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Evaluation of Bt (*Bacillus thuringiensis*) and non-Bt cotton (*Gossypium hirsutum*) hybrids under varied planting time

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ABSTRACT

A field trial was carried out under irrigated situation during the fall seasons i.e. between August and February of 2003-04 and 2004-05 at Coimbatore to evaluate the performance and suitability of popular Bt and non-Bt hybrids (MECH 162 Bt and MECH 162 non Bt) on both optimum and delayed planting conditions under four dates of sowing (15 August, 1 and 15 September, and 1, October). Timely planting of Bt hybrid on 15 August produced significantly higher seed cotton yield (2.05 t/ha) and associated traits. The result revealed that seed cotton yields were similar under Bt (MECH 162 Bt) when sown either on 1 or 15 September and that of non-Bt (MECH 162 non Bt) sown on 15 August. The study also suggested that Bt cotton hybrid could be staggered planted from 15 August to 15 September without significant reduction in yield. Higher yield of 'MECH 162 Bt' was also apparent under late planting condition (1 October) over its isogenic non-Bt as the former recorded significantly (42.5%) higher yield (1.47 t/ha) over the latter (1.04 t/ha). Bt cotton matured early in the season (with higher Bartlett's index) and retained higher number of bolls, which resulted in increased sink strength and seed cotton yield. However, elevated performance in fibre yields due to sowing time differences or Bt gene *per se* (MECH 162 Bt *versus* its non-Bt) could hardly influence the more resilient quality traits except 2.5% span length. Highest net return (₹35,550/ha) and benefit cost ratio (BCR, 1.63) were also calculated with 15 August planting with the Bt hybrid. Even under late sown condition economic advantage of Bt hybrid was evident from increased net return (11.6%) and BCR (37%). Irrespective of dates of sowing, incorporation of Bt gene onto non-Bt hybrid increased gross return, net return and BCR by 15.6, 36.4 and 144.3% respectively. A Regression equation involving yield (Y), maximum air temperature (T_{max}), rainfall (RF) and RH *(Y=117.4+0.06359 T_{max} (0-45 DAS) - 0.04716 RH 07 22 (46-90 DAS) - 0.03115 RF(1-2 weeks)* was validated for yield prediction using chi-square test.

Key words **:** Bt hybrid, Non-Bt hybrid, Sowing time

The Bt gene incorporation in cotton and its commercialization has revolutionized the crop scenario around the globe. The area planted with Bt cotton hybrids has reached to 15 m ha globally during 2007-08, equivalent to 43% of global total cotton area of 35 mha (AICCIP, 2009). Indian Bt cotton also continues to grow beyond 6.9 m ha occupying 73.6% of total cotton area upto 2008-09. Introduction of Bt cotton hybrids targeting at cotton bollworms substantially brought down the cost of cultivation and has been a boon as the technology is eco-friendly and acceptable to farmers. Concomitant with the steep increase in adoption of Bt cotton hybrids between 2002 and 2007, its average lint yield has increased from 308 kg/ha to 560 kg/ha in India (AICCIP, 2009). Further improvement in yield is possible through exploitation of agronomic advantages associated with Bt cotton hybrids, *viz.,* non-monetary inputs like planting window (Praharaj *et al.,* 2009).

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Variable sowing time is mostly dependant upon climate, species specificity and agro-climate (rainfed vs. irrigated). Cotton plant unlike that of rice and wheat possesses narrow range of ecological adaptability and is influenced by the climatic conditions and sowing seasons (Bradow and Davidonis, 2000). Optimum sowing time provides favourable situation for adequate crop growth as it escort to realization of productivity potential of crop (Praharaj *et al* .2009). Besides, inbuilt resistance to bollworm complex in Bt hybrid leads to retention of early formed fruiting parts that might be pronounced with at least 20 to 30 days in earliness (Mayee and Rao, 2002). Thus, higher Bartlett's earliness index (0.80) was observed with Bt hybrids over conventional hybrids 0.67 (Deosarkar *et al.,* 2004). Apart of these, early maturing varieties could play a pivotal role in compensation of yield losses especially under delayed sowing condition (Bange *et al.* 2004) a common feature in cotton**.** Earliness associated with Bt

can be exploited for suitability under late sowing condition. Thus, a field trial was carried out during a winter irrigated cotton under South Zone to study the performance of Bt cotton hybrid under varied planting time as an additional facet for realization of higher yield and quality in cotton fibre.

