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Performance of *Bt* cotton (MECH-162) under Integrated Pest Management in farmers' participatory field trial in Nanded district, Central India

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Farmers' participatory field trail was conducted in 33.18 ha representing rainfed cotton-growing region in Nanded district of the central zone, to evaluate the performance of *Bt* cotton hybrid MECH-162 under Integrated Pest Management (IPM), and to compare it with conventional cotton (CC) hybrids/varieties grown with and without IPM. There was significant reduction in bollworm incidence, particularly the American bollworm (*Heliocoverpa armigera*) and pink bollworm (*Pectinophora gossypiella*) and the damage caused by them to the fruiting bodies in *Bt* MECH-162 compared to CC with IPM. In *Bt* MECH-162, 11.5% of the fruiting bodies were damaged compared to 29.4% in CC with IPM. Maximum damage was observed in CC without IPM, where seven sprays of pesticides were made for control of insect pests in comparison to three on *Bt* MECH-162. Population of the sucking pests and two natural enemies monitored was also lower in *Bt* MECH-162 compared to CC. The latter without IPM recorded the lowest population of natural enemies. Seed cotton yield (12.4 q/ha), and net returns (Rs 16231/ha) were highest for *Bt* MECH-162. CC under

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IPM recorded an yield of 7.1 q/ha, and return of Rs 10507/ha. The results show that IPM in cotton was most effective with *Bt* MECH-162, and provided higher return though the initial seed cost for the farmers was higher.

RESISTANT cultivars are one of the critical components determining the success of the Integrated Pest Management (IPM). *Bacillus thuringiensis* (*Bt*) is the most successful and widely used biological control agent for the control of lepidopteron pests[1]. Insecticidal crystal protein (ICP) produced by this bacterium is highly toxic to the target insects at ppm level. Therefore, using recombinant DNA techniques (genetic engineering), the crystal protein (*Cry*) gene was transferred and expressed in plants for the first time in 1987. Since then, more than 30 plant species have been transformed by using a range of *Bt* genes[2,3]. Currently, one or the other of the three transgenic *Bt* crops (cotton, corn and potato) are under cultivation in USA, China, South Africa, Australia, Argentina, Mexico, Indonesia and India. Approximately 12 million hectare (m ha) of insect-protected transgenic crops incorporating *Bt* ICP are now planted annually worldwide[4], with an expected annual increase of 10% or more. *Bt* cotton is genetically enhanced to resist the three bollworms, American bollworm (*Helicoverpa armigera*), spotted bollworm (*Earias insulana*/*E. vitella*) and pink bollworm (*Pectinophora gossypiella*).

Globally, cotton is grown on >32 m ha with approximately 71% of the production in developing countries[5]. India, USA and China are the main producers contributing 28, 16 and 10% respectively, of world production. Worldwide, maximum amount of pesticides is used on cotton crop. It is estimated that nearly US$ 2.7 billion out of the US$ 8.1 billion spent annually on all insecticides worldwide could be saved using *Bt* transgenic crops[6]. Reduction in the use of broad-spectrum insecticides on *Bt* cotton would result in conservation of natural enemies, non-target organisms, decrease soil and water contamination, and bring health benefits to the farm workers and others who come in contact with these insecticides.

The Genetic Engineering Approval Committee of the Ministry of Environment and Forests approved the commercial cultivation of MECH-12, MECH-162 and MECH-184 hybrids with *Bt* gene developed by Maharashtra Hybrid Seed Company (MAHYCO) in March 2002. The three hybrids were planted in an area of about 40,000 ha in the central and southern parts of the country in 2002.

Genetic resistance is one of the critical components of IPM and hence a systematic effort was made in the present investigation to evaluate the performance of *Bt* MECH-162 cotton under IPM *vis-à-vis* the conventional cotton (CC) in a farmers' participatory approach on 33.18 ha in 2002–03 crop season.

The trial was conducted in Hotala village, located approximately 60 km away from Nanded and representative of the central zone characterized by hot semi-arid climate with mostly shallow-to-medium and deep black soils. The soils suffer from both impeded drainage, waterlogging and run-off problems resulting in soil erosion during heavy downpour and moisture stress under drought[7]. Majority of the fields at Hotala were medium black cotton soils with provisions for partial protective irrigation. Cotton is the main cash crop and the farmers grow pigeonpea (*Cajanus cajan*) as an intercrop. Majority of the farmers have small-to-marginal land holdings.

