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Validation of pink bollworm *Pectinophora gossypiella* (Saunders) management strategies in Bt cotton

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Abstract
A two year field study was conducted on validation of pink bollworm management strategies in Bt cotton in nearly fifty cotton farmer fields during 2018-19 and 2019-20 in selected villages of Kurnool district under IRM-Pink bollworm management project sponsored by Central institute for cotton Research, Nagpur. During the year 2018-19 Pink bollworm infestation ranged from 30-55% in IRM demo plots where as in farmers practice infestation ranged from 31-57%. Average Number of insecticidal sprays in IRM fields was 5.0 where as in farmers practice it was 7.3. IRM demo fields had registered a benefit-cost ratio of 1.9:1 where as in farmers practice it was 1.2:1. During the year 2019-20 IRM farmers had registered a green boll damage of 19-32% where as in farmers practice it was 20-70%, no of Average insecticidal sprays in IRM farmer fields were 4.66 where as in farmers practice it was 7.2, IRM farmer had registered a benefit-cost ratio of 2.17:1 where as in farmers practice it was 1.3:1.

Keywords: Pink bollworm, Insecticide resistance management, green boll damage, pheromone traps

Introduction
In India, single gene Bt cotton (Cry1Ac), Bollgard (BG) was introduced during 2002. Subsequently, two gene Bt cotton (Cry1Ac + Cry2Ab) Bollgard II was approved during 2006. At present, the area under Bt cotton is about 93% of the total cultivated area and share of Bollgard II is almost 100%. With introduction of Bt cotton, the bollworm complex *viz*. American bollworm, Spotted bollworm and Pink bollworm was under control until 2009. Among the bollworm complex, pink bollworm, *Pectinophora gossypiella* (Saunders) is one of the major damaging insect pests of cotton with an extensive range across India leading to severe loss to cotton production [1, 2]. The pink bollworm, *Pectinophora gossypiella* Saunders is native to Asia and it was first described from larvae recovered from infested cotton bolls in India in 1843 [3], The first report of resistance development by pink bollworm (PBW) to Bollgard came in 2010 and subsequently to Bollgard II during 2014. The infestation on Bt cotton was reported with locule damage to an extent of 55% and reduction in seed cotton yield in the range of 35-90% [4]. It was an eye opener to the stakeholders of cotton farming i.e. farmers, researchers, seed industry, policy makers and technology developers as Bt cotton is the first and sole genetically engineered technology approved in India that got broken down due to resistance development by PBW. Unusually high levels of pink bollworm (PBW) infestation and crop damage were experienced in the fields of the dual Bt gene cotton (Bollgard II®) technology, a genetically modified cotton which produces two Bt insecticides (Cry1Ac and Cry2Ab) to combat cotton bollworms, in Gujarat, Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh during kharif season of 2015 [5]. Larval activity of Pink bollworm on tender bolls began in mid November and continued till harvest of the crop [6]. Sangareddy and Patil reported that incidence of PBW commenced from October onwards which gradually increased and reached to a peak during February and declined thereafter [7]. The significant contributors for breakdown of resistance are: extending crop beyond time, non-compliance of refuge, lack of timely and appropriate management initiatives, large number of hybrids with varying flowering and fruiting periods, cultivation of long duration hybrids, long term storage of raw cotton in ginneries (seed cotton harbors PBW larvae), development of resistance to Cry1Ac and Cry2Ab proteins by Pink bollworm, etc.

