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SPLAT-PBW: An eco-friendly, cost-effective mating disruption tool for the management of pink bollworm on cotton

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ABSTRACT

Indian cotton farmers have reaped the benefits of *Bt* cotton cultivation since commercialization (March 2002) until 2013–14. From 2014 onwards, the pink bollworm (PBW) outbreak in the entire cotton-growing regions of the country was witnessed. The pest aggravated and became more problematic, not being controlled with the present management practices due to resistance to cry-toxins and insecticides. However, a non-chemical approach modifying the behavior of PBW was exploited in this study and evaluated its effectiveness in comparison with existing management strategies. An area-wide management trial with mating disruption technology was carried out using specialized pheromone and lure application technology for pink bollworm (SPLAT-PBW). Application of 500, 750, and 1250 g/acre of the lure during 2017–18 in 154 acres and 206 acres during 2018–19 in Raichur district of Karnataka, India, recorded significant control of PBW. The results revealed that SPLAT-PBW applied at 500 g/acre was found to be optimum, as minimum rosette flower (8.23%), green boll damage (7.36%), locule damage (8.41%), and higher yield (33.59 q/ha) recorded as compared to farmers' practice which yielded 22.33 q/ha even after 5–6 rounds of insecticide spray. At the end of the fifth week, 40.36% of the active ingredient of pheromone was present in the field sample. It indicated a slow-release mechanism of pheromone from the SPLAT-PBW lures. Non-chemical approaches of insect pest management in cotton significantly benefit in reducing the load of chemical pesticides and cost of protection. This technology is an alternate option to chemical pesticides to curb the menace of the PBW due to management difficulties with the present pest control tools.

1. Introduction

Cotton, *Gossypium hirsutum* L, is a major commercial crop contributing agricultural and industrial growth in India. India ranks first in cotton cultivation with 105 lakh hectares with an annual production of 35.1 m bales and a mean productivity of 520 kg/ha (Anonymous 2016a; Emeka, 2009). In India, cotton is damaged by 160 insect pests, out of which about 12 are of significant importance (Ayyar 1932; Ingram 1981; Puri et al., 1999). Insect pests *viz.,* sucking pests and bollworm complex (Spotted bollworm, Pink bollworm, and American bollworm) are major production constraint and contribute the loss up to 50–60 % (Dhaliwal et al., 2004). Until 2014, there was the sporadic occurrence of the pink bollworm, *Pectinophra gossypiella* (Saunders) (Lepidoptera: Gelechiidae) in the cotton-growing regions in India. Although unusual survival of pink bollworm larvae on flowers of 60–90 days after sowing was detected in Gujarat, causing measurable damage and led to a heavy infestation in the subsequent years (2015–16). Even after the occurrence, all the efforts were failed to prevent further losses; the pest aggravated and caused 40–80 % damage in different parts of the country (Kranthi, 2015). Cotton farmers in the affected areas were left with virtually no viable control options for the pink bollworm. This pest is typically not controlled by conventional pesticides due to its capacity to develop resistance, nor by the Cry1Ac endotoxin found in bacterial insecticides.

Pink bollworm management in cotton is complex because of its internal feeding habit within the cotton bolls. Newly emerged larva enters the cotton bolls, which feed internally on developing seeds (Singh et al., 1988). Typically larvae undergo obligatory diapauses during the onset of cool, dry conditions. After completing the larval period, it pupate in the soil or litter on the ground (Beasley and Adams, 1995), quiescent

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stage up to 2.5 years (Metcalf and Metcalf, 1992). Pupae measure about 8–10 mm long, and are straw-colored. Adults are tiny, dark brown, and inconspicuous measure about 7–10 mm in length (Venilla et al., 2007). In these paradoxical situations such as resistance to chemicals and *Bt* toxins by PBW, farmers have no choice but to explore the possibility of novel, eco-friendly, long-lasting tools to contain this pest. Mass trapping of insect pests have been tried previously (Taneja and Jayaswal, 1983; Karuppuchamy and Balasubramanian, 1990) and mating disruption (Attique et al., 2000; Athanassiou et al., 2002) tools to manage the pink bollworm in B*t* cotton ecosystems. All these tools were ineffective because traps and pheromone dispensers deployed at a lower density than recommended. Changing the pheromone's formulation can be easy, and bio-safety concerns apart from cost-effectiveness (Mazumder and Khalequzzaman, 2010).