The holistic IPM strategies, including integrated crop management, successfully field-tested earlier at 'Ashta' village[8] were adopted in the IPM blocks. The following treatments were tested under IPM and non-IPM.

For IPM: (i) *Bt* cotton MECH-162; 5.6 ha in seven farmer fields. (ii) Non-*Bt* MECH-162 was grown as 20% refugia in four lines around *Bt* plots; 1.44 ha area around 5.6 ha of *Bt* MECH-162. (iii) CC hybrid/variety with one or two lines of pigeonpea (cv BSMR 736) after every 8 rows of cotton – a traditional practice of the area; 18.70 ha covering 17 farmer fields; 2.75 ha under NHH44, a *hirsutum* hybrid and 15.95 ha under NH-545, an improved *hirsutum* variety.

The IPM approach consisted of the following:

- Cleaning of fields for leftover cotton plants and other un-decomposed plant debris.
- Balanced use of chemical fertilizers.
- Sowing of maize interlaced with cowpea along the borders of cotton fields to conserve and promote activities of natural enemies.
- Growing one row of Setaria between the 9th and 10th row of cotton as an attractant of insect predatory birds.
- Regular scouting and monitoring through pheromone traps.
- IPM interventions (*Trichogramma chilonis*, neem seed extract, HaNPV, mechanical collection of larvae and use of chemical pesticides as a last resort) based on Economic Threshold Levels (ETL) of a pest. ETL is the infestation level of an insect pest[9], which when crossed is capable of causing economic losses in yield.

For non-IPM: (i) CC hybrid/variety with one or two lines of pigeonpea (cv BSMR 736) after every 8 rows of cotton; 7.28 ha covering 5 farmer fields under NHH-44, Banni, Y-1 and Chamatkar consisting of *hirsutum* hybrids and varieties and an *arboreum* hybrid. Farmers' practices included seven sprays of pesticides.

The need-based plant protection interventions in the four treatments are presented in Table 1.

Weekly observations were made for sucking pests – aphids (*Aphis gossypii*), jassids (*Amrasca biguttula biguttula*), thrips (*Thrips tabaci*) and whiteflies (*Bemisia tabaci*) as the number of insects on three leaves each of 20 randomly selected plants per field. The egg and larval counts of spotted bollworm and American bollworm were

Table 1. Plant protection interventions and micronutrient sprays

Treatment	Plant protection intervention and foliar micronutrient spray#	Approximate quantity used/ha*	No. of applications*
IPM			
Bt MECH-162	Imidacloprid-treated seed (@ 10 g/kg seed) (included in seed cost)	Pretreated	–
	Thiomethoxam 25 WG spray	100 g	1
	Carbendazim 50 SP soil drench	500 g	1
	Biozyme (micronutrient) spray	1 l	1
Non-*Bt* MECH-162	Imidacloprid-treated seed (as in *Bt*-MECH-162)	Pretreated	–
	Thiomethoxam 25 WG spray	100 g	1
	Carbendazim 50 SP soil drench	500 g	1
	Biozyme (micronutrient) spray	1 l	1
	NSKE (5%) spray	25 kg	1
	Trichocards release	7.5 cards**	1
CC	Thiomethoxam (70 WS) seed treatment @ 4 g/kg seed	12 g	1
	Aphidin (Ecomax organic compound) spray	1 l	2
	Neem seed kernel extract (5%) spray	25 kg	2
	HaNPV (2×10^9 POBs/ml) spray	250 ml	2
	Trichocards release	7.5 cards**	2
Non-IPM			
CC***	Monocrotophos 36 EC spray	1.25 l	2
	Dimethoate 30 EC spray	1.25 l	2
	Endosulphan 35 EC spray	2.50 l	1
	Profenophos 40 EC spray	2.00 l	1
	Cypermethrin 25 EC spray	1.00 l	1

