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Impact of refugia and integrated pest management on the performance of transgenic (*Bacillus thuringiensis*) cotton (*Gossypium hirsutum*)

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ABSTRACT

Farmers' participatory field trials were conducted with transgenic (*Bacillus thuringiensis*) and conventional cotton (*Gossypium hirsutum* L.) hybrids in integrated pest management and non-integrated pest management modes using different combinations of refugia for two cropping seasons (2003–05) in Nanded district of Maharashtra in central India and one cropping season (2004–05) in Dharwad district of Karnataka of southern India. At Nanded, the experiments were conducted with *Bt* 'MECH 184' and local popular conventional hybrid 'Bunny' and at Dharwad with 'RCH 2' *Bt* and 'RCH 2' conventional popular cotton hybrid. Results on sucking pests indicated no consistent trend with regard to locations and cropping seasons in *Bt* and conventional cottons. The mean incidence of American bollworm (*Helicoverpa armigera* Hubner), pink bollworm (*Pectinophora gossypiella* Saunders) and spotted bollworm (*Earias insulana* Boisd.) larval population and percentage of damaged squares, bolls and shed fruiting bodies at both the locations remained significantly high in conventional cotton treatments compared with all the *Bt* cotton treatments. The population of ladybird beetle and *Chrysoperla zastrowi arabica* Henry *et al.* was not adversely affected in all *Bt* treatments compared with the conventional cotton treatments. The yield data indicated higher seed cotton yield in all the *Bt* treatments compared to conventional cotton at both the locations. Integrated pest management was necessary for getting the best out of *Bt* cotton and 20% refugia reduced the seed cotton yield without giving substantial benefit in terms of bollworm control or conserving higher natural enemy population.

Key words: American bollworm, *Bt*, Conventional cotton, Integrated pest management, Natural enemies, Pink bollworm, Spotted bollworm

Bt cotton was approved for commercial cultivation in India in March 2002 after stringent assessment for biosafety and profitability. Within 6 years of introduction, *Bt* cotton technology had taken firm roots in India covering > 75% of the 9 million ha cotton (*Gossypium hirsutum* L.) area and the number of *Bt* hybrids also increased exponentially to >500 by 2008–09. Reports are available on the incidence of insect pests and diseases in small scale field trials conducted on *Bt* cotton in Tamil Nadu (Kumar and Stanley 2006), Karnataka (Channakeshava and Patil 2006), Andhra Pradesh (Prasad and Rao 2008, Reddy *et al*. 2005) and other states. Though the *Bt* cotton itself is a vital component of integrated pest management (IPM) due to presence of Cry 1 Ac protein, yet there is a need to develop location-specific integrated pest management module, especially for sucking pests and diseases, fitting with *Bt* cotton. In the very first year of commercialization, the vulnerability of *Bt* 'MECH 162' to an abiotic stress, the para wilt, the hyper susceptibility of *Bt* 'MECH 12' to jassids, variability in susceptibility to the bollworms conferred by the toxin which are lower in *Bt* 'MECH 162' compared with the other two *Bt* hybrids and high sensitivity of *Bt* 'MECH 915' (not released and dropped from the trials) to cotton leaf curl virus have been observed. Mealybug has already emerged as a threat to *Bt* cotton in different cotton growing states (Tanwar *et al*. 2007). Many more reports are also evident indicating higher sensitivity of

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these *Bt* cottons to thrips, grey mildew, leaf spots and weevils (AICCIP 2007–08).

The *Bt* technology has already been adopted in many countries and in these countries requirement of refugia is mandatory for avoiding resistance development in bollworms to *Bt* cotton. In India several weeds and other non-*Bt* cotton, companion host crops and non-*Bt* host crops in the cotton-based cropping systems are available which fulfill the need for *Bt*-free host in the surroundings and therefore, there is a need to carry out investigations before making refugia as mandatory. Twenty per cent refugia also entails its proper management as it is a substantial area whose yields cannot be sacrificed by the poor and marginal farmers of India with the very small land holdings. If this 20% refugia is managed only through chemical pesticides, it endangers the population of natural enemies and may indirectly influence the *Bt* cotton. The information available on refugia and its consequences in favour of natural enemies and yields in cotton is inadequate. The National Centre for Integrated Pest Management, New Delhi along with different cooperating centres conducted field studies for two cropping seasons (2003–05) on the requirement of refugia in *Bt* cotton and its evaluation of location-specific integrated pest management in central (Nanded, Maharashtra) and southern (Dharwad, Karnataka) cotton zones.

