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PHYTOMORPHOLOGY

Evaluation of specialized pheromone lures technology for pink bollworm, *Pectinophora gossypiella* (Saunders) management in *Bt* cotton

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Abstract

Field experiment was carried out under large plot techniques with three modules, *viz.*, SPLAT module, insecticidal control module and IPM module in comparison to untreated control by keeping 100 m isolation distance during *Kharif* seasons of 2021 to 2023 at Main Cotton Research Station, Navsari Agricultural University, Surat Gujarat state. The SPLAT module included ready-to-use gossyplure 4% as mating disruption technology, whereas the insecticidal module was comprised of ETL based application of label claimed insecticides and IPM module was developed and validated by ICAR-CICR, Nagpur and SAUs which included eco-friendly window-based strategies for pink bollworm management. The effectiveness of each module was judged by trapping moth activity through installing a pheromone sensor TM-SP trap with lure and the fruiting body damages in each module. The SPLAT technology module was found effective in confusing male population, recorded significantly least male moth catches (mean 4.49 male moth/trap/SMW) and reduced damage to flowers (5.46%), green bolls (4.83%), locules in green bolls (2.79%), open bolls (7.15%) and locules (3.66%) with less PBW larvae (1.11/20 green bolls), which resulted in to highest seed cotton yield of 22.58 q/ha as against 14.17 q/ha in control showing 59.35% yield increase over control. The SPLAT module was found economical highest benefit over control (IRs. 53206/-). The IPM module was found second best module for the management of pink bollworm. The SPLAT technology where the application of ready-to-use gossyplure 4% as small dollops at plant surface in the field @ 200-250 g/ha thrice at 45, 75 and 105 DAS (at 30 days' intervals) was found effective and economical for management of pink bollworm.

Keywords: SPLAT, *Bt* cotton, IPM management, *P. gossypiella*

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Introduction

Cotton, *Gossypium hirsutum,* one of the commercially important fiber crops in the world for fuel, fiber and edible oil, is playing an important role in the Indian economy. In Gujarat, cotton is grown approximately in 26.83 lakh ha with a production of 89.65 lakh bales and 568 kg/ ha productivity during 2023-24 (Anonymous, 2024). Patil (2003) observed that the pink bollworm, *Pectinophora gossypiella* (Saunders) has become economically the most destructive pest and causes 2.8 to 61.9% loss in seed cotton yield, 2.1 to 47.10% loss in oil content and 10.70 to 59.20% loss in normal opening of bolls. In the recent past, pink bollworm (*Pectinophora gossypiella* Saunders) has become a major threat to *Bt c*otton and is causing considerable yield loss. The pink bollworm, once a serious problem for non *Bt* cotton especially in later stage of the crop has now become a major problem in *Bt* cotton hybrids damaging from the flowering stage of the crop and inflicting damage if unattended. Estimated yield losses in the USA due to pink bollworm range from 9% when chemically controlled to 61% when uncontrolled (Schwartz, 1983), although 100% crop loss can occur with heavy infestations. The avoidable loss of seed cotton yield due to pink bollworm was estimated to be 5.05 and 3.32% for RCH 2 BG II when sown early and at normal sowing time, respectively. For RCH 2 non-Bt, the avoidable loss on seed cotton yield was ±42.63% in early and 33.98% when in normal time (Rathod et al., 2017). Under farmers' practices of relying only on insecticides (frequent/mixtures), estimated yield loss of 2.14% (0.88 to 3.61) due to pink bollworms in a study on 274 farmers' fields of 21 villages in Surat and Bharuch districts. A gradual decrease in infestation and loss from 2015-16 to 2017-18 was recorded (Desai et al., 2022). The control of this pest depends largely on the monitoring through pheromone traps and the application of pesticides, which has precipitated the development of resistance. The effectiveness of the Pherosensor TM-SP Sleeve trap against pink bollworm incidence was reported across different locations under ICAR-AICRP trials and validated on farmers' fields too (Anonymous, 2018) and adopted as a common practice for monitoring pink bollworm activity under AICRP experiments. As a result, more chemical applications per season are needed for achieving effective control (Natwick, 1987). Furthermore, other alternative control strategies like release of egg parasitoids at ETLs in combination with insecticidal sprays were being studied. The egg parasitoid, *Trichogrammatoidae* spp. was used in the IPM of cotton for the control of *P. gossypiella* and proved as a good biological agent in the laboratory (Malik, 2000). Several studies revealed the role of *Trichogramma* spp. in controlling different insect pests infesting the cotton crop in different parts of the world (Nadeem et al., 2009). Further, the pink bollworm has developed resistance to both the transgene, *Cry1Ac* and *Cry2Ab* (Naik et al., 2018). ICAR-CICR, Nagpur under a network project formulated and recommended the window-based integrated Pink Bollworm management strategies to the Indian cotton farmers to contain the resistant pink bollworm on *Bt* cotton hybrids emphasizing timely sowing and uprooting of crop with window-based use of green insecticides, monitoring through pheromone traps, release of bioagents and ETL based sprays. The male confusion technique through installation of PB Rope @ 200 LTT/ha starting from 30