Specialized Pheromone and Lure Application Technology (SPLAT) is a wax-based formulation having sustained-release pheromone leads to the mating disruption and prevents insect pests from reproducing. Simulation of emitting the natural pheromone of female insects that causes males to become confused and incapable of locating a female to mate with. This results in collapse of insect pest population due to reduced mating rates. Point sources of pheromone-based SPLAT formulations are applied to the crop. The amount of sex pheromone emitted by each SPLAT dollop would be sufficient to shut down mating as males have diverted away from females due to the powerful allure of the pheromone. Unlike females, SPLAT dollops emit high doses of pheromone continuously. Though many tools are available for pink bollworm management, the disadvantages associated with each one tend to outweigh its advantages. Particularly with the use of mass trapping and mating disruption strategies with the help of sleeve trap (8–10 traps/acre) and delta sticky traps (8–10 traps/acre), both of which are costly and not effective (Shrinivas et al., 2019a,b). Field testing of SPLAT against pink bollworm for modifying the behavior and mating disruption was conducted previously by many researchers (Mahalakshmi et al, 2020; Mafra-Neto et al., 2013; Critchley et al. 1983, 1985; Lykouressis et al., 2005; Unlu and Mezreli, 2011). It effectiveness is exploited against different insect pests *viz.,* oriental beetle (Rodriguez-Saona et al., 2010); season-long mating disruption in leaf folders (Stelinski et al., 2007) and citrus leafminer (Stelinski et al., 2010), grape berry moth (Teixeira et al., 2010), mealybug (Cocco et al., 2018), delayed mating of female European grapevine moth, (Torres-Vila et al., 2002). Reduction in the number of mating is not the only mode of action of mating disruption, as mating delay also play a crucial role (Lentini et al., 2018; Torres-Vila et al., 2002)

Considering these shortcomings in current control methods, an alternative strategy for managing pink bollworm is highly desirable, preferably eco-friendly and cost-effective, and less labor-intensive than existing techniques. The study aimed to assess a novel mating disruption formulation (SPLAT-PBW) to control pink bollworm. A large-scale demonstration trial was conducted in a farmer's field to determine and confirm the product's optimum dosage and elucidate its cost economics against pink bollworm in cotton ecosystems, compared to farmers' practice which is solely an insecticide based.

2. Materials and methods

2.1. Field experiment

Cotton growing farmers were selected and explained about the SPLAT technology and its application to manage the PBW. It was advised not to use the insecticides in the SPLAT pheromone-treated plots. Based on the total area required for documentation and distance between each demonstration block, the farmers were allotted different dosages in the first season trial and effective dosage of 500 g/acre SPLAT-PBW in the second season. A 2-km gap was maintained between each demonstration block. Jadoo, a popular *Bt* cotton hybrid, was planted by most farmers during the second week of June 2017 and 2018 Kharif.

Typically, the incidence of PBW starts at 65–70 days after sowing; however, SPLAT-PBW applied intentionally from 35 to 40 days. This pre-emptive application ensures that, by the time PBW began to appear in the field, the field would effectively permeate by the pheromone released by SPLAT-PBW, maximizing the effect through mating disruption strategy of the pest population. To compare the effectiveness of SPLAT, the efficacy of insecticides on PBW was recorded. Farmers use 4–5 rounds of insecticide chemicals *viz.,* profenophos 50% EC, lambda-cyhalothrin 5% EC, chlorantraniliprole 18.5% SC, emamectin benzoate 5% SG, and lambda-cyhalothrin 5% EC + chlorantraniliprole 10% SC). Each treatment block was divided into five sections for documenting the observations on PBW and natural enemies (irrespective of their size). From each section, ten plants were selected randomly to document observations on pink bollworm representing the rosette flowers, locule damage, and green boll and recorded the observation at weekly intervals starting from 45 days of sowing. Similarly, adult male moths captured in pheromone traps (installed previously at the rate of two per acre) per week were also recorded. Subsequently, observation was recorded at weekly intervals till the complete harvest of the crop (see Table 2).

Insecticides used by the farmers for managing pink bollworm, *P. gossypiella*.

Name of the Insecticides	Dosage
Profenophos 50% EC	2000 ml/ha
Lamda Cyalothrin 5% EC	1000 ml/ha
Chlorantraniliprole 18.5% SC	200 ml/ha
Emamectin Benzoate 5% SG	200 g/ha
Lamda Cyalothrin 5% EC + Chlorantraniliprole 10% SC	1000 ml/ha

2.2. Application of SPLAT

Mating suppression delivered by SPLAT was demonstrated in large-scale about 154 acres with three different dosages *viz.,* 500, 750, and 1250 g per acre, and applied four times (total quantity was split into four applications) during 2017–18 *Kharif* season at an interval from 35 to 40, 65–70, 95–100 and 125–130 days after planting of cotton. Pheromones paste was taken in a plastic spoon (size 2″) and hung on to leaf petiole at the growing tip. Subsequent applications were directly applied with hand to the leaf junction of terminal plant part in the farmers' field (Raichur, Karnataka) during Kharif 2017–18. In the subsequent year, i. e., 2018–19 *Kharif*, the demonstration was conducted in the same villages with a suitable and optimal dosage of 500 g/acre was carried out in a large-scale demonstration of 206 acres in the farmers' field.