Labour cost: @ Rs 160/ha per application of spray/soil drench; @ Rs 40/ha for fixing trichocards.
*Some field variations in quantity used and no. of applications. However, cost of production (Table 4) was computed on actuals over the entire area under a treatment.
**Each card contained 20,00 parasitized eggs.
***Two to three times over-dosages were commonly adopted. Farmers mostly resorted to mixtures of pesticides; only overall quantities used are mentioned.
#Mention of trade names does not imply their recommendation and does not exclude possibility of use of similar products available in the market.

made on 20 plants randomly selected from each field. Infestation of bollworms was recorded by examining all green bolls from five plants per field. For pink bollworm, 100 bolls per field were picked randomly at weekly intervals and the number of damaged locules, and number of larvae were recorded. The counts of two beneficial insects, ladybird beetle (*Coccinella* spp.) and green lacewing (*Chrysoperla carnea*) were recorded on 20 plants per field. The damage to squares, flowers and green bolls was recorded to evaluate comparative effectiveness of induced resistance imparted by *Bt* gene against injury due to lepidopteran insects. Seed cotton yield of each field was recorded over the three pickings.

Data on insect pests, natural enemies, boll damage, yield, etc. were analysed using SAS software. Suitable transformations (square root transformation for population count and arc sine transformation for per cent damage) were applied. Since the number of replications (each field of a treatment constituted a replication) in each treatment was unequal, Proc GLM of SAS software[10] was used. To have pair-wise comparison between four treatments, Least Significant Difference (LSD) tests[11] were carried out.

The mean number of insect pests and natural enemies is presented in Table 2. Sucking pests were mostly active during 30–42 standard weeks. Whereas whiteflies and jassids did not cross the ETL during most part of the season, these also did not vary much amongst *Bt* and non-*Bt* cultivars, the highest being in non-IPM plots. The population of thrips was higher on non-IPM CC. Population of aphids was comparable in *Bt* MECH-162 and non-*BT* MECH-162, whereas it was 20.6 aphids/three leaves on CC-IPM and highest (44.3 aphids/three leaves) on CC non-IPM. Statistical analysis has shown that all the sucking pest populations were not significantly different in *Bt* MECH-162 and non-*Bt* MECH-162, but significantly different compared to CC IPM and non-IPM.

Infestation of American bollworm was in moderate intensity due to the comparatively drier season. The egg load was not significantly different in *Bt* MECH-162 and non-*Bt* MECH-162. It was significantly less in CC IPM and was highest (0.17 eggs/plant) in CC non-IPM. More insecticide use and higher rates of fertilizer application seem to have attracted greater *H. armigera* activity in CC non-IPM fields. On the other hand, the number of larvae was lowest in *Bt* cotton (0.03 larvae/plant) compared to

Table 2. Population of sucking pests, bollworms and natural enemies

Insect pest	Standard week#	IPM *Bt* MECH-162	IPM Non-*Bt* MECH-162	IPM CC	Non-IPM CC
Sucking pests*					
Whiteflies	30–42	0.15[a]	0.15[a]	0.24[b]	0.29[b]
Jassids	30–42	0.07[a]	0.07[a]	0.14[b]	1.97[c]
Thrips	30–42	4.88[a]	4.56[a]	5.98[b]	12.62[c]
Aphids	30–42	3.96[a]	3.50[a]	20.56[b]	44.34[c]
Bollworms**					
American bollworm eggs	31–49	0.12[a]	0.12[a]	0.08[b]	0.17[c]
American bollworm larvae	31–49	0.03[a]	0.06[b]	0.05[b]	0.09[c]
Spotted bollworm larvae	31–49	0.00[a]	0.01[a]	0.03[b]	0.06[c]
Natural enemies**					
Green lacewing eggs	31–49	0.37[a]	0.37[a]	0.61[b]	0.26[c]
Ladybird beetle adults	31–49	1.33[a]	1.23[a]	2.06[b]	0.69[c]

Mean number of pests/natural enemies over the season.

Means with at least one letter common are not significantly different.
#Standard week 30 corresponds to 23–29 July.
*Number of insects/three leaves, **Number of insects/plant.

