Archives of Agronomy and Soil Science

ISSN: 0365-0340 (Print) 1476-3567 (Online) Journal homepage: http://www.tandfonline.com/loi/gags20

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To cite this article: K. Sankaranarayanan & P. Nalayini (2015) Performance and behaviour of Bt cotton hybrids under sub-optimal rainfall situation, Archives of Agronomy and Soil Science, 61:8, 1179-1197, DOI: 10.1080/03650340.2014.986112

To link to this article: http://dx.doi.org/10.1080/03650340.2014.986112

Accepted author version posted online: 14 Nov 2014.
Published online: 06 Dec 2014.

Archives of Agronomy and Soil Science, 2015
Vol. 61, No. 8, 1179–1197, http://dx.doi.org/10.1080/03650340.2014.986112

Performance and behaviour of Bt cotton hybrids under sub-optimal rainfall situation

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(*Received 16 April 2014; accepted 20 October 2014*)

Growth behaviour and yield performance of Bt cotton hybrids under sub-optimal rainfall situation is of practical significance, because more than 60% of the cotton area is under rainfed condition in India. A field trial conducted in a sandy clay loam soil during the seasons 2006–2007, 2007–2008, and 2008–2009 to study the growth behaviour and yield performance under scanty rainfall situation revealed that growth in both Bt and non-Bt cotton hybrids significantly differed under these parameters. The crop experienced moisture stress at the early stages of growth and again during boll development phase in 2006–2007 and 2008–2009. However, Bt hybrids (1691 kg ha^{-1}) produced higher seed cotton yield than non-Bt hybrids (1092 kg ha^{-1}), while the controlled variety (LRA 5166) performed the average of these two (1399 kg ha^{-1}). Similar trend was evident in respect of bolls per plant (at 90 DAP) and the final harvested bolls in both Bt and non-Bt cotton. Because of Bt gene, the early formed bolls were protected from the boll worms which led to less damage and higher yield with Bt hybrids. Amongst the hybrids, RCHB 708 Bt (1917 kg ha^{-1}) performed better over the others.

Keywords: Bt cotton hybrids; sub-optimal rainfall; seed cotton yield

Introduction

Cotton production and the expression of transgene are directly and indirectly influenced by soil characteristics, rainfall, severity of pest and disease, and management (Dong & Li 2007). The variation in the yield of cotton is estimated to be generally 60% which is simply brought out by the influence of weather parameters, whereas it is around 30% in other field crops. Rainfall is the foremost important element for cotton cultivation especially under rainfed condition. Cotton is grown mostly under rainfed condition in India (60%) and the productivity of cotton is low due to uncertainties associated with the variation in both quantity/intensity and distribution of rainfall. Before the Bt cotton era, the excessive and indiscriminate use of pesticides had caused insecticide resistance in major pests (such as bollworms) and the emergence of secondary pests in epidemic form making the cotton production risk prone compared to other crops (Kranthi et al. 2002). The cotton growing area in India declined because of the frequent bollworm infestation and outbreaks, i.e. from an average of 8.7 Mio ha in 2001 to a meagre 7.8 Mio ha in 2002 and 2003 (Kranthi 2012). In Bt cotton with inbuilt resistance of bollworm due to the Bt gene characteristic, the early formed bolls are protected and kept intact in the plant. Thus, Bt cotton is gaining popularity with farmers due to effective control of bollworm complex besides higher productivity (Fitt et al. 1994; Flint et al. 1995; Harries et al. 1996) and this

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resulted in an expansion of acreage under Bt cotton in India from 38,000 ha in 2002 to 10.8 Mio ha in 2012 (Clive 2012). Over the last ten years, the world scenario has also shown a similar trend; the area under the transgenic crops increased by 1.7 Mio ha in 1996 to 170.3 Mio ha in 2010 grown by over 17.3 Mio farmers (Clive 2012). Before the Bt era in India, 45%, 30%, 24.7%, and 0.3% of the total cotton area was covered by hybrids, upland cotton, diploid species, and G*ossypium barbadense*, respectively (Singh & Kairon 2000). LRA-5166, a straight non-Bt variety, was grown in larger parts of the area of the rainfed region of Maharashtra, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu. Presently, Bt hybrid adoption has spread widely across the rainfed, semi-irrigated, and irrigated areas and has reached more than 93% of the total area of cotton produce in 2012. However, there are divergent views with respect to the suitability of Bt hybrids for the rainfed regions. Dong and Li (2007) reported that maintaining the general health of Bt plant is essential for realizing the transgenic potential. Most of the Bt hybrids require long growth duration, input-intensive nature, high moisture, nutrient contents, and improved management practices.