2.3. Safety of SPLAT-PBW to natural enemies

In each experimental plot, ten tagged plants were observed for coccinellids and C*hrysoperla* population. The number of grub and adults of coccinellids; and adult chrysoperla was recorded before treatment imposition, and 15 and 30 days after each SPLAT-PBW application (3–4 application/season), data was subjected to statistical analysis.

2.4. Dissipation of pheromone

Persistence and dissipation of pheromone at different rates applied was determined by randomly collecting samples (spoon) of SPLAT-PBW lure from fields. Samples were collected up to fifth week after application on weekly basis. Samples were wrapped using aluminum foil and stored at 4 °C. Gossyplure (mixture of cis, cis and cis, trans isomers of 7, 11- hexadecadienyl acetate) concentration in samples collected at different week estimated using gas chromatography (GC).

2.4.1. Collection and storages of dispensers

To study the persistence and dissipation of pheromone, 50 dispensers of powder and wax-based SPLAT formulation were placed in the corner of the experimental site on the day of sowing of the crop. For pheromone dissipation, three dispensers containing SPLAT-PBW and powder were collected from the cotton fields at weekly intervals starting from the day of sowing. Each collected dispenser was wrapped immediately in aluminum foil, placed in a therma cool box, and stored in the refrigerator at −20 °C temperature. The pheromone present in these dispensers, which contained PBW pheromone as an active ingredient blended with wax and water in SPLAT formulation and silica in powder formulation, was analyzed using Gas Chromatography (GC).

2.4.2. Sample preparation and extraction

Fifty mg of 1,2Acetate weighed accurately and collected in to 100 ml volumetric flask and volume made-up with ethyl acetate. Further, it was used to prepare working standards. Calibration standard concentrations were made using high pure pheromone standards. Available amount (10 mg) reference standard (pure active) was weighed using a calibrated analytical balance, and 20 ml of internal standard was added.

Samples were extracted following a method given by Meissner et al. (2000). About 200 mg of SPALT sample (formulation) and 10 ml of the internal standard were added and weighed the bottle and noted reading. Using vertex, samples was dissolved thoroughly and subsequently sonicated for 30 min. The sample was kept overnight at room temperature for extraction. After a day, 1 ml of samples was filtered in GC vials using a 0.45 μm nylon syringe filter and analyzed through GC. The pheromone content in the sample was calculated comparing with standard area. The pheromone released at aging period was estimated through comparing the amount contained initially versus those remaining after aging. To know the dissipation pattern, estimated concentration of pheromone content in samples of different weeks was plotted against time (weekly basis).

2.4.3. GC-instrumentation

A gas chromatograph (GC) (Shimadzu) was employed for analysis. The GC compatible HP 5 column (30 m × 0.25 mm x 250 μm of internal diameter) was used. The initial GC temperature was held at 50 °C for 2 min and then ramped at a rate of 10 °C min^{-1} to 300 °C. The total run time was 19 min. High pure helium (99.999 %) was used as carrier gas with a column flow pressure of 13 psi. The pheromone content in the samples calculated using the standard internal method (Stelinksi et al., 2007)

2.5. Statistical analysis

Data generated on rosette flowers, green boll and locule damage were transformed to arc sin values. Data on number of moth trap catches per trap were converted to square root values ($\sqrt{x+1}$). All data recorded, including kapas yield was subjected to statistical analysis and the Duncan's Multiple Range Test (DMRT) was followed to compare the treatment differences in the doses applied (Gomez and Gomez, 1984).

2.6. Economic analysis of SPLAT-PBW

The yield (kapas and lint) of cotton obtained from each treatment was subjected to statistical analysis. The standard cost of cotton crop cultivation was the same for all the treatments. It was obtained from the recommended agricultural practice of the University of Agricultural Sciences, Raichur, India. The total cost of cultivation was calculated by adding the common cost of cultivation and treatment cost. The gross return per treatment was computed by multiplying the total yield per hectare by the prevailing market price, while net returns for each treatment were realized by subtracting total cost from grass returns. Each treatment's benefit-cost ratio was derived by dividing gross returns from net returns (Shabozoi et al., 2011).