DAS on the main stem at one-third of the top branches with 6-7 m distance in the field and 70 days' replacement interval was found very effective against pink bollworm incidence and damage. SPLAT technology is a biologically inert material (waxes, vegetable oils, water and other food grade non-toxic and biodegradable) used for the delivery of semiochemicals including pheromones (Kranthi, 2018). Jethva et al. (2018) found the least trap catches and damage to fruiting bodies by pink bollworms with gel-based mating disruption technology. Shrinivas et al. (2019a) studied the dissipation of SPLAT formulation and SPLAT @ 500 g/acre was found effective. Pheromones play a major role in the monitoring, mass trapping and male confusion/ mating disruption of pink bollworm moth at field level reducing infestation and investment for management, which is found eco-friendly as safe to beneficial insects (Maruti et al., 2020). Recently, the male confusion techniques using gossyplure 4% RTU formulation of pheromone in high concentrations was found effective in management of pink bollworm. In that context, three pink bollworm management modules comprising of three times applications of splat technology, recommended window based pink bollworm management strategies and ETL based chemical insecticides were evaluated in comparison to untreated control through large plot techniques.

Materials and methods

Three pink bollworm management modules were evaluated in *Bt* cotton hybrid "G. Cot. Hy 8 BG II" during *Kharif* seasons of 2021 to 2023 at Main Cotton Research Station, Navsari Agricultural University, Surat Gujarat. The experiment was carried out under large plot techniques with three modules, *viz.*, SPLAT module, Insecticidal control module and IPM module compared with untreated control module (each in 1500 m^2 area) keeping 100 m isolation distance amongst modules. The crop was grown under heavy black soil at a spacing of 120 x 45 cm following all recommended agronomic practices except plant protection measures. The SPLAT module includes ready-to-use gossyplure 4% as mating disruption technology, whereas the insecticidal module comprised of ETL-based application of recommended label-claimed insecticides against pink bollworms and the IPM module developed and validated by ICAR-CICR, Nagpur and SAUs which includes eco-friendly window-based strategies for pink bollworm management (Table 1). In the untreated control plot, no insecticidal sprays were taken up. In the above four modules, the weekly male moth activity was recorded through installation of the recommended Phero-sensor TM-SP Sleeve trap @ 5 traps/ ha for the whole season. In all the treatments, cotton seed treated with imidacloprid 70 WS was sown in order to manage the early sucking pests and the common sprays with alternate applications of recommended insecticides were given for sucking pest management at the economic threshold level. For recording observations on insect pests, each large plot was divided into six spots/ quadrat to minimize observational errors while recording the data. In the module comprising SPLAT technology, applied as a small pea seed sized dollops of gossyplure 4% RTU paste three times at 5 m plant to plant distance in alternate rows (approximately 800 plants/ha, 200- 250 g/ ha) on the primary branch axis (below 3-4 inches from tip) for management of pink

Table 1. Treatment details of different modules in *Bt* cotton

Module 1	Monitoring and Splat technology	1. Monitoring of PBW moths through installation of Phero-sensor TM-SP sleeve trap @ 5/ha with changing lure at 40 days interval starting from 45 DAS 2. Applied as small dollops at plant surface in the field @ 200-250 g/ha thrice at 45, 75, 105 DAS (at 30 days interval)
Module 2	Monitoring and ETL based spray technology	1. Monitoring of PBW moths through installation of Phero-sensor TM-SP sleeve trap @ 5/ha with changing lure at 40 days interval of recommended starting from 45 DAS 2. Application of recommended insecticides at ETL based fruiting body damage (10% rosette flowers or 10% green boll damage-destructive sampling of 20 green bolls/quadrat or 10% open boll damage) and alternative applications of Indoxacarb 14.5 SC@ 5 ml/10 l and Emamectin benzoate 5 SG @ 5 g/ 10 l and Spinosad 45 SC @ 3 ml/10 l at 15 days interval
Module 3	Recommended IPM module for PBW	1. Installation of Phero-sensor TM-SP trap @ 5 traps/ha at 45 DAS and change the Pectino-lure thrice at 40 days interval 2. Spraying of Azadirachtin 1500 PPM @ 2.5 lit/ha at 60 DAS. Three inundative release of egg parasitoid, *Trichogrammatoidae bactrae* @ 1.5 lakh/ha at weekly intervals initiating 7 days after application of neem insecticide 3. ETL (10% fruiting body damage) based application of recommended insecticides (Indoxacarb 14.5 SC @ 5 ml/ 10 l or Emamectin benzoate 5 SG @ 5 g/10 l or Spinosad 45 SC @ 3 ml/10 l) 4. Timely termination of crop (by January 15^{th} of the year)
Module 4	Untreated control	Untreated for PBW