Table 3. Damage to reproductive parts by bollworms

Reproductive part	Standard week#	IPM *Bt* MECH-162	IPM Non-*Bt* MECH-162	IPM CC	Non-IPM CC
Squares and flowers	31–49	0.68[a]	4.40[b]	3.48[c]	6.89[d]
Green bolls	31–49	1.55[a]	7.39[b]	6.21[b]	13.04[c]
Shed reproductive parts	31–49	9.32[a]	21.09[b]	19.69[b]	34.30[c]
	Total % damage	11.55	32.88	29.38	54.23

Mean per cent damage.

Means with at least one letter common are not significantly different.
#Standard week 31 corresponds to 30 July – 5 August.

Table 4. Pink bollworm population and damage

Treatment	Mean per cent damaged locules*	Mean no. of larvae/100 bolls*
IPM		
Bt MECH-162	5.95[a]	3.91[a]
Non-*Bt* MECH-162	14.10[b]	19.83[b]
CC	17.34[bc]	18.00[b]
Non-IPM		
CC	21.07[c]	24.08[b]

*Mean of 1200 bolls for each treatment over 12 weeks.
Means with at least one letter common are not significantly different.

0.05 and 0.09 larvae/plant on CC IPM and non-IPM, respectively. The mean number of larvae per plant was significantly different in *Bt* MECH-162 compared to the other three treatments. *E. vitella* was a minor pest during the season and caused some damage to terminal shoots in CC non-IPM.

The natural enemy population was less on *Bt* MECH-162 compared to CC IPM. Population of natural enemies was lowest on conventional non-IPM cotton, which received maximum pesticidal sprays. These results are similar to those reported on *Bt*-varieties grown in the US[12] and China[13]. The lower population of natural enemies on *Bt* MECH-162 compared to CC IPM in our experiment could have been mainly due to lesser availability of sucking pests, the food for the natural enemies, rather than any direct detrimental impact on these insects. Scouting and monitoring for deciding the interventions for bollworm management are important considerations for the success of IPM approach in *Bt* crop. We noted that in the adjoining villages, farmers rushed to spray *Bt* crop at the appearance of eggs/larvae of *H. armigera* and vitiated the ecological advantage offered by *Bt* technology by way of reduced pesticide load.

The total per cent damage to fruiting bodies, including squares and flowers, green bolls and shed reproductive parts (Table 3) was lowest in *Bt* MECH-162 (11.55) compared to 32.88 in non-*Bt* MECH-162, 29.38 in CC IPM and was highest (54.23) in CC non-IPM.

The mean number of pink bollworm larvae in *Bt* MECH-162 was 3.9 in 100 bolls compared to 18.0 larvae in CC IPM and 24.1 larvae in CC non-IPM and the differences were statistically significant (Table 4). A recent press release[14] about the concern for inefficacy of *Bt* cotton in the management of pink bollworm in the Indian context, especially for the legal *Bt* cotton, appears to be largely unfounded.

The incidence of para wilt was low in *Bt* MECH-162 as the fields were properly levelled with good drainage. Some plant population in *Bt* MECH-162 showing wilt symptoms was managed by soil drenching with 0.1% Carbendazim in the affected and the surrounding plants. Severe incidence of para wilt in *Bt* MECH-162 in the adjoining villages was observed. Para wilt is considered to be a genetically controlled physiological disorder, which appears when there is a long, dry spell followed by heavy downpour. Such conditions were experienced during the season.

Production cost (Table 5) was highest for *Bt* MECH-162 (Rs 12,231/ha), mainly due to the cost of seed. Highest per unit seed cotton yield was obtained for *Bt* MECH-162 (12.375 q/ha; Table 6). Lowest yield was recorded in CC non-IPM (3.704 q/ha). However, there was an additional income from pigeonpea intercrop grown in CC. Net returns were highest in *Bt* MECH-162 (Rs 16,231/ha) and lowest in CC non-IPM (Rs 944/ha).