3. Results and discussion

3.1. Efficacy of SPLAT-PBW against pink bollworm

Results on the evaluation of SPLAT-PBW applied at three dosages (500, 750, and 1250 g / acre) in the first season and effective dosage of 500 g per acre used at the second season in four splits at 40, 70, 100, and 130 days after sowing has revealed that overall incidence of pink bollworm in terms of rosette flowers and green boll damage was minimum (11.24 and 9.70 %, respectively) in 1250 g per acre SPLAT applied treatment, respectively which did not differ significantly with its lower dosages of 750 g (11.80 and 10.27 %) and 500 g (11.76 and 10.20 %) in the first (2017–18) season and 4.70% of rosette flowers and 4.52% green boll damage observed from the application of adequate dosage of 500 g/acre in the second (2018–19) season ($P < 0.05$). But all the dosages tested in both seasons differed significantly from fields subjected to farmers' standard PBW control practices, wherein rosette flowers and green boll damage recorded were 20.96 % and 37.93 % in the first season, 13.67%, and 23.97 % in the second season, respectively ($P < 0.05$).

Similarly, per cent locule damage was found to be minimum (7.86 %) in 750 g per acre SPLAT applied treatments, followed by 8.05 % (1250 g/acre) and 8.65 % (500 g/acre) in the first season trial. In the second season, it was 8.18% (500 g/acre), showing a significant difference with the farmers' practice (34.34 %) and (37.63%) even after four to five rounds of insecticide spray exclusively for pink bollworm management (Fig. 1a &c).

SPLAT being a mating disruption tool has impacted by diverting the male moths away from the source of pheromone. As a result, moths caught per trap per week was minimum *viz.*, 7.59, 7.20, and 9.29 at 1250, 750, and 500 g per acre, respectively, in the first season and an average of 18.92 male moths caught pertrap per week captured in the second season (Fig. 1d). The per cent reduction in male moth catch was 96.84, 97.00, and 96.61 at 1250, 750, and 500 g per acre; and 92.12% reduction during the second season (Fig. 1b). On the contrary, the average male moths caught were highest in farmers' practice (240.38 moths/trap/week) and (155.03 moths/trap/week), indicating that the insecticide used in these fields failed to deliver equivalent control to SPLAT-PBW (Table 1).

SPLAT-PBW applied at three dosages from the beginning of cropping season could keep the pest population in check by mating disruption, which resulted in lower bollworm incidence and higher cotton yields. The highest cotton yield (43.33 q/ha) was observed in treatment with the highest dosage of SPLAT-PBW (1250 g/ha). While, the cotton yields obtained from the other two lower dosages (750 and 500 g/ha) of SPLAT-PBW were on par with the highest dose as they recorded 42.50 q/ha and 40.50 q/ha, respectively, in the first season. A similar trend was also noticed in the second season. The cotton yield realized under insecticide control was 24.68 q per ha and 20.00 q per ha from two seasons. In toto, the yield gain in SPLAT-PBW applied farmers' fields ranged from 15.80 to 18.63 q per ha with a mean yield of 6–7 quintals per hectare (Table 1).

This study explained the field demonstration on the use of SPLAT against PBW population reduction in the *Bt* cotton ecosystem. Field testing of SPLAT against pink bollworm for modifying the behavior and mating disruption was conducted previously by many researchers. However, a similar study during 2020 had recorded a reduction of 86.72 %, 62.03 %, and 74.21 % of male moth catch, larval density, and locule damage in green bolls, respectively, with an increase of 16.89 % of seed cotton yield (Mahalakshmi et al, 2020; Mafra-Neto et al., 2013; Lykouressis et al., 2005; Unlu and Mezreli, 2011). SPLAT-OrB is specialized pheromone ((Z)-7-tetradecen-2) formulations used against oriental beetle tested at 2.5 and 5 g at 1/ha recorded less number male in traps (trap catches) and negligible mating success in caged females with that of untreated plots (Rodriguez-Saona et al., 2010).