Pink bollworm adaptation to transgenic Bt-cotton expressing Cry1Ac (Bollgard) and Cry1Ac+Cry2Ab (BG-II) was assessed in India by ICAR-Central Institute for Cotton Research (ICAR-CICR), Nagpur during 2010-2017 in 38 districts of 10 major cotton-growing states. High pink bollworm larval recovery on BG-II in conjunction with high LC50 values to Cry1Ac and Cry2Ab in major cotton growing districts of central and south India, present evidence of field evolved resistance in the PBW to Bollgard and BG-II cotton. In central and south India, for Cry 1Ac, the resistance ratio (RR) increased from a mean of 47.12 (range 18-121) in 2013 to a mean of 1387 (7042060) in 2017; whereas, for Cry 2Ab, the RR increased from a mean of 5.4 (range 1-31) in 2013 to a mean of 4196 (1306-9366) in 2017. Pink bollworm *Pectinophora gossypiella* Saunders has now emerged as a major pest of Bollgard II in parts of central and south India. The pest mainly feeds on seeds causing economic loss through reduction in yield and deterioration in quality. Infestation occurs in mid and late stage of the crop, remains undetected due to internal feeding behavior and causes loss of yield and quality. It impacts boll opening, coinciding with the second picking of cotton in most of the areas. Since last 4-5 years, PBW is appearing early 45-60 days after sowing on BG-II hybrids in Central and South India. The infestation varies from place to place. During 2017-18, major cotton producing states like Maharashtra, Telangana, Andhra Pradesh, Karnataka and Madhya Pradesh were under the grip of PBW damage and the infestation ranged between 8-92% with corresponding yield losses to the extent of 10-30%. With concerted efforts of all cotton production stakeholders, it was possible to manage the pink bollworm infestation below 30% during the past season of 2018-19. Until past one decade, no incidence of pink bollworm has been reported on BG II in North Indian cotton growing zone. However, during cotton season 2018-19 infestation of pink bollworm above economic threshold level (ETL) on BG-II cotton was reported, though sporadically in the state of Haryana, warranting vigilance in Northern states in the coming crop season. Unless extension initiatives to manage PBW were revitalized and implemented on war footing, the situation might have further lead to yield losses and distress of cotton farmers that in turn had a cascading effect on textile industry and Indian economy. Keeping in view of the catastrophe caused by Pink bollworm on Bollgard II ministry of Agriculture Govt of India had decided to implement pink bollworm management strategies in a project mode in selected states. Central institute for Cotton Research, Nagpur is the nodal agency for over-all implementation of the project. Therefore in Kurnool district the project was being implemented in selected five villages from the year 2018-19.

Materials and Methods

A Field study was conducted during the year 2018-19 and 2019-20 to validate pink bollworm *Pectinophora gossypiella* (Saunders) management strategies in Bt cotton in nearly fifty farmers fields from five selected villages of Kurnool district of Andhra Pradesh under Insecticide Resistance Management-Pink bollworm management project funded by ministry of Agriculture and central institute for cotton research as a nodal implementing agency. One acre from each farmer was selected as demo plot where all the prescribed pink bollworm management strategies were demonstrated, five non IRM farmers were also selected from each village for comparison where farmer practices were implemented in these fields. Prescribed recommended insecticides for the management of pink bollworm as critical inputs were distributed to IRM farmers for an acre i.e. Neemoil @ 1000ml, Thiodicarb@ 300g, Profenophos@400ml, Chloropyriphos@500ml, Lamda cyhalothrin@ 200ml and pheromone traps@ five per farmer. The recommended insecticides were sprayed in recommended dosages as prescribed by Agricultural university after pink bollworm crossing economic threshold levels i.e. eight to ten adult moth catches in pheromone traps for consecutive three days and 10% green boll observed during destructive sampling. Along with chemical inputs IRM famers also demonstrated other integrated pink bollworm management strategies as prescribed by central institute for cotton research, Nagpur (Table.1). Data on pheromone trap catches standard week wise, green boll damage, number of insecticidal sprays, volume of insecticide applied, yield and B:C ratio was recorded from fifty IRM and five non IRM farmers and averaged.

Table 1: Stage wise Integrated Insecticide resistance management strategies adopted by Bt cotton farmer