The dry land areas are characterized by irregular nature and erratic distribution of rainfall which may not be adequate in certain years for a normal crop production and thus, limit the optimum performance of crops. Even in assured rainfall regions, irregular and erratic distribution is not uncommon. Keeping the abovementioned facts in view, the performance of Bt hybrids under rainfed condition – especially in low rainfall regions – requires a location-specific study under sub-optimal rainfall situation. The selected place (Coimbatore, Tamil Nadu, India) for this study is known for receiving sub-optimum rainfall (438 mm, average of 70 years) in the cotton season (August–February) (Veeraputhiran 2003). The study was conducted with an objective to assess the growth behaviour and production performance of Bt hybrids (RCH 2 Bt, RCH 20 Bt, RCHB 708 Bt) in comparison to isogenic lines and existing non-Bt variety (LRA 5166) suitable for rainfed region.

Materials and methods

Design

Three Bt transgenic cotton hybrids RCH 2 Bt and RCH 20 Bt 'intra *G. hirsutum* hybrids', RCHB 708 Bt 'F1 hybrid between *G. hirsutum* x *G. barbadense*' along with their non-Bt counterparts and a non-Bt straight cotton variety (LRA 5166) as a control were taken in a replicated field trial in randomized block design with three replications during the winter rainfed season (August–February) of 2006–2007, 2007–2008, and 2008–2009 at the Central Institute for Cotton Research Regional Station, Coimbatore. The treatments were imposed at gross plot size of 54 m^2; the net plot size was 36 m^2. Planting was done on 9 September 2006, 25 August 2007, and 27 August 2008, respectively, for the seasons 2006–2007, 2007–2008, and 2008–2009. The recommended plant density of hybrids (2.2 plant m^{-2}) was followed for Bt and non-Bt hybrids (RCH 2, RCH20, RCHB 708) and recommended plant density of 4.4 plant m^{-2} was followed for the variety LRA 5166. The average annual rainfall (1961–1990) at the site was 670.6 mm with coefficient variation of 33%, classified under the scanty rainfall zone. The mean seasonal rainfall (70 years average) was 128.2 mm (19.1%) in summer, 16.9 mm (2.5%) in winter; and southwest monsoon contributes 185.8 mm (27.7%) while northeast monsoon contributes 339.7 mm (49%) of rainfall. the total rainfall of 446.4, 438.2, and 436.4 mm and effective rainfall of 253.6, 275.9, and 2670.2 mm were received during the cropping seasons of 2006–2007, 2007–2008, and 2008–2009, respectively.

The recommended spacing of hybrid and variety, respectively, of 75 × 60 cm and 75 × 30 cm was adopted for hybrids (Bt and non-Bt) and non-Bt straight variety (LRA 5166) by following the ridges and furrow method before the onset of the monsoon. A fertilizer dose of 45:19.6:37.3 and 30:13.0:24.9 kg ha^{-1} of N, P, and K were applied at sowing for hybrids (Bt and non-Bt) and variety (LRA 5166), respectively, while equal quantity of N was top dressed at 45 DAP after ensuring the sufficient soil moisture in the field.

Application of the recommended levels of pesticides was carried out as follows: in 2006–2007, methyl demeton at 30 DAP followed by endosulfan with methyl demeton at 50 days after planting (DAP). Subsequently, acetamiprid was sprayed at 62 DAP and tracer at 70 DAP in 2006–2007; in 2007–2008, methyl demeton and monocrotophos at 45 and 78 DAP, spinosad combined with acetamiprid at 105 DAP; in 2008–2009, profenophos at 60 DAP, quinalphos with acetamiprid at 78 DAP, spinosad combined with acetamiprid at 95 DAP. Chemicals meant for the sucking pests were used for both Bt and non-Bt genotypes. Boll worm pesticides were applied only for non-Bt genotypes.