bollworm. This paste was applied for thrice at 45, 75 and 105 days after sowing (DAS). In the chemical-based module, the recommended insecticides were applied at ETL based population or damage of the pink bollworm (ETL-8 male moths/trap for three consecutive nights or 10% fruiting body damage). In the integrated pink bollworm management module, window-based strategies including use of green chemistry in initial window, three releases of egg parasitoid, *Trichogrammatoidae bactrae* @1.5 lakh/ha during sucking pest's free periods (70 DAS), subsequent applications of recommended insecticide at ETL population or damage, and timely termination of crops. The nucleus culture of *T. bactrae* was procured from NBAII, Bangalore and mass reared in the Biocontrol laboratory, Navsari Agricultural University, Navsari. The observations on male moth trap catches were taken at weekly interval in all modules. In each spot/quadrate, the observations on pink bollworm were recorded from 10 randomly selected plants. Damage to different fruiting bodies *viz.,* rosette flowers/50 flowers (45, 60 and 75 DAS), pink bollworm larva/ 20 bolls (90, 120 and 150 DAS), green bolls damaged/20 bolls (90, 120 and 150 DAS) and green bolls locule damaged/20 bolls (90, 120 and 150 DAS) were estimated based on proportion of infested units to the total units. To record the incidence of pink bollworms in fully opened bolls at harvest time, 100 opened bolls per plot were plucked randomly and were collected in polyethylene bags and estimated for locule damage. The seed cotton yield was also recorded and expressed on hectare basis compensating the plucked green and open bolls.

Results and discussion

The pooled analysis over periods and years after arc sin transformation and interpreted randomized block design statistical tests to draw the valid conclusions on respective parameters (Tables 2 to 8).

Trap catches of male moths

The pooled data on trap catches of male moths of pink bollworm (Table 2) in phero sensor TM-SP trap installed in control plots revealed that the moth activity was initiated in 34th SMW (third week of August) and increased during the season showing peak activity during 51st SMW (third week of December). In different modules, the data on pheromone trap catches of male moths of pink bollworm throughout the installation periods pooled over three years were compared with data in control plots through two-way sample mean test which showed that the trap catches of male moths were significantly less in M1 (Monitoring & SPLAT technology) (mean 4.49 male moths/trap/week/season) in comparison to untreated control (mean 13.86 male moths/trap/week/season) as two sample t-test was highly significant whereas M2 (Monitoring and ETL based sprays) and M3 (Monitoring as IPM components) showed no significant differences with respect to male moth catches in control plots. Further, during the season the average male moth trap catches ranged from 0.67 to 8.33 moths/trap/week in M1 (Monitoring & Splat technology) as against 1.67 to 40.0 moths/trap/week. This indicated that the three-time applications of splat technology released high concentration of pheromone in the vicinity of the fields near the source points that confused the male moths in search of female moths and did not attract towards the installed pheromone trap where low concentration of petrochemicals was released.

Flower damage by pink bollworm

At initial stage (45 DAS) was found significant difference in flower damage by pink bollworm in M1 (9.20%) and found comparable with M3 (9.23%). At 60 DAS, M1 recorded the lowest flower damage (4.41%) followed by M3 (6.25%), M2 (8.07%) and M4-untreated control (14.51% flower damage). At 75 DAS, there was lowest flower damage (3.41%) in M1 followed by comparable lower damage (5.33 & 6.68%) in M3 and M2 as against M4-Untreated control (17.71% flower damage). In pooled over periods, lower flower damage was observed in M1 (5.43%) and it was at par with M3 (6.85%). The M2 module recorded significantly higher flower damage (8.72%) and significantly superior to M4-Control (14.82%) (Table 3).