MATERIALS AND METHODS

Field trials were conducted with *Bt* and conventional cotton hybrids in integrated pest management and non-integrated pest management mode using different combinations of refugia for 2 cropping seasons (2003–05) in Nanded district of Maharashtra in Central India and for 1 cropping season (2004–05) in Dharwad district of Karnataka of South India. In Nanded, the experiment in the first year was laid out with 13 treatments with 4 replications in 15.78 ha in 5 villages, i e Hotala, Naigaon, Navandi, Khairgaon and Palasgaon. Each treatment was of 0.40 ha. The experiment included *Bt* 'MECH-184' and local popular conventional hybrid 'Bunny'. The treatment details are presented in Table 1.

Table 1 Treatment details of the experiment on *Bt* 'MECH 184' with refugia in integrated pest management and non-integrated pest management modes conducted in Nanded during 2003–04

Treatment	IPM # interventions/ha
T_1 (*Bt* with 20% refugia + IPM) T_2 (*Bt* with 10% refugia + IPM) T_3 (*Bt* with 5% refugia + IPM) T_4 (*Bt* with no refugia + IPM) T_5 (*Bt* with 5% refugia + 15% pigeonpea + IPM)	Seed treated with imidacloprid; 1 row of cowpea and maize on border + 1 row of *setaria* between every 10th and 11th row of *Bt* cotton; 2 applications of thiomethoxam; 1 application of magnesium sulphate, biozyme, trichocard and 5% NSKE, each
T_6 (*Bt* with 20% refugia + non-IPM) T_7 (*Bt* with 10% refugia + non-IPM) T_8 (*Bt* with 5% refugia + non-IPM) T_9 (*Bt* with no refugia + non-IPM) T_{10} (*Bt* with 5% refugia + 15% pigeonpea + non-IPM)	Imidacloprid treated seed; 2 sprays of thiomethoxam and endosulfan, each; one spray of wettable sulphur, carbendazim, magnesium sulphate and biozyme, each (T_{10} also included 1 row of pigeonpea after 10th row of *Bt* cotton)
T_{11} (non-*Bt* counterpart 'MECH 184' with chemical plant protection)	Seed treatment with imidacloprid; 2 sprays of thiomethoxam, wettable sulphur and endosulfan + dimethoate, each; 1 spray of carbendazim, acephate + indoxacarb, cypermethrin+ dimethoate, each
T_{12} (conventional cotton 'Bunny' with IPM)	Seed treatment with thiomethoxam; 2 sprays of thiomethoxam, 5% NSKE, trichocard each; 1 application of wettable sulphur and magnesium sulphate, each
T_{13} (conventional cotton 'Bunny' non-IPM)	Seed treatment with thiomethoxam; 2 sprays of thiomethoxam and endosulfan each; wettable sulphur + endosulfan, acephate + indoxacarb and cypermethrin + dimethoate, each

#IPM (integrated pest management interventions) also included balanced use of fertilizer, scouting and pheromone monitoring through pheromone traps

(Acephate 75 SP @ 500g/ha, Biozyme @ 1 litre/ha, carbendazim 50 SP @500g/ha; cypermethrin 25 EC @ 1.0 litre/ha, dimethoate 30 EC @ 1.25 litre/ha, endosulfan 35 EC @ 2.5 litre/ha; imidacloprid 17.8 SL @ 10 g/kg seed, imidacloprid 200 SL @ 200 ml/ha (spray), indoxacarb 15.5 SL @ 500 ml/ha, magnesium sulphate @ 2.5 kg/ha, NSKE (neem seed kernel extract) @25kg/ha, thiomethoxam 25 WG @ 100 g/ha, wettable sulphur @ 625 g/ha)

In non-integrated pest management treatments (T_{11} and T_{13}) spray by the farmers included mixture of two pesticides

Table 2 Details of treatments laid out with *Bt* cotton with and without refugia in integrated pest management and non-integrated pest management modes at Nanded and Dharwad during 2004–05

