Effect of Bt cotton hybrids on larval incidence and development of *Helicoverpa armigera* Hübner

T. Surulivelu, V.G. Mathirajan and B. Dhara jothi
Central Institute for Cotton Research, Tamil Nadu, INDIA.
Correspondence author surulivelu@rediffmail.com

ABSTRACT

Three Bt cotton hybrids viz., MECH 12, MECH 162 and MECH 184 were evaluated along with their non-Bt counterparts and two standard controls, Savita and NHH 44. In the Bt cotton hybrids larval population of Helicoverpa armigera *Hüb. was significantly low, 0.5 larva/5 plants as against 1.5 to 3.5 in non-Bt counterparts and 2.1 to 5.0 in the control hybrids. The incidence and or damage of bollworms exceeded ETL only once in the Bt entries mostly after 90 days of sowing whereas it was 3 to 5 times in non-Bt counterparts and 5 times in the control entries commencing from 60 days of sowing. Thus, a minimum saving of 40% in plant protection cost was achieved by cultivation of Bt cotton. The spotted bollworm (*Earias *spp.) incidence was also significantly low, 0 to 1.3 per 5 plants as against 1.8 to 3.5 and 2.0 to 2.3 in non-Bt and control hybrids respectively. The shoot damage by* Earias *spp. in Bt cotton entries was also low 4 to 8% as compared to their non-Bt counterparts, 14 to 19% and control hybrids, 21 to 33%. Similarly, the boll damage due to bollworms was also relatively low in Bt cotton hybrids 19 to 26% when compared to non-Bt counterparts, 46 to 55% and control hybrids, 42 to 54%. The observation on seed cotton yield at harvest showed no significant differences among the Bt, non-Bt and control hybrids.*

Introduction

Cotton is noted for its susceptibility to several insect pests particularly bollworms and sap feeding insects. Large quantities of insecticides are being applied more frequently to maintain desirable/economic yield levels. The excessive use of insecticides against cotton pests very often resulted in development of a high level of resistance in bollworms (particularly *Helicoverpa armigera* Hüb.), resurgence of sap feeding insects (aphids, whitefly), destruction of beneficial organisms in the cotton ecosystem (parasite/ predator/pathogen/scavenger/microbes) and hazards to human health and environment. Pest management continues to receive utmost priority due to its implication in increasing cotton production. Prospects of inserting foreign genes through genetic engineering and evolving transgenic cotton is considered to be an important strategy for controlling major insect pests of cotton (bollworms) without disturbing the ecosystems. Thus, transgenic cotton plays a vital role in cotton pest management in the world. Genetically engineered cotton, soybean and corn varieties have increased yields, profits and decreased pesticide use by farmers in the United States and China (Carlson *et al.,* 1998 and Pray *et al.*, 2001). Very recently, India has opened its gates for commercial cultivation of transgenic cotton namely MECH 12 Bt, MECH 162 Bt and MECH 184 Bt. In this context, little information is available on performance of transgenic cotton. The present paper gives an elaborate account on the effect of three Bt cotton hybrids along with their non-Bt counterparts and two popular control hybrids on bollworm incidence, damage and yield levels under different insecticidal regimes. It also deals with laboratory studies on development on *H. armigera* on Bt cotton.

Experimental procedure

Two field experiments were conducted in randomized block designs with four replications during the main cotton season (August to February) of 2000-01. In the first experiment, the performance of MECH 12 Bt cotton hybrid was assessed under no spray and ETL-based spray conditions, along with the non-Bt version of MECH 12 and two control hybrids, Savita and NHH 44. In the second experiment, three Bt hybrids (MECH 12 Bt, 162 Bt and 184 Bt) were evaluated along with their non–Bt counterparts and the control hybrids (Savita and NHH 44) under ETL-based protection conditions. During 2001-02, two more field experiments were conduced with the same hybrid entries with three replications in randomized block designs, one experiment was based on ETL-protection and the other was under unprotected conditions.

Evaluation under unprotected conditions

The untreated delinted seeds of Bt, non-Bt and control hybrids were sown with a spacing of 90 cm x 60 cm and one plant per hill was maintained. The normal recommended fertilizer schedule for hybrids under irrigated conditions (80:40:40 kg N:P:K/ha) was followed. No plant protection was applied for sucking pests, bollworms and other major and minor pests. Periodic observations were recorded for sucking pests, predators, shoot borer damage, fruiting bodies damage, larval incidence of bollworms and bollworm damage at harvest. The seed cotton yield was assessed. The data were suitably transformed and analyzed statistically.