Green and open boll damage and larval population

With respect to larval population of pink bollworm, there were significant differences at 90, 120 and 150 DAS being less and comparable larval population in M1 and M3 than M4-untreated control. In pooled analysis, there was significantly less larval population in M1 (1.11 larvae/

Table 2. Male moth catches of PBW amongst different modules pooled of 2021-22 to 2023-24)

SMW	Average number of male moths trapped in different modules and control			
	M1	**M2**	**M3**	**M4**
34	0.67	1.67	0.33	1.67
35	2.33	0.67	0.67	1.67
36	2	2	1.33	3
37	2	4	3	2
38	2	3.67	2.33	4.67
39	2.33	2	2	3
40	3	3	4	4.67
41	3	6.67	5.33	5.33
42	4.33	5.33	8.33	8
43	3	6	7	6.67
44	4	8	10	10.33
45	6	9	8	12
46	6	11	12	16
47	7.67	15.67	16	20.67
48	7.33	18	14	25.33
49	8.33	25.67	17.67	30
50	7.33	21	22	37.33
51	7	27.33	17	40
52	7	29.33	15	31
Mean	4.49	10.53	8.74	13.86
Maximum	8.33	29.33	22	40
Minimum	0.67	0.67	0.33	1.67
Rreduction (%)	**67.6**	**24.03**	**36.94**	
SD	2.44	9.42	6.68	12.88

20 bolls) which was found comparable to M3 (1.35 larvae/20 bolls) as against 3.38 larvae/20 bolls in M4-Control (Table 3). Damage to green boll was found less in M1 and M3 modules than the M4-untreated control at 90, 120 and 150 DAS. In pooled analysis over periods, damage to green boll on boll basis was found significantly lowest in M1 (4.83% GBD) and M3 (6.16%) followed by M2 (8.47%) and M4-Untreated control (15.63%) (Table4). Similarly, green boll damage on locule basis was significantly lower in treatment of M1 and M3 as compared to M4-Control at 90, 120 and 150 DAS. In pooled over years, damage to green bolls on locule basis was found lowest in M1 (2.79% LD) which was at par with M3 (3.49%) followed by M2 (4.47%) and M4-untreated control (8.28% locule damage in green bolls) (Table 4). Damage to open boll and locules at harvest was significantly lower in M1 (7.15 & OBD and 3.66% LD) and it was statistically at par to M3 (8.12% OBD & 4.19% LD) as against 15.58 % OBD and 8.92% LD in M4-untreated control (Table 5).

Natural enemies

As far as populations of natural enemies are concerned, LBB, Chrysoperla and spider were found higher in M4-Untreated control and M1 (Monitoring & Splat technology) compared to other two modules of M2 (Monitoring & ETL based sprays) and M3 (Monitoring & IPM), which may be due to insecticide applications in later two modules (Table 6, 7).

Economics

The seed cotton yield was found highest in M1 (22.58 q/ha) followed by M3 (21.01 q/ha) and M2 (17.13 q/ha) and all three modules were significantly superior to M4 (14.17 q/ha) (Table 5). The economics worked out over three years revealed that M1 (Monitoring & Splat technology) recorded maximum benefit over control (IRs. 53206/-) followed by M3 (Monitoring & IPM) recording IRs. 43395/- benefit over

Table 3. Evaluation of different modules against pink bollworm in *Bt* cotton at Surat (Pooled of 2021-22 to 2023-24)

Sr. No.	Modules	Flower damage/50 flowers (%)					Pink bollworm larvae/20 green bolls				
		45 DAS	60 DAS	75 DAS	Mean	ROC	90 DAS	120 DAS	150 DAS	Mean	ROC
1	**SPLAT**	17.65[a] (9.20)	12.13[a] (4.41)	10.65[a] (3.41)	13.48[a] (5.43)	63.36	1.05[a] (0.61)	1.29[a] (1.17)	1.47[a] (1.66)	1.27[a] (1.11)	67.16
2	**Insecticides spray**	20.08[b] (11.78)	16.50[c] (8.07)	14.98[b] (6.68)	17.18[b] (8.72)	43.86	1.34[b] (1.31)	1.42[b] (1.51)	1.91[b] (3.16)	1.56[b] (1.93)	42.90
3	**IPM module**	17.69[a] (9.23)	14.47[b] (6.25)	13.34[b] (5.33)	15.17[ab] (6.85)	53.78	1.11[a] (0.74)	1.35[ab] (1.33)	1.60[a] (2.06)	1.36[a] (1.35)	60.06
4	**Control**	20.64[b] (12.43)	22.39[d] (14.51)	24.89[c] (17.71)	22.64[c] (14.82)	-	1.60[c] (2.07)	1.82[c] (2.83)	2.47[c] (5.61)	1.97[c] (3.38)	-
5	**Mean**	19.01 (10.61)	16.37 (7.94)	15.96 (7.56)	17.12 (8.67)	-	1.28 (1.13)	1.47 (1.67)	1.86 (2.97)	1.54 (1.87)	-