Water balance

The consumptive water use (CU) has been calculated as per the following formula (Equation (1)):

$$CU = E_p \times K_c \times K_p \ (L) \tag{1}$$

where E_p is the mean pan evaporation (mm day^{-1}), K_c is the crop factor, K_p is the pan factor; the values of K_c varies with the crop duration viz., 0.45 for 0–25 days, 0.75 for 26–70 days, 1.15 for 71–120 days, and 0.70 for 121–150 days. Effective rainfall (ER) was calculated as per the methods proposed by Mishra and Ahmed (1987). The net water holding capacity of the 1 m depth soil was estimated as 100 mm (field capacity was 23.10%, permanent wilting point was 16.44%, and bulk density was 1.50 g cm^{-3}), the initial soil moisture content was estimated gravimetrically before planting, and the available soil moisture balance (ASMB) and effective rainfall were calculated by the following formula (Equations (2) and (3)):

$$ASMB_d = ASMB_{d-1} + RF_d - CU_d \tag{2}$$

$$\text{if } ASMB_d \le 100 \text{ then } ER_d = RF_d \text{ if } SMB_d > 100,\ ER_d = RF_d - (ASMB_d - 100), \tag{3}$$

where ASM_d is the available soil moisture balance of the day (mm), $ASMB_{d-1}$ is the available soil moisture balance one day before (mm), RF_d is the rainfall of the day (mm), and CU_d is the consumptive water use of the day (mm).

Plant analyses

Five plants were selected at random from the net area of each plot and tagged, and a biometric observation was made on these plants. The height of the plant was measured from the cotyledon node up to the tip of the last opened leaf. For leaf area index (LAI) estimation, the leaf length (L in cm) and maximum width (W in cm) of the third leaf from the top was measured. The total number of leaves (N in number) in each plant was counted. LAI was calculated using the following formula suggested by Ashley et al. (1963) (Equation (4)):

$$\mathrm{LAI} = \frac{L \times W \times N \times 0.775}{\text{Land area } (\mathrm{cm}^2) \text{ occupied by the plant}} \tag{4}$$

The crop dry matter was estimated at harvest by removing five plants from the sampling row, air dried, and then oven dried at 65°C for constant weight. From the dried moisture-free samples, the dry matter production was recorded and expressed in kg ha^{-1}. The total number of bolls per plant in the randomly selected five plants were recorded and expressed as number of bolls per plant. The kapas of fully opened bolls of the five randomly selected plants were weighed, and accordingly the average number of bursted bolls per plant, yield per plant, and boll weight were calculated. The seed cotton yield was recorded from the net plot and expressed in kg ha^{-1}. Kapas samples having 100 seed cotton from each plot were taken and weighed. The seed and the lint weight were recorded after ginning. The ginning percentage was calculated by employing the following formula (Equation (5)):

$$\text{Ginning percentage} = \frac{\text{Weight of lint (g)}}{\text{Weight of seed cotton (g)}} \tag{5}$$

The seed obtained from ginning of hundred seed cotton was weighed (g) and expressed as seed index. Likewise, the lint obtained from ginning of hundred seed cotton was weighed (g) and expressed as lint index. Fibre quality parameters viz., 2.5% span length, maturity ratio, uniformity ratio, micronaire, fibre strength, and fibre elongation were also analysed using high volume instruments (HVI, Fibrotex, Statex Engineering (P) Ltd, Gurichy, TN, India). In addition to that the fibre quality index (FQI = $L \times T/\sqrt{M}$), where L is the 2.5% span length (mm), fibre bundle tenacity at 3.2 mm gauge (T in g tex^{-1}), and micronaire value (M in µg inch^{-1}) were also worked out.