Evaluation under ETL based protection

The delinted seeds of Bt, non-Bt and control hybrids were treated with imidacloprid seed treatment at a dosage of 5 g a.i./kg of seed. The treated seeds were sown with a spacing of 90 cm x 60 cm and one plant per hill was maintained. The recommended fertilizer schedule (80:40:40 kg N:P:K/ha) was followed. Plant protection was followed based on weekly pest scouting for the economic threshold level (ETL). The threshold followed for various pests are as follows: aphids; 10/leaf; jassids: 2/leaf; thrips: 10/leaf; whitefly: 5-10 nymphs and or adults/leaf; bollworm damage: 5% and *Helicoverpa* bollworm larval incidence: 1 larva/plant. Foliar sprays were given for protection against sucking pests whenever ETL was exceeded with methyl-o-demeton at 150 g a.i./ha or imidacloprid at 20 g a.i./ha. Similarly endosulfan (700g a.i/ha) or indoxacarb (75 g a.i./ha) or spinosad (50 g a.i/ha) or chlorpyriphos (500 g a.i/ha) or quinalphos (500 g a.i./ ha) were applied for protection against bollworms in both Bt and non-Bt (including the control varieties) cotton hybrids whenever ETL was exceeded. Periodic observations were made as mentioned in the earlier section on the unprotected crop. The data were suitably transformed and analyzed statistically.

Laboratory studies

Laboratory maintained *H. armigera* neonate larvae (40) were released on tender leaves collected from 105-109 days old) of Bt and non-Bt cotton hybrids and kept in Petri dishes (9.5 cm diameter) at 25 ^{0}C and RH of 70%. The larval mortality was observed at 12 hour intervals, while the larval weight gain was assessed on 4, 5 and 6 days after feeding.

Results and Discussion

Experiment 1: Performance of MECH 12 Bt cotton hybrid – 2000-01

Bollworms incidence and damage threshold Both the control hybrids (Savita and NHH 44) and MECH 12 non-Bt exceeded the ETL five times on 75, 89, 100,110 and 121 days after sowing (DAS) as against three times in MECH 12 Bt on 100,110 and 121 DAS (Table 1). The results indicated that Bt hybrids did not require spray for bollworms until 100 DAS, whereas conventional hybrids required spray commencing on 75 DAS. Thus, a saving of 40 percent on insecticides and cost on plant protection was observed in the control of bollworms with Bt cotton.

***H. armigera* larval population** The mean population of *H. armigera* for four observations (74, 89, 100 and 110 DAS) ranged from 0.5 to 5.1/5 plants. MECH 12 had a significant higher population of 2.96/ 5 plants (Figure 1). Thus, the results indicated a population in the control hybrids six to seven times higher than that observed for the Bt hybrids.

***Earias* damaged plants** MECH 12 Bt recorded significantly lower shoot damage (7.3-8.1%) by *Earias* spp. under both no spray and ETL spraying conditions. The non-Bt counterpart MECH 12 has significantly higher shoot damage (16.5-18.4%). The control hybrids also had very high levels of shoot damage (30-34%). The results indicated the superiority in reduction of shoot damage by *Earias* spp. in the Bt cotton over non-Bt and control hybrids (Table 2).

Bollworms damage in fruiting bodies MECH 12 Bt consistently recorded significantly low damage (0.5-2.2%) in the fruiting bodies by bollworms while the counterparts of non-Bt had fairly higher level (4-11%). The control hybrids also had higher levels of fruiting body damage (6-13%) and thus Bt cotton revealed its superiority over non-Bt and control hybrids (Table 2).

Boll and locule damage in the opened bolls at harvest The boll damage in the opened bolls at harvest was significantly lower (25-27%) in MECH 12 Bt under both no spray and ETL spray conditions (Table 2). In contrast to these the non-Bt counterpart of MECH 12 and control hybrids also had fairly higher level of boll damage (49-58 and 44-55% respectively). Similar trends were also observed for the results of locule damage. MECH 12 Bt registered significantly lower damage (8-10%). While the non-Bt version of MECH 12 and the control hybrids recorded very high levels of locule damage (34 to 36 and 28 to 42 percent, respectively). Although Bt hybrids recorded lower incidences and damage by bollworms (*H. armigera, Earias* spp.), boll damage at harvest (in the opened bolls) was fairly higher, which indicated the moderate protection offered by Bt cotton at the later stages of crop growth. However, with regard to locule damage, the protection offered by Bt cotton was somewhat better. The Bt hybrids had distinct advantage in reducing damage significantly in the fruiting bodies, bolls and loculi.

Seed cotton yield Despite significant levels of reduction in bollworm populations and the damage, seed cotton yields showed no significant differences among the Bt, non-Bt and control hybrids. However, MECH 12 Bt registered an increase of about 500 kg/ ha seed cotton yield compared to its non-Bt counter part under both no spray and ETL spray conditions. The Bt cotton yield increase compared to the control hybrids was about 200 kg/ha (Table 2).

Experiment 2: Evaluation of three Bt cotton hybrids-2000-01

Bollworms incidence and damage threshold The bollworm incidences in MECH 12 Bt and 184 Bt exceeded ETL only once on 123 DAS while their non-Bt counterparts exceeded ETL three to four times on 75, 90, 110 and 123 DAS (Table 1). MECH 162 Bt and non-Bt exceeded ETL three times on 99, 111 and 123 DAS. The control hybrids NHH 44 exceeded ETL five times on 75, 90, 99, 111 and 123 DAS. As observed in Experiment 1, the non-Bt and control hybrids were more susceptible to bollworms and required three to five sprays compared to the one spray needed for MECH 12 and 148 and the three sprays for MECH 162 Bt. MECH 162, both Bt and non-Bt, had more fruiting bodies, which may be one of the probable reasons for higher incidence of bollworms, which resulted in a higher number of sprays, as compared to other entries.