Treatment	Details of interventions in different treatments	
	Nanded	Dharwad
T_1 (20% refugia + 80% *Bt* cotton: entire area in IPM mode)	*80%* Bt *IPM:* 1 row of cowpea and maize on border + 1 row of *setaria* between every 10th and 11th row of *Bt* cotton; 1 spray of thiamethoxam and NSKE, each 20% *refugia IPM*: same as above + 1 spray of HaNPV + mechanical collection of larvae	*IPM:* Seed treatment with imidacloprid; growing okra as trap crop, detopping the tip of plant at 85 days, hand collection of grownup larvae and shed material, one spray of acetamiprid, imidacloprid and NSKE, each *Non-IPM:* Two sprays of imidacloprid and acetamiprid each and one spray of quinalphos and indoxacarb, each
T_2 (20% refugia + 80% *Bt* cotton: entire area in non-IPM)	*80%* Bt *cotton* (Bt *non-IPM*) + *20% refugia both in* (*non-IPM*)*:* Two sprays of thiomethoxam and 1 spray of endosulfan and cypermethrin, each	
T_3 (20% refugia + 80% *Bt* cotton: IPM in only *Bt* cotton)	*80%* Bt *cotton* (*IPM*)*:* 1 row of cowpea and maize on border + 1 row of *setaria* between every 10th and 11th row of Bt cotton; one spray of thiamethoxam and NSKE, each *Non-IPM in 20% refugia:* 2 sprays of endosulfan and one spray of thiomethoxam or acetamiprid	
T_4 (no refugia, 100% *Bt* cotton: IPM)	1 row of cowpea and maize on border + 1 row of *setaria* between every 10th and 11th row of Bt cotton; one spray of thiamethoxam and acetamiprid, each	
T_5 (no refugia, 100% *Bt* cotton: non-IPM)	Two sprays of thiamethoxam (sucking pests) and endosulfan (bollworms), each	
T_6 (ruling conventional cotton hybrid* – IPM)	1 row of cowpea and maize on border + 1 row of *setaria* between every 10th and 11th row of cotton; 2 sprays of acetamiprid and 1 spray of endosulfan, HaNPV and NSKE each, 2 releases of trichocards	
T_7 (ruling conventional cotton hybrid –non-IPM)	Two sprays of dimethoate and 1 spray of dimethoate + endosulfan, acephate, endosulfan, cypermethrin, each	

[#] IPM (integrated pest management) interventions also included balanced use of fertilizer, scouting and pheromone monitoring through pheromone traps

* Conventional cotton hybrid included 'Bunny' at Nanded and 'RCH 2' *Bt* and 'RCH 2' conventional at Dharwad

(Acephate 75 SP @ 500g/ha, acetamiprid 20 SP @ 100 g/ha, Biozyme @1 litre/ha, carbendazim @ 50 SP @ 500g/ha; cypermethrin 25 EC @ 1.0 litre /ha, dimethoate 30 EC @1.25 litre/ha, endosulfan 35 EC @ 2.5 L/ha; HaNPV @ 250 LE/ha, imidacloprid 17.8 SL @ 10 g/kg seed, imidacloprid 200 SL @ 200 ml/ha (spray), indoxacarb 15.5 SL @ 500 ml/ha, magnesium sulphate @ 2.5 kg/ha, NSKE 25kg/ha, quinalphos 25 EC @ 1.5 litre /ha, thiomethoxam 25 WG @ 100 g/ha, wettable sulphur @ 625 g/ha, 7 Trichocards/ha

The trials in the second year were conducted in 4 villages (Naigaon, Palasgaon, Golegaon and Khairgaon) in Nanded and in 1 block in Dharwad with 7 treatments and 4 replications with an overall area of 11.33 ha at each location. The details of the treatments at both the locations are given in Table 2. Each plot was of 0.40 ha with 90 cm × 60 cm spacing. The experiment included *Bt* 'MECH 184' and local popular conventional hybrid 'Bunny' in Nanded and 'RCH 2' *Bt* and 'RCH 2' conventional popular hybrids in Dharwad. Details of other IPM interventions carried out during experiment are indicated in Table 2.