Modules	Flower damage/50 flowers (%)									Pink bollworm larvae/20 green bolls								
	45 DAS		60 DAS		75 DAS		Mean		ROC	90 DAS		120 DAS		150 DAS		Mean		ROC
	SEm	±CD	SEm	± CD	SEm	±CD	SEm	±CD	-	SEm ±	CD	SEm ±	CD	SEm ±	CD	SEm ±	CD	-
Treatment (T)	0.50	1.43	0.48	1.36	0.81	2.31	0.68	2.05	-	0.06	0.16	0.04	0.12	0.05	0.14	0.06	0.17	-
Period (P)	-	-	-	-	-	-	0.31	0.85	-	-	-	-	-	-	-	0.03	0.08	-
Year (Y)	-	-	-	-	-	-	0.31	NS	-	-	-	-	-	-	-	0.03	0.08	-
T x P	-	-	-	-	-	-	0.53	1.48	-	-	-	-	-	-	-	0.05	0.13	-
T x Y	0.89	NS	0.86	NS	1.49	NS	0.62	NS	-	0.10	NS	0.08	NS	0.09	NS	0.06	NS	-
P x Y	-	-	-	-	-	-	0.62	NS	-	-	-	-	-	-	-	0.06	NS	-
T x P x Y	-	-	-	-	-	-	1.07	NS	-	-	-	-	-	-	-	0.10	NS	-

Figures in parentheses are retransformed values; those outside are square root transformed values for PBW larva and Arc sine transformed values for RF; ROC - reduction over control
Treatment means with the letter(s) in common are non-significant at 5% level of significance

Table 4. Evaluation of different modules against pink bollworm in *Bt* cotton at Surat (Pooled of 2021-22 to 2023-24)

Sr. No.	Modules	Green boll damage/20 bolls (%)					Locule damage in 20 green bolls (%)				
		45 DAS	60 DAS	75 DAS	Mean	ROC	90 DAS	120 DAS	150 DAS	Mean	ROC
1	SPLAT	7.89[a] (1.88)	13.58[a] (5.51)	16.63[a] (8.19)	12.70[a] (4.83)	69.10	6.93[a] (1.46)	9.58[a] (2.77)	12.35[a] (4.57)	9.62[a] (2.79)	66.30
2	Insecticides spray	12.11[b] (4.40)	15.61[b] (7.24)	23.04[c] (15.31)	16.92[b] (8.47)	45.81	8.40[a] (2.13)	11.69[b] (4.11)	16.54[c] (8.11)	12.21[b] (4.47)	46.01
3	IPM module	10.43[ab] (3.28)	14.50[ab] (6.27)	18.18[b] (9.73)	14.37[a] (6.16)	60.59	7.68[a] (1.78)	10.42[ab] (3.27)	14.20[b] (6.02)	10.77[ab] (3.49)	57.85
4	Control	17.38[c] (8.92)	21.09[c] (12.94)	31.39[d] (27.14)	23.29[c] (15.63)	-	12.10[b] (4.39)	15.36[c] (7.01)	22.71[d] (14.90)	16.72[c] (8.28)	-
5	Mean	11.95 (4.29)	16.19 (7.77)	22.31 (14.41)	16.82 (8.37)	-	8.78 (2.33)	11.76 (4.15)	16.45 (8.02)	12.33 (4.56)	-

Modules	Green boll damage/20 bolls (%)									Locule damage in 20 green bolls (%)								
	45 DAS		60 DAS		75 DAS		Mean		ROC	90 DAS		120 DAS		150 DAS		Mean		ROC
	SEm ±	CD	SEm ±	CD	SEm ±	CD	SEm ±	CD	-	SEm ±	CD	SEm ±	CD	SEm ±	CD	SEm ±	CD	-
Treatment(T)	0.94	2.68	0.69	1.95	0.74	2.11	0.75	2.26	-	0.58	1.65	0.45	1.28	0.54	1.54	0.55	1.66	-
Period (P)	-	-	-	-	-	-	0.46	1.27	-	-	-	-	-	-	-	0.27	0.75	-
Year (Y)	-	-	-	-	-	-	0.46	NS	-	-	-	-	-	-	-	0.27	0.75	-
T x P	-	-	-	-	-	-	0.79	2.20	-	-	-	-	-	-	-	0.47	1.30	-
T x Y	1.72	NS	1.26	NS	1.37	NS	0.92	NS	-	1.03	NS	0.82	NS	0.99	NS	0.54	NS	-
P x Y	-	-	-	-	-	-	0.92	NS	-	-	-	-	-	-	-	0.54	NS	-
T x P x Y	-	-	-	-	-	-	1.59	NS	-	-	-	-	-	-	-	0.94	NS	-
C. V. %	35.29		19.12		14.99		23.12		-	28.81		17.09	1	4.73		18.67		-