***H. armigera* larval population** The mean population of *H. armigera* larvae for four observations (75, 99, 111 and 123 DAS) ranged from 0.4 to 2.5/5 plants. MECH 162 had a significant higher population of 1.7/ 5 plants (Table 3). Thus, the results indicated nearly a three to five times higher population in the control hybrids compared to the Bt hybrids.

***Earias* spp. damage** The shoot damage by *Earias* bollworms was significant lower in all the three Bt hybrids (2.2 to 5.7%), while it was significantly higher in all the non-Bt counterparts (9.1 to 18.2%). The control hybrids also had significantly higher levels of damage (18 to 24%) (Table 4). As observed in Experiment 1, *Earias* spp. damage was significantly low in Bt hybrids compared to the non-Bt and the control hybrids. This confirms the superiority of Bt entries in reducing the shoot damage by *Earias* spp.

Fruiting body damage All the three Bt hybrids consistently recorded lower damage (0.2-2.7%), whereas the non-Bt counterparts had higher damage (2 to 11%) (Table 4). The control hybrids also have significantly higher damage (7 to 10%). These results confirmed the earlier observation in Experiment 1 on this aspect.

Boll and locule damage in the opened bolls at harvest All the three Bt hybrids recorded significantly lower boll damage (17 to 23%), while their non-Bt counterparts have very high levels of damage (36 to 51%). The control hybrids also registered significantly higher damage (35 to 49%). The same trends were observed in the locule damage (Table 4). The Bt hybrids had significantly lower locule damage (8 to 11%) while the non-Bt counterparts had higher damage (19 to 30%). The control hybrids also registered higher levels of damage (17 to 27%). As observed and discussed in Experiment 1, the boll damage in Bt cotton hybrids was moderately higher, even though the incidence of bollworms was low. This suggests that the expression of the Bt gene is relatively higher in early and mid stages. Later, the dilution of Bt gene leads to a moderately low effect on bollworms. The observation of ETL also confirmed these findings.

Seed cotton yield The seed cotton yield showed no significant differences among the Bt, non-Bt and control hybrids. However, the Bt hybrids registered 10 to 17 percent higher yield over their non-Bt counterparts and 0.5 to 100 kg/ha compared to the control hybrids, NHH 44 (Table 4).

Experiment3 Evaluation of three Bt cotton hybrids under unprotected conditions (2001-02)

***H. armigera* larval incidence**

MECH12 Bt The variety recorded significantly lower population throughout the observation period with a mean of 0.32 larva/5 plants as compared to its non-Bt counter part that registered a significantly higher population (1.57/5 plants) during the late reproductive stage of the crop, after 118 days of growth (Figure 2).

MECH 162 Bt The variety registered almost no population from 74 to 103 days after sowing, a significantly lower population on 118 DAS and averaged 0.77 larva/5 plants, whereas its non-Bt version recorded a significantly higher population ranging from 1.7 to 5.7 with a mean of 2.97 larvae/5 plants (Figure 2).

MECH 184 Bt The variety registered a significantly lower population ranging from 0 to 1.7 and averaged 0.38 larva/5 plants as compared to the significantly higher population ranging from 1.7 and 4.7 and averaged 2.08 larva/5 plants in its non-Bt version (Figure 2).

Thus, the larval incidence in all the three Bt hybrids showed superiority over non-Bt and control hybrids in recording significantly lower population. This observation was in conformity with earlier findings of Experiment 1 and 2 during 2000-01. Both control hybrids (Savita and NHH 44) registered significantly higher populations as compared to all the three Bt hybrids. The mean larval populations in Savita and NHH 44 were 2.9 and 3.92/5 plants, respectively. As high as 6-7 larvae/5 plants were observed in both control hybrids during the late reproductive stage of the crop. The higher populations observed in the late reproductive stage of the control hybrids and non-Bt hybrids might be due to a heavy pressure of insect population, availability of highly nutritious food material (maturing bolls) and an inadequate compensation mechanism during the late stages of the crop. Comparatively higher populations observed in the Bt hybrids during the late reproductive stage were probably due to dilution effect of Bt toxin in addition to heavy insect pressure and availability of nutritious food material (maturing bolls).

Incidence and damage of *Earias* spp. All the Bt entries recorded no larval populations while their non-Bt counterparts had 1.3 to 3.7/5 plants. The control hybrids also had higher populations ranging from 3 to 3.3 larvae/5 plants. MECH 12 Bt and 184 Bt recorded significantly lower shoot damage (1.7 to 2.3%) as compared to their non-Bt counterparts (9 to 12%). MECH 162 Bt and non-Bt registered 17 and 23 percent damage respectively. The control hybrids also had fairly higher damage (28 to 37%).

Seed cotton yield There were no significant differences among the entries and all returned seed cotton yields (Figure 3). However, damaged seed cotton was significantly less in all the Bt entries (5-9%) as compared to non-Bt entries (18-33%) and control hybrids (14-32%).