Weekly observations were recorded for sucking pests– aphids (*Aphis gossypii* Glover), jassids (*Amrasca bigutulla bigutulla* Ishida), thrips (*Thrips tabaci* Linn.) and whiteflies (*Bemisia tabaci* Gennadius) as number of insects on 3 leaves each of 20 randomly selected plants/field. The eggs of American bollworm, larvae of spotted and American bollworms and beneficial insects (ladybird beetle and *Chrysoperla zastrowi arabica* Henry *et al.*) were recorded on 20 randomly selected plants from each field. Infestation of bollworms was recorded by examining all green bolls from 5 plants/field. The damage to squares, flowers and green bolls was recorded to evaluate comparative effectiveness of resistance imparted by *Bt* gene against injury due to lepidopteran insects. For pink bollworm, 100 bolls/field were picked randomly at weekly intervals and the number of damaged locules, and number of larvae were recorded. Seed cotton yield of each field was recorded over the 3 pickings.

The data were analyzed using the procedure GLM of SAS V 8 software (Little *et al*. 1991). For the treatments, which were significant, the comparisons among the pair-wise differences were obtained using Tukey's Test. To have pair-wise comparison between 4 treatments, least significant difference (LSD) tests (Gomez and Gomez 1984) were carried out.

RESULTS AND DISCUSSION

Sucking pests

Results of 2003–04 indicated that the differences in the population of sucking pests among different treatments were statistically not significant (Table 3) except whitefly, which remained significantly less in conventional cotton in integrated pest management mode (T_{12}) compared with other treatments (except treatments 2 and 5). This could be due to more number of pesticide applications in conventional cotton against bollworms as compared to *Bt* cotton already having *Bt* toxin against bollworms. The results of the second year field trial at Nanded (Table 4) indicated that the average population of jassids, thrips and whitefly remained significantly high in conventional cotton both in integrated pest management as well as non-integrated pest management mode as compared to *Bt* treatments except treatment 5 in case of thrips which was at par with treatment 7. At Dharwad no clearcut trend was observed with regard to *Bt* and conventional cotton for sucking pests, but among all the treatments, the population of sucking pests, in general,

Table 3 Incidence of sucking pests, bollworms, natural enemies and seed cotton yield in different treatments at Nanded (2003–04)

Treatment	Sucking insects (no./3 leaves)*				Bollworms			Natural enemies/plant		
	Whiteflies (32-51 SMW)	Aphids^{NS} (29-39 SMW)	Thrips^{NS} (29-39 SMW)	Jassids^{NS} (29-43 SMW)	ABW (larvae/ plant)	PBW (larvae/ 10 bolls)	Spotted bollworm larvae/plant	LBB (adults)	GLW (eggs)	Seed cotton yield (kg/ha)
T_1	0.61^{abc}	8.51	4.24	2.46	0.04^{cd}	0.24^{c}	0.002^{c}	0.27^{bc}	1.82^{bc}	2 184^{a}
T_2	0.52^{cd}	7.65	4.31	0.87	0.03^{cd}	0.21^{c}	0.005^{c}	0.36^{ab}	2.10^{ab}	2 011^{abc}
T_3	0.63^{abc}	8.53	4.28	0.80	0.02^{d}	0.18^{c}	0.002^{c}	0.33^{abc}	1.83^{bc}	1 989^{abc}
T_4	0.63^{abc}	6.67	4.57	0.83	0.03^{d}	0.18^{c}	0.002^{c}	0.34^{abc}	1.96^{bc}	2 076^{ab}
T_5	0.55^{bcd}	10.91	4.39	0.93	0.04^{cd}	0.12^{c}	0.007^{c}	0.54^{a}	1.80^{bc}	1 939^{abcd}
T_6	0.62^{abc}	6.416	5.52	0.80	0.04^{cd}	0.21^{c}	0.010^{c}	0.32^{abc}	1.66^{bc}	1 571^{cd}
T_7	0.61^{abc}	7.23	4.08	0.63	0.07^{c}	0.30^{c}	0.004^{c}	0.32^{abc}	1.64^{c}	1 616^{bcd}
T_8	0.62^{bc}	9.26	5.25	0.73	0.06^{cd}	0.24^{c}	0.002^{c}	0.28^{bc}	1.69^{bc}	1 642^{bcd}
T_9	0.79^{ab}	6.24	6.73	0.76	0.03^{cd}	0.15^{c}	0.006^{c}	0.27^{bc}	1.86^{bc}	1 880^{abcd}
T_{10}	0.61^{abc}	5.46	5.33	0.74	0.03^{cd}	0.30^{c}	0.009^{c}	0.27^{bc}	1.76^{bc}	1 476de
T_{11}	0.94^{a}	9.34	5.42	0.88	0.30^{a}	3.58^{ab}	0.055^{b}	0.37^{ab}	1.74^{bc}	721^{f}
T_{12}	0.36^{d}	3.10	5.15	0.83	0.12^{b}	3.21^{b}	0.043^{b}	0.23^{c}	2.52^{a}	1 082^{ef}
T_{13}	0.64^{bc}	18.27	6.20	0.50	0.26^{a}	4.70^{a}	0.073^{a}	0.12^{d}	0.82^{d}	858^{f}