MATERIALS AND METHODS

A field trial was conducted under irrigated condition at Regional station of Central Institute for Cotton Research, Coimbatore, Tamil Nadu during winter (August to February) between 2003-04 and 2004-05. The soil was clay loam in texture, low in available N (154 kg/ha), medium in available P (17 kg/ha) and high in available K (779 kg/ha) with a pH 8.5 and EC 0.23 dS/m. Soil test on micronutrient showed 0.52, 1.4, 2.64, 2.40 and 0.07 ppm of DTPA-extractable zinc, copper, manganese, iron and boron (hot water extract) respectively. The treatments comprised of all the combination involving 4 sowing dates (15 August, 1 September, 15 September and 1 October) and two hybrids (MECH 162 Bt and MECH 162 non Bt) in a randomised block design with three replications. A basal dose of N_{45}-P_{20}-K_{37} kg/ha was applied to all the treatments followed by a top dressing of 45 kg N/ha at the earthing up at 45-50 DAS. The MECH 162 Bt and its isogenic non-Bt hybrid (MECH 162 non-Bt) were used as test hybrids and planted at 90 cm X 60 cm spacing. Other cultivation practices were adopted uniformly for all the treatments and population was maintained. For weed control, fluchloralin @1 kg/ha as pre-emergence was applied uniformly in all the plots followed by two hand weedings. Methyl demeton (metasystox) @ 500 ml/ha and monocrotophos (nuvacron) @ 1000 ml/ha were sprayed respectively between 2003-04 and 2004-05 to contain the menace of sucking pest problem. Based on economic threshold level (ETL) (10% of fruiting damage) one spray of Endosulfan (thiodan) @ 2000 ml/ha was done from 2003 to 2004 and Quinalphos (Ekalux) @ 1500 ml/ha during 2004-05 to control boll worm complex associated with the non Bt hybrid. Indoxicarp (avaunt) @ 500 ml/ha was sprayed for control of bollworms in both Bt (as first spray) and non-Bt (as second spray) since ETL was crossed during 2004-05. In all, two pickings were carried out during the season. The crop completed its life-cycle in 6 months.

Growth attributes, yield parameters and seed cotton yield were recorded during the course of investigation. Crop reached mean maturity at 157 and 168 days after planting for Bt and non-Bt respectively. Fibre quality parameters, *viz.,* ginning percentage, seed index, lint index, 2.5% span length, maturity ratio, uniformity ratio, micronaire, fibre strength and fibre elongation were also analyzed. Fibre quality index (FQI= LT/ÖM, where L, 2.5% span length (mm), T, fibre bundle tenacity at 3.2 mm gauge (g/tex) and M, micronaire), count (C=0.196 FQI – 16) and count strength product (CSP=1.740 FQI + 1600) were also worked out. The quality parameters (except GP) were analyzed by using high volume instruments (HVI, Statex- Fibrotex model). Growing Degree Days (GDD) as an arithmetic accumulation of daily mean temperature above threshold temperature was also computed using the base temperature as 15.5^0C. Relative Temperature Disparity (RTD) is calculated as the % difference in $Temp_{max}$ & $Temp_{min}$ over $Temp_{max}$. Similarly, the differences in relative humidities between the morning and evening values were considered for calculating the relative humidity disparity (RHD) for the cropping period. Pooled analysis was made from two years data after the second year to assess the overall effect of the variables on Bt and non Bt hybrid on different plant attributes related to growth, yield, quality, BCR and other indices. Since year X treatments were not significant, hence only the treatment effects were given.

RESULTS AND DISCUSSION

Growth characters

Biometric observation recorded at 90 and 120 DAS revealed that leaf area index (LAI), dry matter production (DMP), seed cotton yield and burst boll were influenced significantly by planting of winter irrigated cotton hybrids at diverse planting dates (Table 1). However, highest LAI and dry weight were recorded with MECH 162 non-Bt planted on 15 August, yet significantly higher number of bolls/plant were counted in MECH 162 Bt sown on 15 August. This was due to prevalence of congenial weather conditions resulting in increased plant growth, greater vegetative and reproductive branches under early planted condition. Earlier studies also showed that accumulated total solar radiation decreased as the sowing was delayed from 15 August leading to progressive drop in the growth characters and DMP in cotton crop (Gopalswamy *et al.,* 1988).