Experiment 4: Evaluation of three Bt cotton hybrids under ETL Based protection (2001-02)

***H. armigera* larval incidence** In MECH 12 Bt, the larval incidence was significantly lower almost throughout the period (except later stage on 132 DAS) and averaged 0.6 larvae/5 plants whereas in the non-Bt version of this hybrid, the incidence was four fold higher and averaged 2.5 larvae/5 plants (Figure 4). In MECH 162 Bt, the incidence was significantly lower throughout the period and averaged 0.8 larvae/5 plants whereas in the non-Bt version of this hybrid, it was significantly higher and averaged 4.8 larvae/5 plants (Figure 4). In MECH 162 Bt, the larval incidence was significantly lower and averaged 0.3 larvae/5 plants as compared to the non-Bt version of this hybrid, which recorded a 10 fold increase in larval population (average 3.1 larvae/5 plants). In the regional control hybrids Savita, the larval incidence was significantly higher ranged form 2.5 to 6.3 and averaged 4.0 larvae/55 plants. In the national control hybrid NHH 44 also the incidence was significantly higher ranged from 2.8 to 6.3 and averaged 4.4 larvae/5 plants. Thus, observation on larval incidence of *H. armigera* on all the Bt hybrids showed superiority in reducing the incidence found in earlier experiments 1, 2 and 3.

Incidence and damage of *Earias* spp. MECH 12 BT and 184 Bt recorded significantly less shoot damage (1.3 to 2.5%) as compared to the non-Bt entries (11 to 16%). MECH 162 Bt and non-Bt recorded 11 and 31 percent damage respectively. The control hybrids registered fairly higher (26 to 32%) damage. Larval incidence observed during the peak squaring-phase revealed that all the Bt entries recorded significantly lower populations (0.0 to 1.3/5 plants) as compared to non-Bt entries (1.8 to 3.5/5 plants) and the control hybrids (2.0 to 2.3/5 plants). This result confirmed the earlier observations in Experiment 1, 2 and 3.

Seed cotton yield There were no significant differences among the entries for seed cotton yield. However, the Bt hybrids registered a 19 to 25 percent increase in seed cotton yields compared to the best hybrid Savita (Figure 5). With regard to damage of seed cotton, it was significantly lower (11 to 15%) in all the three Bt entries compared to their non-Bt counterparts (25 to 29%) and the control hybrids (27 to 36%).

Laboratory studies

The data on larval mortality, larval weight an developmental periods of *H. armigera* are summarized in Tables 5, 6 and 7, respectively. Larval mortality in Bt cotton ranged from 52.5 to 70 percent, while it was 22 to 40 percent in their non-Bt counterparts. The average percentages mortality in Bt and non-Bt hybrids were 60.8 and 28.3 percent respectively. Larval weight reduction in MECH 162 Bt, MECH 184 Bt and MECH 12 Bt was 69.3, 70.8 and 76.2 percent respectively. The average percent weight reduction in Bt hybrids was 72.2 % compared to their on-Bt counterparts. Developmental variations observed in the laboratory revealed that the larval and pupal periods were prolonged by 6 to 7 days in Bt hybrids, while the pupal weight was reduced by 32.6 percent in Bt compared to its non-Bt counterparts.

It has been reported that Bt cotton offers an effective way of controlling serious pests of cotton, particularly bollworms, reduces pesticide use and improves the health of farmers and farm workers in China (Pray *et al*., 2001). The present study also brought out the superior efficacy of Bt cotton hybrids *viz*., MECH 12, MECH 162 and MECH 184 in consistently reducing the larval incidence of *H. armigera* and shoot damaged plants by *Earias* spp. in both evaluation seasons as tested at Coimbatore in India. Furthermore, the boll and locule damages were also found to be significantly lower in the Bt hybrids compared to their non-Bt counterparts and the control hybrids. Such superiority in the pest control of transgenic cotton has also been reported from several countries such as USA (Simmons *et al*., 1988 and Stewart *et al*., 1998), China (Pray *et al*., 2001) and Australia.

In the present study, it has also been observed that the use of insecticides and subsequently the cost of plant protection was substantially reduced in Bt cotton. Similar observations were also noted by several workers (Davis *et al.*, 1995; Carlson *et al.*, 1998). Several studies have reported the increase of seed cotton yield with the cultivation of Bt cotton (Lambert *et al*., 1997; Carlson *et al*., 1998 and Stewart, *et al*., 1998). The present study has also demonstrated an increase in seed cotton yield by 100 to 500 kg/ha over their non-Bt counterparts.

The Bt cotton hybrids showed a higher retention of first formed bolls and balanced plant growth due to lower damage by bollworms. This also resulted in early boll opening (15 to 20 days earlier) and required fewer pickings to complete the harvest. Bt cotton hybrids exceeded ETL for bollworms only once after 90 DAS whereas the non-Bt and control hybrids exceeded the ETL more than three times from 60 DAS. Furthermore, the populations of all the bollworm species were significantly lower in Bt cotton hybrids compared to their non-Bt counterparts and the control hybrids.