*P=0.05 In a column means with at least one letter common are not significant; NS, not significant.

ABW, American bollworm; PBW, pink bollworm; LBB, ladybird beetle; GLW, green lacewing; SMW, standard meteorological week

Table 4 Population of sucking pests, bollworms and natural enemies in different treatments at Nanded during 2004–05

Treatment	Sucking insects (no./3 leaves)*				Bollworms				Natural enemies/plant	
	Aphids	Jassids	Thrips	Whiteflies	ABW eggs/plant plant)	ABW larvae/ plant	PBW larvae/ 10 bolls	Spotted bolloworm larva/plant	LBB	GLW eggs
T_1	4.61	0.46^{a}	2.72^{a}	0.64^{a}	0.30^{bc}	0.039^{d}	0.00^{a}	0.00^{a}	1.52^{a}	0.39^{ab}
T_2	6.13	0.51^{a}	3.23^{a}	0.81^{a}	0.37^{ab}	0.068^{c}	0.00^{a}	0.00^{a}	1.04^{b}	0.29^{b}
T_3	5.30	0.67^{a}	2.74^{a}	0.63^{a}	0.28^{c}	0.045^{cd}	0.00^{a}	0.00^{a}	1.64^{a}	0.37^{ab}
T_4	4.72	0.50^{a}	3.11^{a}	0.67^{a}	0.33^{bc}	0.038^{d}	0.00^{a}	0.00^{a}	1.59^{a}	0.41^{a}
T_5	6.46	0.55^{a}	3.48^{ab}	0.75^{a}	0.36^{ab}	0.067^{c}	0.00^{a}	0.00^{a}	1.15^{b}	0.29^{b}
T_6	3.97	0.98^{b}	7.58^{c}	1.05^{b}	0.33^{ab}	0.201^{b}	0.04^{b}	0.05^{b}	1.46^{a}	0.43^{a}
T_7	6.77	0.87^{b}	4.20^{bc}	0.97^{b}	0.37^{a}	0.402^{a}	0.04^{b}	0.09^{c}	0.96^{b}	0.31^{b}

*In a column means sharing any common letters are not significantly different at P=0.05 level of significance using Tukey's mean comparison test; NS, not significant

ABW, American bollworm; PBW, pink bollworm; LBB, ladybird beetle; GLW, green lacewing remained low in integrated pest management treatments as compared to non-integrated pest management (Table 5). Zhang-Long Wa *et al*. (2005) had earlier reported that *Bt* cotton could suppress the population of caterpillar, but had little effect on the sucking pests and natural enemies. However, the results of the systematic investigations carried out on the effect of transgenic *Bt* cotton on the population dynamics of non-target pests and natural enemies of pests in Hubei province of China in 2000–01 indicated that the population densities of non-target pests in transgenic *Bt* cotton fields were significantly higher as compared to non-*Bt* (Deng *et al*. 2003).