For managing *Phyllocnistis citrella* Stainton (Gracillariidae:

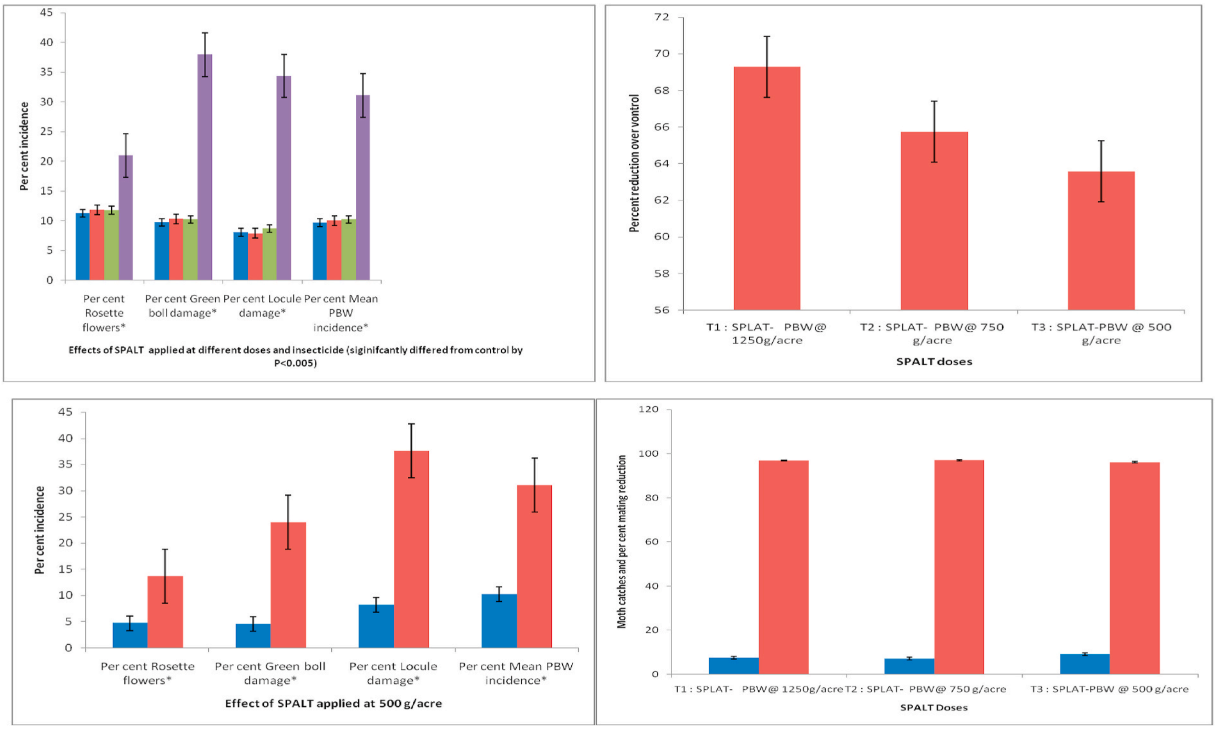

Fig. 1. Effect of SPLAT-PBW mating disruption tool against pink bollworm, *Pectinophora gossypiella* on *Bt* cotton.(a) reduction of incidence; (b) Percent reduction of PBW incidence over control (P < 0.05) (c) Effect of SPLT dose during 2018–19 and (d) Number of moth catches and percent mating reduction

Table 1
Evaluation of SPLAT-PBW against pink bollworm on *Bt* cotton during *Kharif* 2017–18 and 2018–19.

Treatment details	Per cent Rosette flowers[a]		Per cent Green boll damage[a]		Per cent Locule damage[a]		Per cent Mean PBW incidence[a]		Per cent decrease in PBW incidence over farmer's practice		Average number of moths catches/ week[b]		Percentage mating disruption#		Cotton yield (q/ha)	
T_1: SPLAT- PBW@ 1250 g/acre	11.24	–	9.70	–	8.05	–	9.66	–	69.29	–	7.59	–	96.84	–	43.33	–
T_2: SPLAT- PBW@ 750 g/ acre	11.80	–	10.27	–	7.86	–	9.97	–	65.75	–	7.20	–	97.00	–	42.50	–
T_3: SPLAT-PBW @ 500 g/acre	11.76	4.70	10.20	4.52	8.65	8.18	10.20	5.80	63.57	76.88	9.29	18.92	96.14		40.50	26.67
T_4: Conventional farmer's practice (Control)	20.96	13.67	37.93	23.97	34.34	37.63	31.07	25.09	–	–	240.38	155.03	–		24.68	20.00
S. Em (±)	0.98	0.58	0.86	1.47	0.68	2.14	–	–	–	–	0.15	0.55	–	–	0.99	0.56
CD @ 0.05	3.03	1.81	2.64	4.54	2.09	6.60	–	–	–	–	0.46	1.70	–	–	2.97	1.68
CV (%)	10.13	12.33	8.20	13.52	7.13	11.38	–	–	–	–	5.40	12.72	–	–	10.20	10.23

[a] Figures in the parentheses are arc sin transformed values.
[b] Figures in the parentheses are square root ($\sqrt{x+1}$) transformed values; Significant difference from control at $P < 0.05$%.