The interaction of Bt hybrid sown on 15 August resulted in highest burst bolls (27.9). Thus, less vegetative growth in Bt might have resulted due to utilization of more photosynthates for the nourishments of higher number of bolls (increased sink strength) that were escaped from being damaged due to production of Bt toxin (Mayee and Rao, 2002). Conversely, retaining of early formed bolls, by preventing the bollworm attack as a result of inbuilt protection, had suppressed the vegetative growth parameters like leaf area index and dry weight but increased the reproductive parts like bolls and yield per plant in Bt cotton. On the contrary, conventional non-Bt hybrid, due to absence of Bt gene, was susceptible to boll worm attack

frequently and lost the early formed square and bolls and produced more vegetative growth at initial stages.

Planting of MECH 162 Bt hybrid even under late sowing condition registered significantly higher number of bolls/plant resulting in 93 and 61% increases over non Bt. Similar results on other yield attributes were also evident. MECH 162 Bt planted on 1 October also produced 61.2 and 67.2% higher single plant yield and burst bolls per plant respectively as compared to non Bt. Inbuilt resistance to boll worms and early maturing character observed in case of Bt hybrid helped to retain more number of bolls and higher yield attributes by avoiding its exposure to unfavorable weather period during peak period of growth that may commence probably during later stages.

Non-Bt hybrids recorded 40% higher LAI and increased plant heights, without corresponding increase in yield over Bt hybrids under rainfed condition at Coimbatore (Sankaranarayanan *et al.* 2008). Bt hybrids plants were shorter by 7% with 10.8% reduced LAI over those in non-Bt hybrids (Rekha, 2007). Apparently change in morphoframe of the plants following incorporation of Bt gene resulted in dwarf plants with less vegetative growth and more reproductive parts amenable to good early boll setting could be the reason for productivity increases in these crops. Moreover, individual or combined effect of transgene X genetic X environment interaction or utilization of more photosynthates for the nourishments of higher number of bolls observed in Bt suppressing vegetative growth and favouring reproductive growth could be the key physiological phenomenon in Bt cotton for increased efficiency.

Growth analysis

Crop growth parameters showed upward trend in case of crop growth rate (CGR) whereas relative growth rate (RGR) and net assimilation rate (NAR) showed the reverse trend. Similar to crop growth attributes, 15 August planting of MECH 162 Bt hybrid showed the highest NAR of 0.78 and 0.5 mg/cm^2/day. Similar was the case for higher CGR (2.6 and 4.8 g/m^2/day for 45-90 DAS and 91-120 DAS respectively) observed under the said optimum planting time. Least CGR of 1.8 and 2.0 g/m^2/day respectively observed during the crop growth period of 45-90 DAS and 91-120 DAS with the late planting on 1 October. Higher performance of analyzed growth characters observed under 15 August might be due to favourable climatic parameters prevailed during the growth period of crop. Growth analysis trend observed between Bt *vis-à-vis* non-Bt revealed that Bt hybrids recorded lesser CGR of 8.9 and 10.6% and RGR of 2.6 and 1.8% during 45-90 and 91-120 DAS respectively over non Bt hybrid.

Seed cotton yield

The seed cotton yield was varied significantly following planting of hybrids on diverse planting time as highest yield of 2.05 t/ha was recorded with the Bt hybrid 'MECH 162' when planted on 15 August (Table 2). Bt hybrids trials conducted during *rabi* season under AICCIP also revealed that timely planting of Bt cotton recorded 1.69 t/ha when compared with delayed one (1.39 t/ha) at Surat (AICCIP, 2009) as delayed sowing normally reduce yield through shortening life-cycle of the crop due to unfavorable environmental factors at reproductive stage. Pettigrew (2002) also observed that the early planted cotton yielded 10% more lint than that produced by the late planted cotton.

Despite the fact that the yields were decreased following staggered planting schedules from 15 August to 15 September, yet these were at par only in Bt due to greater resilience of the Bt hybrid towards change in environmental parameters. Contrarily, there was decline in yields in non-Bt following the above planting schedule with the highest one (1.93 t/ha) obtained with the optimum schedule (15 August) only. Thus, it was evident that Bt cotton hybrid could be planted staggered in the growing season (15 August to 15 September) without significant yield reduction.

Coincidently, timely planting (15 August) could also enable in realization of similar yields both in case of Bt and non-Bt, (Table 2). This could be seen as advantageous even for non-Bt when sown in optimum time. Yet, with known advantages, Bt effects could prove its upper edge both under timely and delayed planting condition, warranted by many factors since agronomic performance of transgenic cultivars may vary substantially compared with the non transgenic cultivars or germplasm lines from which they were originally developed. Moreover, comparison made between the performance of Bt hybrids versus non Bt hybrids at Nanded (Maharashtra) revealed that on an average 48.5% higher seed cotton yield was realized with Bt over non-Bt (Deosarkar, 2004).