While transgenic cotton may be useful in several ways and is likely to be adopted at quick pace, the technology remains controversial due to various concerns. These are

Table 5. Economics of production (Rs/ha)

	IPM			Non-IPM
Field operations	*Bt* MECH-162	Non-*Bt* MECH-162	CC	CC
Labour cost				
Land preparation	1400	1400	1400	1400
Sowing and fertilizer application	550	550	550	550
Irrigation	80	80	–	–
Pesticide/bioagent application	480	680	1040	1120
Hand weeding and hoeing	1100	1100	1100	1100
Monitoring and scouting	250	250	250	–
Mechanical collection of larvae	–	200	200	–
Harvesting and picking @ Rs 1.50 per kg seed cotton	1856	1443	1059	555
Pigeonpea harvest @ Rs 50/quintal	–	–	123	74
Total	5716	5703	5722	4799
Material cost				
Seed	4000	1000	250	250
Fertilizer	1300	1300	1300	2050
Water	250	250	–	–
Pesticides and bioagents	965	1440	2641	2975
Total	6515	3990	4191	5275
Grand total (labour cost + material cost)	12,231	9693	9913	10,074

Table 6. Performance of *Bt* MECH-162, non-*Bt* MECH-162, CC under IPM and CC without IPM

Treatment	Area (ha)	Seed cotton yield (q/ha)*	Yield of pigeonpea (q/ha)**	Returns (Rs/ha)	Cost of production, including protection (Rs/ha)	Net returns (Rs/ha)	B : C ratio
IPM							
Bt MECH-162	5.76	12.375[a]	Nil	28462	12231	16231	2.327
Non-*Bt* MECH-162	1.44	9.620[b]	Nil	22126	9693	12433	2.283
CC	18.70	7.060[c]	2.46	20420	9913	10507	2.060
Non-IPM							
CC	7.28	3.704[d]	1.47	11018	10074	944	1.094

Means with at least one letter common are not significantly different.
*Market rate Rs 2300 per q seed cotton.
**Market rate Rs 1700 per q.

mainly about the proneness of the technology to other biotic and abiotic stresses, likely harmful and side effects to natural enemies and non-target organisms, including human health, development of resistance in populations of the target insects and possible ecological consequences of gene flow to non-engineered crops and wild relatives. In the very first year of its commercialization, *Bt* MECH-162 was found to be prone to para wilt, and a sizable area was affected by the malady. *Bt* MECH-12 is known to be highly sensitive to jassids, whereas some of the *Bt* hybrids in the pipeline are susceptible to leaf curl. Some reports in the Indian press[15,16] have even indicated failure of *Bt* crop in the 2002 season due to *H. armigera* or drought situations. Debate has arisen on implications and utility of *Bt* cotton. Earlier, Qaim and Zilberman[17] analysed the performance of 157 field trials carried out by MAHYCO on their *Bt* hybrids in 2001–02 (one year before commercialization) in India mainly for yield and pesticide use and presented a highly positive scenario. At about the same time, reports on 2002 *Bt* cotton crop failure started appearing in the Indian press, and the publication[17] came under close scrutiny[18,19]. It was concluded that the claim lacked a systematic effort and appropriate data to support it. There were claims and counterclaims about the viability of *Bt* cotton technology for the Indian situation.

In the present investigation, an effort was made to evaluate the performance of *Bt* MECH-162 on a larger scale in one village covering 33.18 ha cotton crop in farmers' participatory mode. The trial showed better performance of *Bt* MECH-162 in spite of the different biotic and abiotic stresses experienced during the season. The pest loads in *Bt* cotton (sucking as well as bollworms) were low and so were the damages due to bollworms to fruiting parts. Thus, *Bt* MECH-162 used in an IPM mode resulted in highest yields and economic gains to the farmers; pesticide consumption was also reduced. The results show clearly that *Bt* cotton technology is not only economically viable but is also able to reduce reliance on pesticide use. Reports of the 2003 season also indicated better performance of *Bt* cotton and in particular, *Bt* MECH-184 has been found to be promising (our unpublished data). Currently, farmers have a choice between three *Bt* cotton hybrids and some more are likely to be available from the 2004 season. Under the present circumstances, there is need to monitor the technology carefully on different *Bt* cotton hybrids according to the climatic and pest situations arising in subsequent years. The IPM approach, which also takes care of varying pest situations, appears essential for gaining higher advantage from *Bt* cotton.

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