Operation	IRM recommendations
Sowing	Timely sowing i.e. July month wherever applicable Use jassid tolerant, short duration Varieties/BGII hybrids recommended for the region
Refugia	Refuge planting (120 g non Bt) around Bt cotton or separate as strip if supplied with seed packet or cultivation of Bt cotton provided with refuge- in-built.
Monitoring	Install pheromone traps @ 5/acre for monitoring pink bollworm moth activity at 45 DAS
Pesticide	Spray neem seed extract 5% + Neem oil 5 ml/ litre of water at 50-60 DAS, At boll formation stage, farmers are advised to inspect presence and damage of PBW by plucking 20 green bolls from different plants randomly (one boll per plant). ETL at this stage is 10% damaged green bolls (at least two bolls having white or pink larvae). Thiodicarb 75% WP 15 g or Chlorpyriphos 20% EC 25 ml or 20 g per 10 lit water 10 lit water. At 90 Days after sowing release of the egg parasitoid *Trichogramma bactrae* @ 60,000 eggs /acre. After 120 Days after sowing spray of Fenvelerate 20% EC 10 ml or Cypermethrin 10% EC 10 ml or Lamda cyalothrin 5%EC 10ml per 10 lit water
Crop termination	After 180 days after sowing termination and Uprooting of the crop not extending the cotton crop beyond 180 DAS Cleaning up fields of residual stalks and partially opened bolls.

Results

During 2018-19 the results indicate that the range of pink bollworm infestation in IRM fields was 30.0-55.0 where as in non IRM infestation range was 31.0- 57.0. Average number of insecticidal sprays for sucking pests and boll worms were 2.72 and 2.2 respectively with a total of 4.92 in IRM fields, where as in non IRM fields Average number of insecticidal sprays for sucking pests and boll worms were 3.8 and 3.50 respectively with a total of 7.30. With regard to sucking pests population Leaf hopper population population was 8.57/3 leaves in IRM fields where as in non IRM fields the population was 14.34/3 leaves, whiteflies population was 22.12/3 leaves in IRM fields where as in non IRM fields population was 27.65/3 leaves, with regard to thrips IRM field

had recorded a population of 12.98/3 leaves where as non IRM field had recorded a population of 24.65/3 leaves. Additional profit due to IRM practices was Rs, 35,612 with benefit cost ratio of 1.9:1 where as in non IRM fields B:C ratio recorded was 1.2:1 reduction in pesticide usage due to IRM practices was 19.78%. Seed cotton yield of 3201 kg/ha was recorded in IRM fields where as in non IRM fields yield was 2814 kg/ha

During the year 2019-20 the results indicate that the range of pink bollworm infestation in IRM fields was 19.0-32.0 where as in non IRM infestation range was 20.0- 70.0. Average number of insecticidal sprays for sucking pests and boll worms were 2.66 and 2.0, respectively with a total of 4.66 in IRM fields, where as in non IRM fields Average number of insecticidal sprays for sucking pests and boll worms were 4.08 and 3.16, respectively with a total of 7.24. With regard to sucking pests population Leaf hopper population was 9.20/3 leaves in IRM fields where as in non IRM fields the population was 11.0/3 leaves, whiteflies population was 11.0/3 leaves in IRM fields where as in non IRM fields population was 16.0/3 leaves. An additional profit of Rs 35,612/ was recorded in IRM fields with benefit cost ratio of 2.1:1 where as non IRM fields had recorded a benefit-cost ratio of 1.3:1, reduction in pesticide usage in due to IRM practices was 15.28%. Seed cotton yield of 3400 kg/ha was recorded in IRM field where as in non IRM field yield was 2610 Kg/ha (Table. 2,3,4,5 &6)

Table 2: Impact of Insecticide Resistance management (IRM) module on green boll damage during 2018-19 & 2019-20

% infestation of Pink bollworm in green bolls		
Year	**IRM plots**	**Non IRM plots**
2018-19	30.00-55.00	31.00-57.00
2019-20	19.00-32.00	20.00-70.00

Table 3: Average number of insecticidal sprays and seed cotton yield in Kg/ha in IRM and non IRM fields during the year 2018-19 & 2019-20.