Besides normal planting, Bt cotton maintained its superiority as significantly higher yield (1.47 t/ha) was obtained under very late planting condition (1 October) as compared to non-Bt (1.04 t/ha). Evidently, higher Barlett's index (0.79) was observed in Bt when compared with non-Bt (0.61) under very late sowing situation (Table 2) due to protection of early formed bolls and earliness associated with the former. Similar observations were also recorded elsewhere, where Bt cotton hybrids recorded higher yield under delayed sowing in comparison to non Bt hybrids (AICCIP, 2009).

Table 1. Effect of Planting time and hybrids on plant growth characters at 90 and 120 DAS (Mean of two years)

Treatment	Leaf Area Index						Bolls/plant						Dry weight (kg/ha)					
	90 DAS			120 DAS			90 DAS			120 DAS			90 DAS			120 DAS		
	Bt	Non-Bt	Mean	Bt	Non-Bt	Mean	Bt	Non-Bt	Mean	Bt	Non-Bt	Mean	Bt	Non-Bt	Mean	Bt	Non-Bt	Mean
Planting time																		
15 August	1.54	1.70	1.62	1.82	2.50	2.18	16.5	14.1	15.3	22.1	19.7	20.6	1214	1239	1227	2575	2737	2656
1 September	1.40	1.42	1.41	1.77	2.40	2.10	9.7	7.3	8.5	18.5	16.1	17.3	982	1042	1012	2101	2269	2185
15 September	1.30	1.50	1.40	1.62	2.30	1.94	9.1	7.5	8.3	16.3	12.1	14.2	964	1176	1070	2045	2481	2263
1 October	0.96	1.08	1.02	0.99	1.30	1.15	8.7	4.5	6.6	14.3	8.9	11.6	828	856	842	1367	1519	1443
Mean	1.30	1.43	-	1.55	2.14	-	11	8.35	-	17.8	13.9	-	997	1079	-	2022	2251	-
Variables	H	T	HxT	H	T	HxT	H	T	HxT	H	T	H x T	H	T	HxT	H	T	HxT
SEm±	0.07	0.07	0.14	0.07	0.14	0.21	0.85	1.27	1.41	0.99	1.49	1.70	77.8	109	134	73	102	132
CD (P=0.05)	NS	0.2	0.4	0.2	0.3	0.5	2.4	3.6	4.0	2.9	4.7	4.9	NS	316	NS	211	295	381

Mean of 2 years

Table 2. Effect of Planting time and hybrids on yield attributes, seed cotton yield and fibre quality (Mean of two years)

Treatment	Boll weight (g)			Seed cotton Yield (t/ha)			Bartlett's Index			2.5% Span Length (mm)			Fibre quality Index		
	Bt	Non-Bt	Mean	Bt	Non-Bt	Mean	Bt	Non-Bt	Mean	Bt	Non-Bt	Mean	Bt	Non-Bt	Mean
Planting time															
15 August	4.50	3.90	4.20	2.05	1.93	1.99	0.65	0.57	0.61	26.4	25.8	26.1	258	257	257
1 September	4.40	3.80	4.10	1.99	1.61	1.80	0.54	0.50	0.52	26.5	26.1	26.3	258	275	266
15 September	4.40	4.20	4.30	1.91	1.85	1.88	0.82	0.76	0.79	25.2	25.6	25.4	255	271	263
1 October	4.30	3.60	3.95	1.47	1.04	1.26	0.79	0.61	0.70	25.5	23.9	24.7	250	233	242
Mean	4.40	3.90	4.15	1.86	1.61	1.73	0.70	0.60	0.65	25.9	25.6		255	262	
Variables	H	T	HxT	H	T	HxT	H	T	HxT	H	T	HxT	H	T	HxT
SEm±	0.07	0.14	0.21	0.04	0.06	0.07	-	-	-	0.21	0.28	0.35	5.16	7.64	11.39
CD (P=0.05)	0.3	NS	NS	0.11	0.16	0.18	-	-	-	NS	0.8	1.1	NS	22	32.7

Quality characters

Increase in productivity alone could not benefit the cotton growers as quality of cotton fibre is the primary concern for fetching higher price. Lint samples analyzed by HVI mode to assess on quality characters revealed that except a few deviations these were little influenced by the hybrids or planting time (Table 2). Least 2.5% span length (23.9 mm) was measured following late planting on 1 October under non-Bt hybrid only resulting in lesser fibre quality index (233), spinable count (30) and count strength product (2005). It was mainly attributed to the prevalence of unfavorable weather condition providing unsuitable conditions for the development of fibres. Similar non significant influences were also observed between Bt versus non-Bt (Sankaranarayanan *et al*. 2008). Ethridge and Hequet, (2000) could not find differences in micronaire, uniformity ratio, strength and elongation measured in HVI as a result of transgenic technology.