Bollworm complex

During 2003–04 the larval population of American bollworm (*Helicoverpa armigera* Hubner), pink bollworm (*Pectinophora gossypiella* Saunders) and spotted bollworm (*Earias insulana* Boisd.) remained significantly low in all the *Bt* treatments compared with the conventional cotton (non-*Bt*) at Nanded (Table 3). American bollworm female moths had shown no definite preference for *Bt* or conventional cotton for egg laying, however the number of eggs, in general, remained low in integrated pest management treatments (T_1, T_3, T_4, T_6) in 2004–05 (Table 4). The pair-wise comparisons indicated a significant reduction in the number of eggs in T_3 as compared to T_2, T_5, T_6 and T_7. The average American bollworm larval population at Nanded as well as at Dharwad remained significantly high in non-*Bt* treatments, i e conventional cotton (integrated pest management), followed by conventional cotton non-integrated pest management as compared to all *Bt* cotton treatments (1–5) (Tables 4, 5). Among different *Bt* treatments, treatment of entire area under IPM mode, i e treatments T_1 and T_4 indicated low American bollworm larval population as compared to treatments 2, 3 and 5. The larval population of pink bollworm and spotted bollworm at both the places also remained significantly low in *Bt* treatments (T_1 to T_5) as compared to non-*Bt* treatments (T_6 and T_7). Laboratory study had also confirmed that the transgenic *Bt* cotton was highly toxic to *Earias vittella*, causing 100% larval mortality (Abro *et al*. 2004).

Table 5 Population of sucking pests, bollworms, natural enemies in different treatments at Dharwad during 2004–05

Treatment	Sucking insect pests# (number/3 leaves)			Bollworms			Natural enemies/plant)	
	Jassids	Thrips	Aphids	ABW larvae/ plant	PBW larvae /10 bolls	Spotted bollworm/plant	LBB	GLW eggs
T_1	3.13^{c}	3.26^{c}	14.38^{c}	0.21^{cd}	0.43^{cd}	0.03^{c}	4.81^{c}	0.78^{c}
T_2	5.97^{a}	4.06^{abc}	18.32^{ab}	0.33^{c}	0.53^{c}	0.08^{c}	6.64^{b}	0.84^{c}
T_3	2.86^{c}	3.49^{bc}	16.16^{bc}	0.25^{cd}	0.43^{d}	0.11^{c}	3.68^{c}	0.92^{c}
T_4	3.60^{bc}	3.42^{c}	15.65^{bc}	0.16^{d}	0.42^{d}	0.06^{c}	8.45^{a}	1.50^{ab}
T_5	4.54^{ab}	4.34^{ab}	18.35^{ab}	0.33^{c}	0.53^{cd}	0.10^{c}	8.08^{ab}	1.57^{a}
T_6	3.23^{c}	4.27^{abc}	16.89^{c}	0.77^{b}	1.17^{b}	0.47^{b}	1.25^{d}	0.53^{c}
T_7	4.50^{ab}	5.24^{a}	20.66^{ab}	1.06^{a}	2.35^{a}	0.75^{a}	0.93^{d}	1.03^{bc}

#Whiteflies were in traces, therefore, not recorded

In a column means sharing any common letters are not significantly different at P=0.05 level of significance using Tukey's mean comparison test

ABW, American bollworm; PBW, pink bollworm; LBB, ladybird beetle; GLW, green lacewing

Table 6 Damage to fruiting bodies and seed cotton yield in different treatments at Nanded and Dharwad during 2004–05

Treatment	Nanded				Dharwad				
	Square damage (%)	Boll damage (%)	Shed fruiting bodies (%)	Seed cotton yield (kg/ha)	Boll damage (%)	Good open bolls /plant	Bad open bolls/plant	Locule damage (%)	Seed cotton yield (kg/ha)
T_1	0.82^{cd}	0.88^{c}	11.68^{cd}	$1\,156^{ab}$	2.07^{d}	39.20^{bc}	1.93^{b}	5.19^{c}	$1\,352^{bc}$
T_2	1.21^{c}	1.23^{c}	12.21^{cd}	$1\,025^{b}$	2.44^{cd}	39.70^{bc}	2.09^{b}	5.65^{c}	$1\,273^{d}$
T_3	0.64^{d}	0.80^{c}	8.64^{d}	$1\,186^{ab}$	2.00^{d}	36.93^{c}	2.21^{b}	6.93^{b}	$1\,335^{cd}$
T_4	0.71^{d}	0.83^{c}	11.27^{cd}	$1\,390^{a}$	1.89^{d}	52.84^{a}	1.14^{c}	3.14^{e}	$1\,4710^{a}$
T_5	1.15^{c}	1.28^{c}	13.53^{c}	$1\,146^{ab}$	2.80^{c}	43.65^{b}	2.03^{b}	4.09^{d}	$1\,430^{ab}$
T_6	5.60^{b}	4.27^{b}	36.31^{b}	$1\,029^{b}$	7.24^{b}	21.61^{d}	12.49^{a}	28.44^{a}	$1\,050^{e}$
T_7	12.39^{a}	9.51^{a}	46.01^{a}	551^{c}	12.23^{a}	17.50^{d}	12.25^{a}	28.87^{a}	990^{e}