Average no of insecticide sprays								
Year	**IRM Sucking pests**		**Boll worms Total**	**Non IRM Sucking pests**		**Boll worms Total**	**Seed cotton yield Kg/ha IRM**	**Non IRM**
2018-19	2.72	2.2	4.92	3.8	3.50	7.30	3201	2814
2019-20	2.66	2	4.66	4.08	3.16	7.24	3400	2610
Mean	2.69	2.1	4.79	3.94	3.33	7.27	3300	2712

Table 4: Sucking pests infestation in IRM vs Non-IRM fields during the years 2018-19 and 2019-20

Seasonal average of sucking pest population per 3 leaves Jassids Whiteflies Thrips						
Year	**IRM**	**Non IRM**	**IRM**	**Non IRM**	**IRM**	**Non IRM**
2018-19	8.57	14.34	22.12	27.65	12.98	24.65
2019-20	9.20	11.00	11.00	16.00	0.00	0.00
Mean	8.88	12.67	16.56	21.82	6.49	12.32

Table 5: Impact of IRM on the Benefit Cost ratio during the years 2018-19& 2019-20

Year	**Cost of spray (Rs/ha) IRM**	**Non IRM**	**Cost of cultivation (Rs/ha) IRM**	**Non IRM**	**Net profit (Rs/ha) IRM**	**Non IRM**	**Additional profit due to IRM (Rs/ha) IRM**	**Non IRM**	**Benefit Cost Ratio IRM**	**Non IRM**
2018-19	6398	7976	63100	67905	103321	79219.7	35612		1.9	1.2
2019-20	11606	13700	66152.9	69922	86847	64737	23950		**2.1**	1.3
Mean	9002	10838	64626	68913	95084	71978	29781		**2.0**	1.25

Table 6: Reduction in pesticide usage in IRM Vs nonIRM fields

Year	**Cost of spray in IRM in Rs (A)**	**Cost of spray in non IRM in Rs (B)**	**Difference (C) in Rs A-B**	**% Reduction in usage C/Bx100**
2018-19	6398	7976	1578	19.78
2019-20	11606	13700	2094	15.28
Mean	9002	10838	1836	17.43

Discussion

The above results indicate that management of Pink bollworm with merely chemical insecticides will not give satisfactory results, chemical insecticide with a combination of bio intensive model which includes spray of botanicals like neem oil and application of semio chemicals like pheromone traps, use of egg parasitoid like *Trichogramma bactrae* and economic threshold level basis spray of recommended insecticides with proper dosages adopted on community basis effectively manages pink bollworm. The results obtained during field study were in corroboration with the findings of El-Hafez *et al*. in year 2000 who determined the role of augmenting *Trichogramma bactrae* in the IPM programme for controlling Pectinophora *gossypiella* in Egypt [8]. The above results are also supported by the reports of Anonymous in 2008 and 2009 in which the multi-location trials conducted at Rahuri, Maharashtra, Warangal and Rajendranagar (AP) and Coimbature (TN) showed similar results [9, 10]. Adoption of IRM based IPM modules has resulted into reduction in population of sucking pests over recommended plant protection practices with lesser use of insecticides [11]. The results demonstrated the superiority of IRM strategy over the present farmer's practice unnecessary use of insecticides, and practically no monitoring where a significant increase in cotton yield was observed [12]. Providing refuge of the host plants to pests that do not make Bt proteins i.e., non Bt crop. Refuge allows survival of insects that are susceptible to Bt proteins and reduces the chances that two resistant insects will mate and produce resistant offspring. This strategy is particularly effective for delaying resistance. This concept was widely accepted by eminent scientist working on IRM strategies [13, 14]. The efficacy of pheromone traps such as sleeve trap and yellow funnel was well demonstrated by some researchers [15], Pheromones at higher dosages or frequency of lures can also be used in mass trapping and to confuse mating, good correlation has been obtained between the pheromone trap catches and larval incidence in the field [16]. Management of pink bollworm by way of mass trapping was also demonstrated by some workers [17], Present results are in confirmation with the earlier studies, which reported that the adaptability of IPM module integrated with Bt cotton genotypes proved superior by recording least percentage of infestation and higher seed cotton yield with more net returns [18]. Under IPM technology, higher net profit was recorded

from Bunny BG-II followed by Nathbaba (Rs. 103905.00/ha). On the contrary net profit in non Bt IPM module was more compared to the farmer practice [19].

Conclusion

From the above study it can be concluded that by adopting Insecticide resistance management (IRM) based integrated pest management (IPM) strategies in Bt cotton pink bollworm can be efficiently managed. Relying on chemical insecticides alone for the management of pink bollworm is not sustainable and increases cost of cultivation and reduces net returns.

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