Influence of climate

As compared to 30% yield loss recorded in food crops viz., cereals, oilseeds and pulses, cotton could suffer from 60% of the yield loss due to unfavorable climate alone (Dason, 1996). Significant positive correlations for seed cotton yield in Bt was observed (Table 3) with respect to $temp_{max}$ during sowing to 45 DAS, morning RH during 46-90 DAS and GDD during 0-45 DAS; and negative correlation both to rainfall and rainy days during first 2 weeks.

Amongst the planting time, sum of $temp_{max}$ of 1507°C and GDD of 550 during 0-45 DAS were highest under 15 August while these were lowest (1408°C and 505) during 0-45 DAS (along with morning RH of 3995 during 46-90 DAS) under 1 October. Cotton being a heat loving crop, higher $temp_{max}$ and GDD prevailed during 15 August positively influenced growth and yield as early growth in cotton up to 5 expanded leaf stage is mostly temperature controlled. Although 1 October planted crop received maximum rainfall (124.1 mm) and rainy days (7.5) during initial two weeks, these however, negatively influenced the seed cotton yield. Continuous rains after planting also affect germination by poor soil aeration and low temperature leading to poor crop growth and yield.

A Regression equation involving yield (Y), maximum air temperature (T_{max}), rainfall (RF) and RH (Y=117.4+0.06359 T_{max} (0-45 DAS) - 0.04716 RH 07 22 (46-90 DAS) - 0.03115 RF(1-2 weeks) was validated for yield prediction using chi-square test.

Economics

Increases in net return (12.3%) and BCR (8.2%) were calculated with 15 August planting of Bt hybrid in com-

Table 3. Effect of Planting time and hybrids on net return, BCR and agro-meteorological parameters.

Treatments	Net Return (₹'000/ha)			BCR			$Temp_{Max}$ (0-45 DAS)	GDD (0-45 DAS)	RH 0722 (46-90)	Rainfall (mm) (first 2 wks)	Rainy days (first 2 wks)	Yield of Bt hybrid (t/ha)	Estimated yield by model(t/ha)
	Bt	Non-Bt	Mean	Bt	Non-Bt	Mean							
Planting time													
15 August	35.6	31.2	33.4	1.63	1.36	1.50	1507	550	4085	5.3	1	2.05	2.05
1 September	33.9	22.2	28.1	1.55	0.97	1.26	1501	548	4093	0.5	0.5	1.99	1.99
15 September	31.7	28.8	30.2	1.45	1.26	1.36	1464	533	4051	15.0	1.5	1.91	1.91
1 October	19.5	6.13	12.8	0.89	0.27	0.58	1408	505	3995	124.1	7.5	1.48	1.47
Mean	30.1	22.1	-	1.38	0.97		1470	534	4056	36.225	2.625	1.86	1.86
r value							0.97	0.98	0.96	-0.98	-0.98		
T_{cal}							6.16*	7.42*	5.11*	8.52*	7.68*		1.0**
T_{tab} at 5%							4.30	4.30	4.30	4.30	4.30		7.81***
T_{tab} at 1%							9.93	9.93	9.93	9.93	9.93		

Cost of cultivation of Bt (₹21,845/ha) and non Bt ₹22,850

* Significant at 5 % level, ** Calculated chi square value, *** Tabulated chi square value

parison to sowing of corresponding non-Bt hybrid (Table 3). Even under late sown condition (1 October), Bt hybrid produced higher net return (11.6%) and BCR (37%) in comparison to non-Bt hybrid. As manual picking charges are contributing 40 to 50% of cost of cultivation, least cost of cultivation was calculated with non Bt hybrid under late sowing (1 October) due to less picking charges associated with less seed cotton yield.

It is concluded that Bt cotton hybrid could be staggered planted from early to later dates without significant yield reduction. Higher performance of Bt hybrid was conspicuous even under late planting condition over non-Bt.

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