Boll, locule and seed cotton damages were significantly lower in all the Bt cotton hybrids (MECH 12, 162 and 184) as compared to their non-Bt counterparts, as well as the control hybrids (Savita and NHH 44) in both the protected (ETL-based protection for bollworms and sucking pests) and unprotected crop. However, the seed cotton yield showed no significant differences among the Bt, non-Bt and control hybrids in ETL-based protection, while under unprotected conditions, MECH 162 Bt registered a significantly higher yield compared to the other two Bt and non-Bt control hybrid (Savita).

References

- Carlson, G.A., Marra, M.C., Hubbell, B.J. and Dugger P. (1998). Yield, insecticide use and profit changes from adoption of Bt cotton in the South East. Proceedings Beltwide Cotton Conference, Vol. 2 pp 973-974, San Diego, California , UAS, 5-9 January, 1998.
- Davis, M.K., Layton, M.B, Varner, J.D. and Little, G. (1995). Field evaluation of Bt transgenic cotton in the Mississippe delta. Proceedings of Beltwide Cotton Conference, Vol.1. pp 171-173. San Antonio, TX, USA, January, 4-7, 1995.

- Lambert, A.L., Bradley, J.R., Duyn, J.W. and Van, D.J.W. (1997). Interactions of *Helicoverpa zea* and Bt cotton in North Carolina. Proceedings of Beltwide Cotton Conference, Vol.2, pp-870-873. New Orleans, LA, UAS, January 6-10, 1997.
- Pray, C., Danmeng, M.A., Huang, J. and Qiao, F. (2001). Impact of Bt cotton in China. *World Cotton Development*, **29**: 813-825.
- Simmons, A. L., Dennehy, T. J., Tabashnik, B. E., Antilla, L., Barlett, A., Gouge, D., Staten, R and Dugger, P. (1998). Evaluation of Bt cotton deployment strategies and efficacy against PBW in Arizona. Proceedings of Beltwide Cotton Conference, pp. 1025-1030. San Diego, California, USA, 5-9 January, 1998.
- Stewart, S., Reed, J., Luttrell, R., Harris, F. A., Dugger, P. and Richter, D. (1998). Comparing Bt and conventional cotton management and plant bug control strategies at five locations in Mississipi, 1995-97. Proceedings of Beltwide Cotton Conference, Vol.2. San Diego, California, USA, 5-9 January, 1998.

Table 1. *ETL based spray details for Bt, non-Bt and control hybrids.*

Experiment	Entries	ETL based spray no.	Spray days Days after sowing
2000-01 Experiment I	MECH 12 Bt	3 sprays	100, 110 and 121
	MECH 12 NBt	5 sprays	75, 89, 100, 110 and 120
2000-01 Experiment II	MECH 12 Bt	1 spray	123
	MECH 12 NBt	4 sprays	75, 90, 111 and 123
	MECH 162 Bt	3 sprays	99, 111 and 123
	MECH 162 NBt	3 sprays	99, 111 and 123
	MECH 184 Bt	1 spray	123
	MECH 184 NBt	3 sprays	99, 111 and 123
	NHH 44	5 sprays	75, 90, 99, 111 and 123
	SAVITA	4 sprays	75, 99, 111 and 123
2001-02 Experiment III	MECH 12 Bt	1 spray	136
	MECH 12 NBt	2 sprays	117 and 136
	MECH 162 Bt	1 spray	136
	MECH 162 NBt	4 sprays	81, 103, 117 and 136
	MECH 184 Bt	1 spray	136
	MECH 184 NBt	4 sprays	81, 103, 117 and 136
	NHH 44	4 sprays	81, 103, 117 and 136
	SAVITA	3 sprays	103, 117 and 136

Table 2. *Bollworms damage and yield in MECH 12 Bt-cotton 2000/01*[1]*.*

Entries	*Earias* damaged plants (%)	Fruiting bodies damage (%)		Open boll damage (%)	Locule damage (%)	Yield kg/ha
		74 DAS	100 DAS			
MECH 12 Non Bt No Spray	16.5 (23.9)	6.3 (14.3)	10.7 (18.4)	58.2 (49.8)	35.9 (36.8)	1120
MECH 12 Non Bt ETL Spray	18.4 (25.3)	3.7 (10.5)	9.3 (17.5)	48.9 (44.3)	33.5 (35.2)	1181
MECH 12 Bt No Spray	8.1 (16.3)	1.4 (6.4)	1.1 (6.0)	25.3 (29.9)	9.7 (15.7)	1663
MECH 12 Bt ETL Spray	7.3 (13.9)	0.5 (4.9)	2.2 (8.1)	26.6 (30.7)	8.1 (15.2)	1760
NHH 44 ETL spray	34.0 (35.4)	9.6 (17.6)	9.9 (17.9)	44.4 (41.7)	27.6 (31.4)	1721
SAVITA ETL spray	29.9 (32.6)	5.7 (13.6)	12.9 (20.5)	54.9 (47.8)	41.9 (40.3)	1547
CD (P = 0.05)	8.2	4.7	5.3	8.58	10.8	NS

[1]Figures in parenthesis are arc-sin transformed values.