Lepidoptera) pheromone formulation at 490 g per ha (0.2 % a. i at 3: 1 blend of (Z, Z, E)-7, 11,13-hexadecatrienal:(Z,Z)-7,11-hexadecadienal) applied twice per season resulted in season-long disruption of male moth catch in pheromone traps as well as reduced leaf infestation. Further, the moth behavior in the field suggested the mating disruption is through non-competitive mechanism (Stelinski et al., 2010). Phenology of males of *Proeulia auraria* (Lepidoptera: Tortricidae) in vineyards, apples, and blueberries was conducted with application of the pheromone blend (78 g/ha) provided high disruption for mating in all crops for five months. This suggested that, through SPALT, it is feasible to manage the *P*. auraria through mating disruption (Flores et al., 2021).

Significant reduction in grape berry moth *Paralobesia viteana* (Lepidoptera: Tortricidae) infestation in treated plot through mating disruption after application of SPLAT-GBM (0.8 g drops at a density of 1544 or 3089 drops per hectare for a total of 1.3 or 2.5 kg per hectare) twice at 1.3 or 2.5 kg per ha compared with control plots. Trials conducted during subsequent year with application 2.5 kg per ha caused a significant reduction in the infestation on harvested clusters and border of the vineyards (Teixeira et al., 2010).

Mating disruption recorded a significant reduction by 18.8–66.2 % of ovipositing females of mealybug, *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae). The absence of ovipositing females in subsequent years indicates mating disruption's effectiveness, which leads to a decrease in population and delay in female mating. Further, consecutive applications of specialized pheromone formulations would significantly increase the effectiveness against vine mealybug by mating disruption (Cocco et al., 2018). Present findings on PBW is in accordance with results of Lapointe and Stelinski (2011) on citrus leaf miner *P citrella* with an application rate of pheromone baited dispensers at 250 or 500 g per ha containing 0.15% (Z, Z, E)-7,11,13- hexadecatrienal resulted in more than 90% of a male moth caught in traps. Findings of Stelinski et al. (2009) on citrus leaf miner with the application of emulsified pheromone of a wax dispenser, SPLAT-CLM (Z, Z, E −7,11,13 hexadecatrienal + Z, Z-7,11-hexadecadienal) applied at 0.2 % loading rate of a. i. by weight recorded a season-long mating disruption of the leaf minors. SPLAT-GM is a sprayable formulation developed for controlled release of the gypsy moth applied at a dosage of 15–75 g of a. i. per ha in the first and second year resulted in a reduction of mating success in the female of gypsy moth more than 99 % and male moth caught in pheromone baited trap were reduced by more than 90 %. Dosage response tests conducted in the third year of the study indicated that SPLAT-GM applied at 7.5 g a. i. per ha was as effective as against a dosage of 15 g a. i. per ha (Ksenia et al., 2010). These techniques was also found effective against two lepidopteron insect pests of apple, *Bonagota salubricola* and *Grapholita molesta* (Lepidoptera: Tortricidae) and compared with insecticides (Patrick et al., 2012) using mating disruption formulation SPLAT Grafo + Bona (SG + B). The population of this insect reduced lesser extent in the integrated apple production system (IAP) and males caught in delta traps compared to SPLAT –treated field (1 kg/ha), which could reduce the damage to the extent 1.63–4.75 % by *B. salubricola* at harvest stage and damage by *G. molesta* was near zero. Application of SPLAT-Grafo + Bona also reduced the number of sprays of insecticides by 43 %.

3.2. SPALT-PBW influence on natural enemies population

In general, the population of coccinellids and *Chrysoperla* spp. Were found throughout the cropping period, but their populations were found maximum in November. In SPLAT applied treatments, irrespective of the dosages,*Chrysoperla* population's ranged from 5.10 to 9.80 per plant and coccinellids from 3.10 to 4.40 per plant and observed the non-significant difference between the treatments. On the contrary, the lowest population of natural enemies *viz., Chrysoperla* (2.0–3.0 and 1.50 of eggs and adult/plant) and coccinellids (1.0–2.10 and 1.20–2.0 of grubs and adults) was recorded in insecticide control (Table 2). SPLAT-PBW is a species-specific and non-chemical approach. Hence its residue did not cause any damage to natural enemies in general. A similar observation was recorded in rice ecosystem after the application of SPLAT-YSB pheromone against the yellow stem borer of paddy. The spiders (2.62 per plant) and coccinellids (0.62 per plant) population in pheromone treated plots did not affect, whereas conventional practice (Farmers practice) significant reduction of spider and coccinellids (1.05 spiders and 0.35 coccinellids) population was noticed Badariprasad (2019).