Figures in parentheses are retransformed values; those outside are square root transformed values for GBD larva and Arc sine transformed values for GLD; ROC = reduction over control
Treatment means with the letter(s) in common are non-significant at 5% level of significance

Table 5. Evaluation of different modules against pink bollworm in *Bt* cotton at Surat (Pooled of 2021-22 to 2023-24)

Sr. No.	Modules	OBD	ROC	OBLD	ROC	SCY (q/ha)
1	**SPLAT**	15.51[a] (7.15)	54.11	11.04[a] (3.66)	58.97	22.58[a]
2	**Insecticides spray**	18.52[b] (10.09)	35.24	13.78[b] (5.67)	36.43	17.13[c]
3	**IPM module**	16.56[a] (8.12)	47.88	11.81[a] (4.19)	53.03	21.01[b]
4	**Control**	23.25[c] (15.58)	-	17.38[c] (8.92)	-	14.17[d]
	Mean	18.46 (10.02)	-	13.50 (5.45)	-	18.72
	S. Em. ±	0.44	-	0.31	-	0.44
	CD at 5%	1.24	-	0.87	-	1.26
	S.Em. ± (YxT)	0.81	-	0.56	-	0.76
	CD at 5% (YxT)	NS	-	NS	-	NS

Figures in parentheses are retransformed values; those outside are Arc sine transformed values. Treatment means with the letter(s) in common are non-significant at 5% level of significance. OBD - Open boll damage/20 bolls at harvest (%), OBLD - Open boll locule damage/20 bolls at harvest (%), ROC - reduction over control

control and M2 (Monitoring and ETL based sprays) having IRs. 12725/- benefit over control (Table 8).

In the present experiment, monitoring tool was very important to determine the effectiveness of the applied strategies in different modules as indirectly gives clue to the reduction in incidence and damage through the monitoring of male moths in the pheromone traps. The trap catches showed significant differences when compared to control plots with respect to SPLAT technology being less trap catches of pink bollworm male moths than control showing effective releases of sex pheromones in higher concentrations at source points than low concentrations of sex pheromones in installed phero sensor-SM-TP traps that leads to confusion in the wandering males. While with chemical-based and IPM modules, though the trap catches were a little bit less due to management strategies than control plots but the differences remained not significant as the low concentrations of the sex phero-chemicals in pheromone traps was only used for the monitoring purposes and similar sex phero-chemicals as male confusion was not used as components in above modules. The effectiveness of the Phero-sensor TM-SP Sleeve trap against pink bollworm incidence was reported across different locations under ICAR-AICRP trials and validated on farmers' fields too (Anonymous, 2018). In comparative performance, phero-sensor-TM-SP trap was reported to be more effective than Delta trap and PCI- funnel trap due to small plastic and wider distance of lid with lure attachment

Table 6. Evaluation of different modules against natural enemies in *Bt* cotton at Surat (Pooled of 2021-22 to 2023-24)

Sr. No.	Modules	Ladybird beetles/plant				*Chrysoperla*/plant			
		90 DAS	120 DAS	150 DAS	Mean	90 DAS	120 DAS	150 DAS	Mean
1	**SPLAT**	1.97^{a} (3.37)	2.29^{a} (4.76)	2.21^{b} (4.40)	2.16^{a} (4.17)	1.64^{a} (2.20)	1.81^{a} (2.76)	1.89^{a} (3.08)	1.78^{a} (2.67)
2	**Insecticides spray**	1.46^{c} (1.64)	1.69^{d} (2.37)	1.77^{d} (2.64)	1.64^{c} (2.19)	1.10^{c} (0.72)	1.22^{c} (0.99)	1.31^{c} (1.21)	1.21^{c} (0.96)
3	**IPM module**	1.77^{b} (2.64)	1.89^{c} (3.08)	2.06^{c} (3.76)	1.91^{b} (3.15)	1.32^{b} (1.25)	1.54^{b} (1.88)	1.65^{b} (2.22)	1.51^{b} (1.78)
4	**Control**	2.05^{a} (3.70)	2.15^{b} (4.14)	2.37^{a} (5.09)	2.19^{a} (4.30)	1.71^{a} (2.42)	1.89^{a} (3.08)	1.97^{a} (3.38)	1.86^{a} (2.96)
5	**Mean**	1.81 (2.79)	2.01 (3.53)	2.10 (3.92)	1.98 (3.40)	1.44 (1.59)	1.62 (2.11)	1.70 (2.41)	1.59 (2.03)