Table 3. Helicoverpa *larval incidence in three Bt-cotton hybrids (2000/01).*

Entries	*H. armigera* larvae/5 plants				
	Days after sowing				
	75	99	111	123	Mean
MECH 12 Bt	1.0	0.3	0.5	0.0	0.5
MECH 12 NBt	2.3	0.3	1.8	0.3	1.2
MECH 162 Bt	0.0	0.8	1.3	0.0	0.5
MECH 162 NBt	0.3	2.8	2.	0.8	1.7
MECH 184 Bt	0.5	0.0	0.5	0.5	0.4
MECH 184 NBt	0.0	3.5	2.3	0.8	1.7
NHH 44	2.5	3.8	2.8	0.8	2.5
SAVITA	1.3	2.3	2.3	1.0	1.7
CD (P = 0.05)	NS	NS	NS	NS	

Table 4. *Bollworms damage and yield in three Bt cotton hybrids (2000/01)*[1]*.*

Entries	*Earias* damaged plants (%)	Fruiting bodies damage (%) 75 DAS	111 DAS	Open boll damage (%)	Locule damage (%)	Yield kg/ha
MECH 12 Bt	2.7	1.2	1.6	17.9	7.7	739
	(8.9)	(6.4)	(7.1)	(24.7)	(15.3)	
MECH 12 NBt	9.1	6.8	7.1	51.1	29.9	670
	(16.7)	(13.3)	(15.0)	(45.7)	(32.9)	
MECH 162 Bt	5.7	1.3	2.7	16.8	7.8	786
	(13.7)	(6.4)	(9.0)	(23.9)	(16.0)	
MECH 162 NBt	15.4	4.2	10.9	35.8	19.2	707
	(22.5)	(10.5)	(17.1)	(36.2)	(25.2)	
MECH 184 Bt	2.2	0.2	2.2	23.3	11.3	690
	(8.3)	(4.4)	(8.0)	(27.7)	(19.5)	
MECH 184 NBt	18.2	1.7	7.6	49.6	29.3	589
	(24.7)	(7.3)	(15.0)	(44.7)	(32.4)	
NHH 44	23.8	7.0	9.5	34.6	16.6	684
	(28.9)	(15.2)	(17.4)	(35.9)	(23.9)	
SAVITA	17.6	7.6	7.9	48.9	27.4	962
	(24.7)	(15.8)	(14.6)	(44.4)	(31.4)	
CD (P = 0.05)	6.81	6.71	7.67	11.3	7.67	NS

[1]Figures in parenthesis are arc-sin transformed values.

Table 5. Helicoverpa armigera *larval mortality – hours after exposure in Bt- and NBt-cotton hybrids (105 DAS).*

Cotton hybrid/variety	Number of larvae dead after 12 h	24 h	36 h	48 h	72 h	96 h	Mortality % (96 h)
MECH 12 Bt	2	7	8	13	19	28	70.0
MECH 12 NBt	1	3	5	5	6	8	20.0
MECH 162 Bt	5	9	14	17	20	21	52.5
MECH 162 NBt	0	2	4	6	7	8	20.0
MECH 184 Bt	8	12	22	24	24	24	60.0
MECH 184 NBt	3	6	11	12	14	18	45.0
NHH 44	2	2	3	3	4	7	17.5
SAVITA	5	6	6	6	7	8	20.0
LRA 5166 (variety)	4	5	6	6	8	9	22.5
Bt (mean for 3 hybrids)						60.8	
NBt (mean for 3 hybrids)						28.3	

N-40 Neonate larvae released

Table 6. Larval weight gains – days after exposure in Bt and NBt cotton hybrid (105 DAS).

Cotton hybrid/variety	Larval weight gain in mg after*			Weight reduction (%)
	4 days	5 days	6 days	
MECH 12 Bt	1.35 (12)	1.75 (12)	1.90 (10)	76.2
MECH 12 NBt	2.34 (32)	3.83 (30)	7.97 (29)	
MECH 162 Bt	1.26 (19)	1.50 (14)	2.31 (13)	69.3
MECH 162 NBt	2.66 (32)	3.72 (29)	7.52 (29)	
MECH 184 Bt	13.1 (16)	1.50 (12)	2.29 (7)	70.8
MECH 184 NBt	2.55 (22)	3.25 (20)	7.84 (19)	
NHH 44	1.91 (33)	2.82 (29)	7.00 (29)	
SAVITA	2.38 (32)	6.40 (30)	12.93 (27)	
LRA 5166 (variety)	1.58 (31)	4.13 (31)	7.10 (30)	
Bt (mean for 3 hybrids)			2.16	72.2
NBt (mean for 3 hybrids)			7.77	

*Figures in parentheses are number of surviving larvae

Table 7. Development variations of Helicoverpa armigera *fed in Bt and NBt cotton hybrids*.*

Cotton hybrid	Larval period (days)	Pupal period (days)	Pupal weight (mg)
MECH 12 Bt	32 (1)	17 (1)	93 (1)
MECH 12 NBt	25 (1)	11 (1)	138 (1)
MECH 162 Bt	26 (1)	Dead	-
MECH 162 NBt	25.1 (11)	11.7 (9)	132 (9)
MECH 184 Bt	Dead	-	-
MECH 184 NBt	23.2 (8)	10.4 (7)	117.4 (7)
NHH 44	24.0 (6)	9.5 (6)	134.8 (6)
SAVITA	22.3 (4)	9.0 (4)	147.3 (4)

N-40 neonate larvae released.