3.3. Economic analysis of SPLAT-PBW

SPLAT-PBW tested at three dosages (500, 750, and 1250 g/acre) did not show significant difference amomng the doses. The lowest dosage (500 g per acre) applied in four splits was sufficient for mating disruption of pink bollworm. Hence, the net returns realized from SPLAT-PBW treated at 500 g /acre was with the highest benefit: cost ratio (B: C) of 3.04, followed by 3.0 for dose 750 g per acre treatment and 2.70 for the dose 1250 g per acre treatment during the first season. The highest benefit: cost ratio (B: C) of 1.84 was observed in the second season trial upon application of 500 g per acre of SPLAT-PBW (Table 3). Cost economics is advantageous when estimated with respect to the application of mating disruption pheromone tools in pest management. It was reported in the present study, that SPLAT treatments gave significantly higher net returns at the end of the season. It was noticed that the application of 750 g per acre recorded the highest B: C ratio and which was non-significantly different from the other two doses, i.e., SPLAT @ 1250 g and 500 g / acre (Shrinivas et al., 2019)

3.4. Dissipation of pheromone from SPLAT-PBW

The results revealed that there was 3.10 % of pheromone present in the sample by weight on the day of application. While 2.42, 1.97, 1.65, 1.47, and 1.25% of pheromone was recorded in the sample collected at end of the first, second, third, fourth, and fifth week, respectively (Fig. 2). Dissipation of (loss of) (Z,Z/Z,E) 7, 11-hexadecadienyl acetate was 22.06% to the original compound during first week and 36.43% in subsequent week. Further, slower dissipation rate was observed and recorded loss of 46.86 and 52.70% at the end of the third and fourth week, respectively (Table 4).

The persistence (high or low) of the dispenser depends on the type of SPLAT® formulation, composition, time of application, manner of application, and abiotic parameter following the application. SPLAT products are typically formulated to release semiochemicals for two weeks to 6 months. Control of *P. citrella* by mating disruption was highly effective at very low deployment rate of pheromone (1.5 g of a. i/ha) (Stelinski et al., 2009). It was observed that application of SPLAT-PBW is as effective as that previous study even at the end of the fifth week which contains significant amount (40.36 %) of pheromone in the samples. This indicated the slow-release mechanism of wax-based formulation of *P. gosspiella* pheromone SPLAT-PBW found effective in containing the population in the field. The longer persistence of pheromones in the paddy ecosystem was also proved after the application of SPLAT-YSB against the yellow stem borer. In different doses, it was ranged from ranged 19.3 to 67.3 and 3.57–79% in wax and powder formulation, respectively from first to sixteenth week, and it retains more than 20% pheromone in the formulation even after sixteen weeks of exposure in the field (Badariprasad et al., 2019). Hence it is proved that the SPALT formulations can be used effectively for the slow release of pheromones in the area for managing insect pests.

4. Conclusion

Pheromone-based SPLAT formulations applied to the source point of the crop. The mating process was ceased by the required amount of sex pheromone released by each SPLAT dollop. Males have diverted away from females due to the powerful allure of the pheromone being emitted by each SPLAT dollop. Unlike females, SPLAT dollops emit high doses of pheromone continuously. Area-wide management of pink bollworm

Table 2
Effect of SPLAT-PBW on natural enemies in cotton ecosystem during *Kharif* 2017–18 and 2018–19.

Treatments	*Chrysoperla*				Coccinellids			
	Eggs/plant[a]		Adults/plant[a]		Grubs/plant[a]		Adults/plant[a]	
Treatment season	2017–18	2018–19	2017–18	2018–19	2017–18	2018–19	2017–18	2018–19
T_1: SPLAT-PBW @ 1250 g/acre	9.40	–	5.60	–	3.20	–	3.80	–
T_2: SPLAT-PBW @ 750 g/acre	8.70	–	6.30	–	3.60	–	4.00	–
T_3: SPLAT-PBW @ 500 g/acre	9.20	9.80	5.10	6.20	3.10	4.40	4.20	3.20
T_4: Conventional farmer's practice	3.00	2.00	1.50	1.50	1.00	2.10	2.00	1.20
S. Em (±)	0.17	0.14	0.11	0.18	0.08	0.15	0.12	0.12
CD @ 0.05	0.51	0.43	0.35	0.54	0.24	0.44	0.37	0.36
CV (%)	12.92	9.56	10.93	10.11	9.17	9.43	12.70	9.67

[a] Average of 50 plants.