Modules	Ladybird beetles/plant								*Chrysoperla*/plant							
	90 DAS		120 DAS		150 DAS		Mean		90 DAS		120 DAS		150 DAS		Mean	
	SEm ±	CD	SEm ±	CD	SEm ±	CD	SEm ±	CD	SEm ±	CD	SEm ±	CD	SEm ±	CD	SEm ±	CD
Treatment (T)	0.04	0.12	0.04	0.10	0.04	0.12	0.05	0.14	0.02	0.07	0.07	0.18	0.07	0.21	0.07	0.22
Period (P)	-	-	-	-	-	-	0.02	0.05	-	-	-	-	-	-	0.03	0.09
Year (Y)	-	-	-	-	-	-	0.02	NS	-	-	-	-	-	-	0.03	NS
T x P	-	-	-	-	-	-	0.03	0.08	-	-	-	-	-	-	0.06	NS
T x Y	0.08	NS	0.06	NS	0.08	NS	0.03	NS	0.07	NS	0.12	NS	0.14	NS	0.06	NS
P x Y	-	-	-	-	-	-	0.03	NS	-	-	-	-	-	-	0.06	NS
T x P x Y	-	-	-	-	-	-	0.06	NS	-	-	-	-	-	-	0.11	NS
C. V. %	10.11		7.85		9.06		7.17		20.23		20.70	1	6.20		17.11	

Figures in parentheses are retransformed values; those outside are square root transformed values

Treatment means with the letter(s) in common are non-significant at 5% level of significance

Table 7. Evaluation of different modules against natural enemies in *Bt* cotton at Surat (Pooled of 2021-22 to 2023-24)

Sr. No.	Modules	Spiders/plant							
		90 DAS		120 DAS		150 DAS		Mean	
1	**SPLAT**	1.60[a] (2.07)		1.81[a] (2.79)		1.97[a] (3.38)		1.80[a] (2.74)	
2	**Insecticides spray**	1.32[c] (1.23)		1.44[b] (1.59)		1.68[b] (2.31)		1.48[b] (1.69)	
3	**IPM module**	1.40[b] (1.45)		1.55[b] (1.90)		1.80[b] (2.73)		1.58[b] (2.00)	
4	**Control**	1.70[a] (2.38)		1.89[a] (3.08)		2.06[a] (3.75)		1.88[a] (3.03)	
5	**Mean**	1.50 (1.76)		1.68 (2.31)		1.88 (3.02)		1.69 (2.34)	
		SEm ±	CD	SEm ±	CD	SEm ±	CD	S Em ±	CD
	Treatment (T)	0.06	0.16	0.05	0.15	0.06	0.16	0.07	0.20
	Period (P)	-	-	-	-	-	-	0.03	0.09
	Year (Y)	-	-	-	-	-	-	0.03	NS
	T x P	-	-	-	-	-	-	0.05	NS
	T x Y	0.11	NS	0.10	NS	0.10	NS	0.06	NS
	P x Y	-	-	-	-	-	-	0.06	NS
	T x P x Y	-	-	-	-	-	-	0.11	NS

Figures in parentheses are retransformed values; those outside are square root transformed values. Treatment means with the letter(s) in common are non-significant at 5% level of significance

(Anonymous, 2022). In the experiment with the mass trapping, Shrinivas et al. (2019a) found phero-sensor-TM-SP trap more effective than delta trap and also reported similar performance of the phero-sensor-TM-SP trap in trapping the male moths when splat technology was used at two different doses (500 & 750 g/acre). Amongst three doses of SPLAT-PBW applied at 500, 750 and 1250 g/acre, owing to similar performance, SPLAT technology @ 500 g/acre was found effective and economical where average moth catches/trap/week was 3.62 and lower damage of pink bollworm (6.38% rosette flower, 6.86% Green boll and 12.28% locule damage) with higher seed cotton yields (46.25 q/ha) with high B:C ratio (Sreenivas et al., 2021). In the present results also, SPLAT application *viz.* 200-250 g/ha thrice at 45, 75 and 105 DAS (at 30 days interval) was found to have effectively reduced male moth catches, reduced flower damage, green bolls damage, locule damage and larval population. The open boll and locule damage were also significantly reduced at harvest and found economical (IRs. 53206) recording seed cotton yield of 22.58 q/ha as against 14.17 q/ha in control showing 59.35% increase over control. Thus, the

Table 8. Economics (in IRs/ha) of different modules against pink bollworm in *Bt* cotton at Surat (mean of 2021-22 to 2023-24)