*Figures in parentheses are number of surviving larvae/ pupae; 96 – 128 DAS

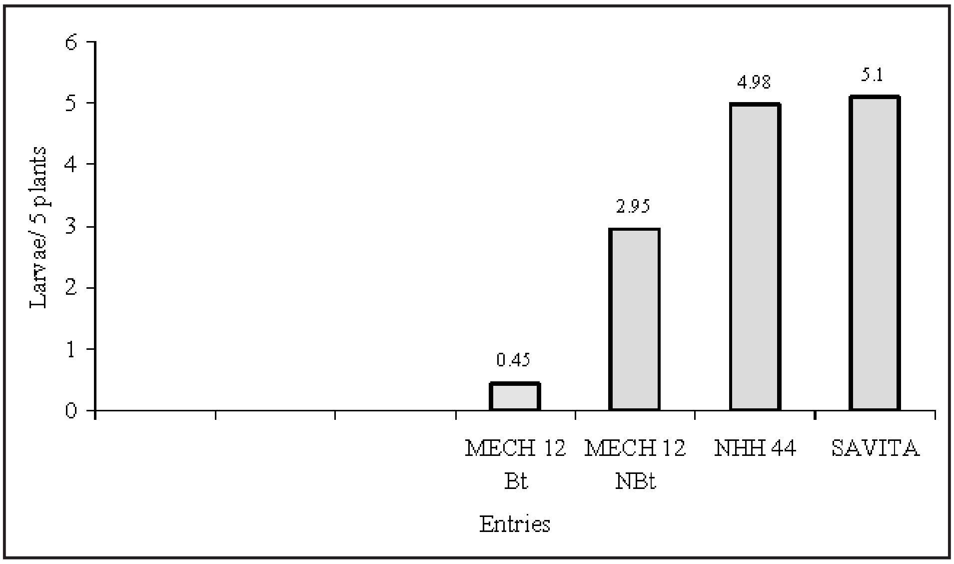

Figure 1. Helicoverpa *larval incidence in MECH 12 Bt cotton (2000/ 01).*

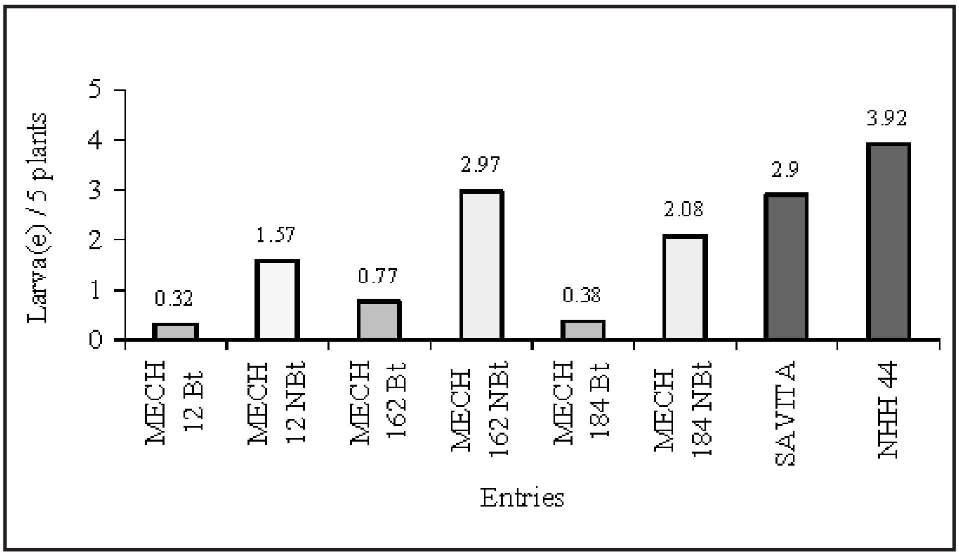

Figure 2. Effect of Bt cotton hybrids on larval incidence of H. armigera (2001-02) unprotected.