Table 3
Cost economics of SPLAT-PBW in cotton ecosystem during 2017–18 and 2018–19.

Treatments[a]	Cotton yield (q/ha)		Cost of cultivation (Rs./ha)		Cost of Treatment (Rs./ha)		Total Cost (Rs./ha)		Gross returns (Rs./ha)		Net Returns (Rs./ha)		B:C ratio	
Treatment season	2017–18	2018–19	2017–18	2018–19	2017–18	2018–19	2017–18	2018–19	2017–18	2018–19	2017–18	2018–19	2017–18	2018–19
T_1: SPLAT-PBW @ 1250 g/acre	43.33	–	55,000	–	25,000	–	80,000	–	216,650	–	136,650	–	2.70	–
T_2: SPLAT-PBW @ 750 g/acre	42.50	–	55,000	–	16,000	–	71,000	–	212,500	–	141,500	–	3.00	–
T_3: SPLAT-PBW @ 500 g/acre	40.50	26.67	55,000	55,000	11,500	25,000	66,500	80,000	202,500	146,685	136,000	66,685	3.04	1.84
T_4: Conventional farmer's practice (control)	24.68	20.00	55,000	55,000	–	12,500	55,000	67,500	123,400	110,000	68,400	42,500	2.24	1.62

Note: Price of cotton: Rs. 5500/qt.
Cost of SPLAT: Rs. 11500/ha (Rs. 2250/application hence, for 4 applications it is 9000 plus cost of application Rs.2500/ha for four times).
Cost in farmer's practice: Rs. 12500/ha (Rs. 10,000 is chemical cost and Rs. 2500 for labour four times application).
[a] Applied in 4 splits.

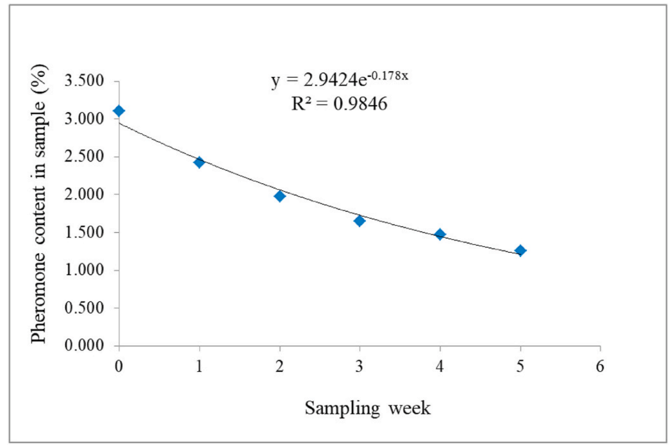

Fig. 2. Dissipation of pheromone content from the SPALT lure.

Table 4
Per cent lost and per cent residues of pink bollworm pheromone from SPLAT-PBW at weekly interval.

Sampling week	Per cent loss	Per cent residues
0	0	100
1	22.06	77.94
2	36.43	63.57
3	46.86	53.14
4	52.7	47.3
5	59.64	40.36

over an area of 350 acres with SPLAT-PBW, a mating disruption tool applied at 500 g m/acre in 4 splits at 35-40, 65-70, 95-100 and 125-130 days after sowing recorded more than 80–90 % control of pink bollworm with maximum yield gain of 33.58 q perha compared to conventional farmers practice who realized 22.34 q per ha even after 4–5 chemical spray. The concentration of pheromone leftover in SPLAT–PBW applied fields even after 45 days was 40%, disrupting the male moths from mating. All the dosages of SPLAT tested were found safe to natural enemies in the cotton ecosystem. The non-chemical approach of PBW management offers significant control over conventional practices. Hence, under present circumstances, the best way to curb the menace of pink bollworm is insect family planning using SPLAT-PBW.

CRediT authorship contribution statement

Sreenivas A G: Conceptualization, Methodology, Validation, Supervision, Formal analysis, Writing – review & editing, Visualization. **Markandeya G:** Conceptualization, Methodology, Validation. **Harischandra Naik R:** Methodology, Validation, Formal analysis, Writing – review & editing, Visualization. **Usha R:** Investigation, Data curation, Writing – draft. **Hanchinal S.G.:** Investigation, Data curation. **Badariprasad P.R.:** Investigation, Validation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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