In a column means sharing any common letters are not significantly different at P=0.05 level of significance using Tukey's mean comparison test

Bollworm damage of fruiting bodies

The percentage damage in squares, bolls and shed fruiting bodies at Nanded and Dharwad remained significantly high in conventional cotton both in integrated pest management as well as non-integrated pest management mode as compared to *Bt* treatments (T_1 to T_5) (Table 6). Within the conventional cotton the bollworm damage remained significantly low in integrated pest management (T_6) as compared to non-integrated pest management (T_7). Amongst *Bt* cotton treatments, *Bt* in integrated pest management mode (T_1, T_3, T_4) recorded significantly low boll damage as compared to *Bt* in non-integrated pest management mode (T_5). In conventional cotton also the integrated pest management interventions were able to reduce the boll damage due to better bollworm management as compared to non-integrated pest management in conventional cotton. The number of good open bolls was significantly high in all *Bt* treatments as compared to non-*Bt*; bad open bolls and locule damage reflected the reverse trend.

Natural enemies

The population of ladybird beetle remained highest in *Bt* with 5% refugia+15% pigeonpea (*Cajanus cajan* L. Millsp) + integrated pest management (T_5) having maximum crop diversity and lowest in conventional cotton non-integrated pest management (T_{13}) in 2003–04. *Chrysoperla* egg population was highest in conventional cotton integrated pest management (T_{12}) and remained lowest in conventional cotton non-integrated pest management (T_{13}) (Table 3). During 2004–05, the population of ladybird beetle at Nanded remained significantly high in all the treatments performed in integrated pest management mode (T_1, T_3, T_4, T_6), irrespective of *Bt* or conventional *Bt* (Table 4). No definite trend was observed at Dharwad with respect to *Bt* or conventional, however, the crop with maximum diversity (T_4) showed highest number of ladybird beetles (Table 5). Pilcher *et al*. (1997) and Zhang *et al*. (2004) also observed through laboratory studies that *Bt* had no detrimental effect on abundance and movement of the predators with similar development survival rates and reproductive ability as on the control. Thus, *Bt* cotton did not negatively influence ladybird beetle and green lacewing, and rather conserved it in integrated pest management mode.

Yield

The yield data at Nanded during 2003–04 indicated higher seed cotton yield in all the *Bt* treatments (T_1 to T_{10}) as compared to non-*Bt* (T_{11}–T_{13}) (Table 3). Similar trend of higher seed cotton yield in the *Bt* treatments (T_1 to T_5) as compared to non-*Bt* (T_6–T_7) was also observed during 2004–05 trials conducted at both the locations (Table 6). Qaim and Ziberman (2003), based on one year's trial in India, also claimed that genetically modified crops increased yield due to the inserted gene. A significant positive impact of *Bt* on average yields of cotton had earlier been reported in Maharashtra (Bambawale *et al*. 2004, Bennett *et al*. 2004) and Andhra Pradesh (Reddy *et al*. 2005). Transgenic technology modified many characteristics, such as resistance to insects (Pray *et al*. 2002, James 2001) or diseases (Ferreira *et al*. 2002) and modification in plant nutrition (Potrykus 2001). Among these factors only resistance to insects and diseases is the contributing factor for preventing loss in yield. Increase in yield for *Bt* cotton in a developed country, such as USA and developing country like China was reported to be 10–15% (Jenkins and Saha 2001, Zhang and Feng 2000).

Thus, from the above study it is evident that *Bt* cotton treatments proved to be superior in managing the 3 bollworms and the damage caused by them to the fruiting bodies. Twenty per cent refugia either in integrated pest management or non-integrated pest management modes appeared to lower the overall yield of *Bt* cotton in a unit area of chosen plot size. Integrated pest management in refugia did not help in improving the yields as well as population of natural enemies. *Bt* cotton in integrated pest management mode without any refugia has shown significantly higher yields compared to all other treatments, including conventional cotton, at both the locations in 2004–05 and has not adversely influenced the natural enemies such as ladybird beetle and *Chrysoperla*.

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