Treatment	Schedule	Quantity/ha	Price	Cost	Labour charge	PP cost	Total	Yield (q/ha)	GR	NR	BOC
Monitoring and Splat technology (M1)											
Installation of phero-sensor TM-SP trap	45 DAS	5 traps/ha	17/piece	85	67	317	8801	22.58	165579	156778	53206
Pectino-lure for trap (Viability-40 days)	45, 85,125	3/trap/season	11/piece	165							
Application of SPLAT 4% RTU (Thrice)											
First application	45 DAS	250 g/ha	2560/250 g	2560	268	8484					
Second application	75 DAS	250 g/ha	2560/250 g	2560	268						
Third Application	105 DAS	250 g/ha	2560/250 g	2560	268						
Monitoring and ETL based spray of recommended technology (M2)											
Installation of phero-sensor TM-SP trap	45 DAS	5 traps/ha	17/piece	85	67	317	9317	17.13	125614	116297	12725
Pectino-lure for trap (Viability-40 days)	45, 85,125	3/trap/season	11/piece	165							
Spraying of insecticides against pink bollworm at ETL population or damage											
Spray 1 (Indoxacarb 14.5 SC)		500 ml/ha	1887/500 ml	1887	804	9000					
Spray 2 (Emamectin benzoate 5 SG)		200 g/ha	528/200 g	528	804						
Spray 3 (Spinosad 45 SC)		150 ml/ha	4173/150 ml	4173	804						
Recommended IPM module for PBW (M3)											
Installation of phero-sensor TM-SP trap	45 DAS	5 traps/ha	17/piece	85	67	317	7099	21.01	154066	146967	43395
Pectino-lure for trap (Viability-40 days)	45, 85,125	3/trap/season	11/piece	165							
Azadirachtin 1500 PPM @ 2.5 l/ha	60 DAS	2.5 l/ha	448/l	1120	804	1924					
Release of Tricho card (*Trichogrammatoidae bactrae*) at least 7 days after neem application											
First release	67 DAS	1.5 lakh/ha	27/ card	189	268	835					
Second release	72 DAS	1.5 lakh/ha	27/ card	189							
Third release	79 DAS	1.5 lakh/ha	27/ card	189							
Spraying of insecticides against pink bollworm at ETL population or damage											
Spray 1 (Indoxacarb 14.5 SC)		500 ml/ha	1887/500 ml	1887	804	2691					
Spray 2 (Emamectin benzoate 5 SG)		200 g/ha	528/200 g	528	804	1332					
Untreated for PBW (M4)											
Installation of phero-sensor TM-SP trap	45 DAS	5 traps/ha	17/piece	85	67	317	337	14.17	103909	103572	-
Pectino-lure for trap (Viability-40 days)	45, 85,125	3/trap/season	11/piece	165							

Note: Labour @ 268/8 hours/day and Seed cotton@7333/q. GR - Gross return, NR - Net return, BOC - Benefit over control technology was found as effective as reported by Sreenivas et al. (2021). SPLAT technology is a biologically inert material (waxes, vegetable oils, water and other food grade non-toxic and bio-degradable) used for the delivery of semiochemicals including pheromones (Kranthi, 2018). Jethva et al. (2018) found least moth's catches (3.90 moths/trap), rosette flowers (1.90%), green bolls (1.33%), open bolls (2.88%) and locules (3.58%) damage with highest yield (3089 kg/ha) and ICBR (1:8.93) in mating disruption technology treated plot as compared to farmer's practices. Shrinivas et al. (2019a) studied the dissipation of SPLAT formulation and found 40.36% of active ingredient left in the samples even by end of fifth week clearly indicating slow release compared to other lures. Shrinivas et al. (2019b) recorded lowest rosette flower (6.38%), green bolls (6.86%) and locule (12.28%) damage with higher seed cotton yield (46.25q/ha) and greater B:C ratio (2.48) in SPLAT @ 500 g/acre compared to farmers' practices. In peach orchards also, the similar results were obtained by Hristina et al. (2015) where there was reduction of shoot and fruit damage to 0% by Oriental fruit moth, *Cydia molesta* (Busck) in Isomate ®OFM treated orchards, compared to reference orchards where there was 25.4% shoot damage and 4.9% fruit damage.

Conclusion

Amongst three modules evaluated for three years, the module M1 comprising of monitoring of pink bollworm moths through installation of Phero-sensor TM-SP sleeve trap @ 5/ha with changing lure at 40 days interval starting from 45 DAS and application of SPLAT as small dollops at plant surface in the field at 200-250 g/ha thrice at 45, 75 and 105 DAS (at 30 days interval) was found effective reducing male moth catches (67.60%), reduction of flower damage (63.36%), green bolls on boll basis (69.10%), locules in green bolls (66.30% LD) with reduction in larval population (67.16%) and reduction in open boll damage (54.11%) and locule damage (58.97%) at harvest. The module also recorded highest seed cotton yield of 22.58 q/ha as against 14.17 q/ha in control showing 59.35% increase over control which was found economical recording highest benefit over control (IRs. 53206).

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