. Hence, there is a need to look for alternatives that are less hazardous to mankind, livestock and other non-target organisms (Kumar et al. 2019). Newer insecticides are much safer for non-target organisms and natural enemies. The emamectin benzoate, which is a neurotoxic insecticide belonging to the avermectin group of insecticides, was reported to be more selective against Lepidoptera. Although toxicity to some natural enemies and non-target arthropods has been reported, this insecticide is considered less harmful to beneficial arthropods as compared with broad-spectrum compounds (Cruces et al. 2021). Terrestrial vertebrates are sensitive to neuro-toxicants and respiratory inhibitors, but birds and mammals do not seem to be affected by insecticides made from natural toxins made by plants or fungi (like avermectins and spinosad). As chemical pesticides cannot be fully included in the management practices, the use of green chemicals *viz.*, chlorantraniliprole are approved for the safer management of insect pests (Muralikrishna et al. 2019).

Efficacy of botanicals against the pink bollworm in cotton

The insecticidal property of Neem was explained earlier by several workers (Mordue and Nisbet 2000; Aziz et al. 2013; Senthil-Nathan 2013). Though botanical pesticides are less effective in comparison to chemical insecticides, they are also safer and less costly alternatives to chemical insecticides. The highest reduction in the pink bollworm population was reported in tobacco extract (17.45-15.09 %) followed by neem extract (14.58-15.33 %) and datura extract (11.72-7.81 %) (Rajput et al. 2017). The alternate sprays of neem-based insecticides with chemical insecticides under field conditions were found to reduce the synthetic insecticide load by 50 % in the cotton ecosystem (Kumar et al. 2019).

CONCLUSION

Neem oil at 1.5-2.0 % and neem seed water extract at 2-3 % resulted in significant damage than control (Rashid et al. 2012). NSKE contains azadirachtin with several effects on phytophagous insects and is thought to disrupt insect moulting by antagonizing the effects of ecdysteroids. This effect is independent of feeding inhibition, which is another observed effect of the compound. Minimum bollworm damage was observed in Karanj (methanol extract of *Pongamia pinnata*) and bollworm infestation ranged from 5.44 to 11.21 % (Gangadhar et al. 2007) and in American bollworm more than 50 % first instar larval mortality and more than 65 % third instar larval feeding deterrence were observed (Reena et al. 2012).

The antifeedant/ repellent effects are dramatic, with many insects avoiding treated crops. *Pongamia pinnata* (L.), is a potent deterrent to different genera of insects and mites in a wide range of crops. Karanjin extracted from *Pongamia pinnata* (L.), has an antifeedant / repellent effect against insect pests. It suppresses the effects of ecdysteroids and thereby acts as an Insect Growth Regulator (IGR) and antifeedant. There are claims that it inhibits cytochrome P-450 in susceptible insects and mites (Gonzalez-Coloma et al. 2013). The Jatropha leaf extract treatment had the lowest efficacy, in terms of percent green boll damage (31.67–43.89 %) and locule damage (20.00–21.67 %). Though Jatropha contains toxic metabolites such as sterols and terpene alcohols, which are known to have insecticidal properties (Oskoueian et al. 2011).

Intensive monitoring of pink bollworm with pheromone baited traps for males and mating disruption when applied in early seasons (Lykouressis et al. 2005). Combinations of biological agents, botanicals and chemical control have proved to be successful in the management of pink bollworm. Among the alternatives, the use of bio-control agents and bio-pesticides are safer pest management strategies used under Integrated Pest Management practices (Kumar et al. 2019). Thus crop protection with the need-based use of safer insecticides and botanicals is considered an effective component of Integrated Pest Management and one of the most important aspects of agro-ecosystem management regarding the ecological and socio-economic values. In this context, some newer groups of insecticides and botanicals at recommended doses can be used for bringing about effective pink bollworm management in the cotton ecosystem (Sarma et al. 2020).

For the management of pink bollworm damage on cotton, among the insecticide molecules tested, foliar application of emamectin benzoate 5 SG and chlorantraniliprole 18.5 SC were found most effective in the management of pink bollworm. Among the botanicals tested, 5 % NSKE was found to be effective against green boll damage followed by a neem-based formulation of 1500 ppm. With these insecticides and botanicals, it is possible to manage the pink bollworm and keep cotton farming going in India.

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Ethics statement

No specific permits were required for the described field studies because no human or animal subjects were involved in this research.

Originality and plagiarism

Authors should ensure that they have written and submit only entirely original works, and if they have used the work and/or words of others, that this has been appropriately cited. Plagiarism in all its forms constitutes unethical publishing behavior and is unacceptable.

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All the authors agreed to publish the content.

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There were no conflict of interest in the publication of this content

Data availability

All the data of this manuscript are included in the MS. No separate external data source is required. If anything is required from the MS, certainly, this will be extended by communicating with the corresponding author through corresponding official mail; padhushree1996@gmail.com

Author contributions

Idea conceptualization - MMS, Experiments - IP ,Guidance - KS, SR, NMB, Writing original draft - IP, Writing- reviewing & editing - MMS, KS, Correction - KS, SR, NMB

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