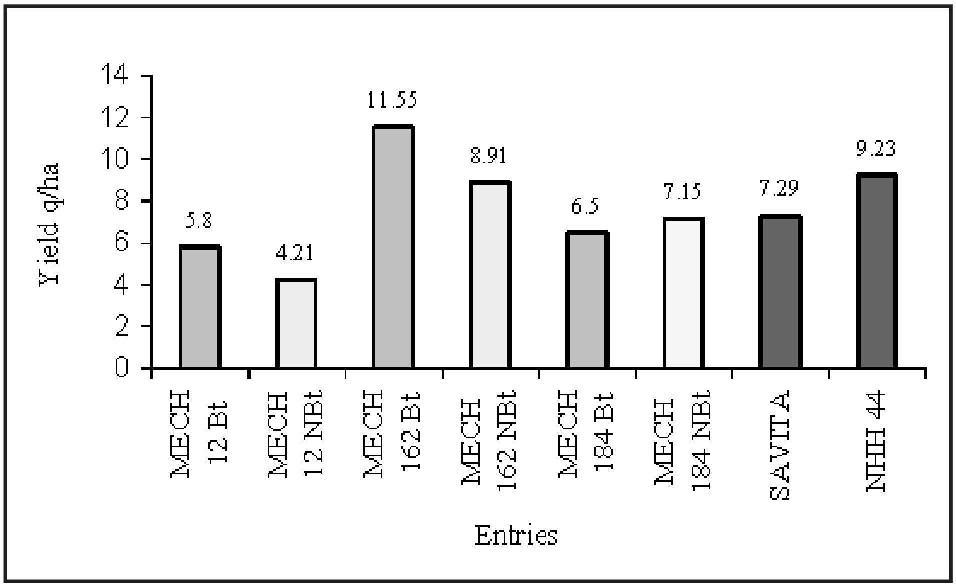

Figure 3. Seed cotton yield in three Bt cotton hybrids (2001/02) unprotected.

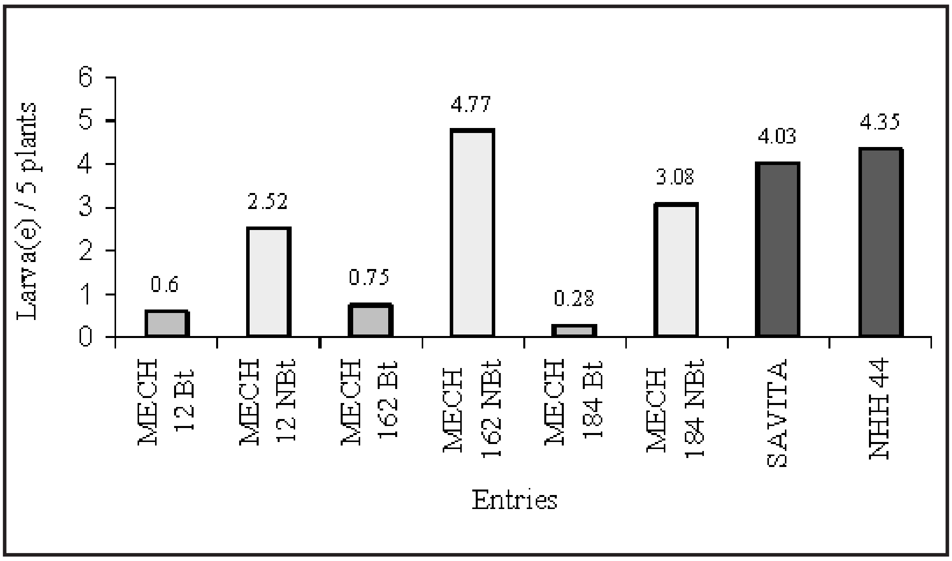

Figure 4. Effect of Bt cotton hybrids on larval incidence of H. armigera (2001/02) ETL based protection.

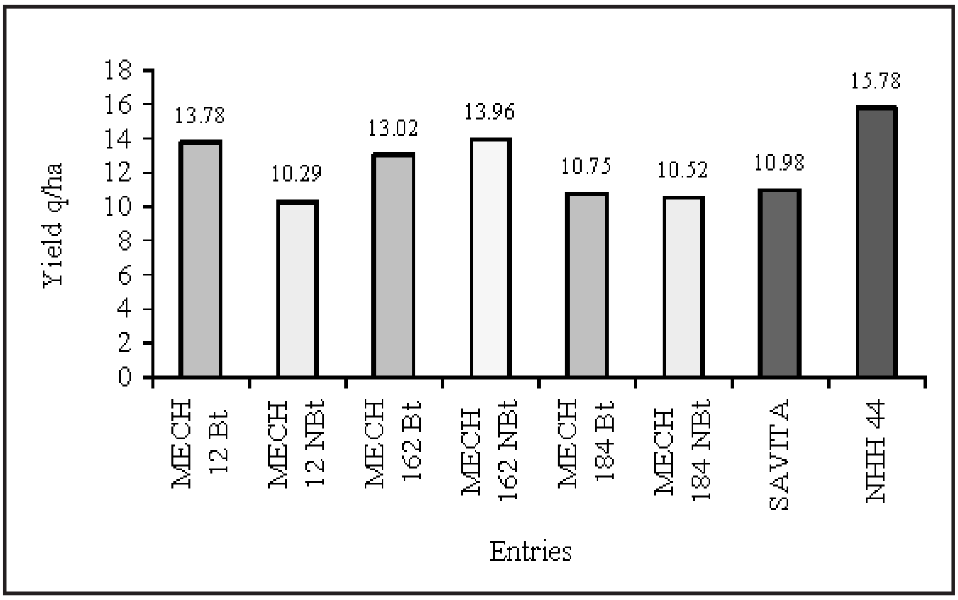

Figure 5. *Seed cotton yield in three Bt cotton hybrids (2001/02) ETL based protection.*