Plant analysis was done using the samples taken for dry matter production. The samples were dried and ground through a mill. The ground samples were analysed for nitrogen, phosphorus, and potassium contents and the uptake values were calculated. The nitrogen content was estimated by the micro-Kjeldahl method (Humphries 1956), phosphorous by colorimetric method (Jackson 1973) and potassium by flame photometer method (Jackson 1973), respectively, multiplied with dry matter production and expressed in kg ha^{-1}.

Soil analyses

Soil samples were collected before the experimental setup and after harvesting of the crop. The soil samples were shade dried and gently powdered with the help of wooden mallet to pass through a 2-mm sieve and analysed. The soil mechanical analysis was done using the Piper (1966) method, organic carbon was analysed using the Walkley and Black (1934) method, available nitrogen by the Subbiah and Asija (1956) method; the available phosphorus was estimated using the bicarbonate extraction method proposed by Olsen et al. (1954), and the available potassium using the ammonium acetate extractant method proposed by Stanford and English (1949).

The site exhibited texture that was sandy clay loam, had pH of 8.3, EC of 1.3 dS m^{-1}, was low in organic carbon (0.42%), low in available N (58.5 mg kg^{-1}) and available P (3.3 mg kg^{-1}), and high in available K (425.4 mg kg^{-1}).

Economics

The cost of cultivation includes variable cost and rent value of the land for the particular cropping periods. The variable cost includes expenditure on labour, bullock, machinery, seeds, manures, fertilizers, plant protection chemicals, irrigation charges, and interest on working capital. The prevailing market price of inputs was taken into account in calculating the cost of cultivation. The market price of kapas of the selected genotypes was the base for calculating gross returns. The indices were calculated using the following Equations (6–8):

$$\text{B.C ratio} = \frac{\text{Gross return } (\text{Rs ha}^{-1})}{\text{Cost of cultivation} (\text{Rs ha}^{-1})} \tag{6}$$

$$\text{Per day productivity} \left(\text{kg ha}^{-1}\right) = \frac{\text{Seed cotton yield } (\text{kg ha}^{-1})}{\text{Number of days on field occupied by the genotypes}} \tag{7}$$

$$\text{Per day profitability } \left(\text{Rs ha}^{-1}\right) = \frac{\text{Net Return} (\text{Rs ha}^{-1})}{\text{Number of days on field occupied by the genotypes}} \tag{8}$$

Statistics

The pooled data was subjected to ANOVA (Gomez & Gomez 1984) by using the factorial randomized block design concept to assess the interaction effect of Bt versus non-Bt, including their hybrids (RCH 2, RCH 20, RCHB 708). A simple randomized block design (RBD) concept was used to analyse the data of all seven genotypes tested in the experiment and compare the performance of Bt and non-Bt hybrids against the straight variety (LRA 5166).

Results and discussion

Consumptive use and effective rainfall

The total evaporation and rainfall recorded during the crop growth periods were 602, 620.4, and 627.2 mm and 446.4, 438.2, and 436.4 mm, respectively, for the seasons of 2006–2007, 2007–2008, and 2008–2009; the results did not extensively. Similar trend was also followed in consumptive use and effective rainfall, which were 338.6, 351.5, and 346.0 mm and 253.6, 275.9, and 270.2 mm, respectively, for the 2006–2007, 2007–2008, and 2008–2009 seasons (Table 1). The recorded effective rainfall of the season was less in comparison to the consumptive use with 25.1%, 21.5%, and 21.9% for the seasons of 2006–2007, 2007–2008, and 2008–2009, respectively; thus the trial data was found

Table 1. Evaporation (mm), consumptive use (mm), rainfall (mm), and effective rainfall (mm) of 2006–2007, 2007–2008, and 2008–2009 seasons.

	Evaporation (mm)				Consumptive use (mm)				Rainfall (mm)				Effective rainfall (mm)			
DAP	2006–2007	2007–2008	2008–2009	Mean	2006–2007	2007–2008	2008–2009	Mean	2006–2007	2007–2008	2008–2009	Mean	2006–2007	2007–2008	2008–2009	Mean
0–25	130.5	123.6	130.2	128.1	41.1	38.9	41.0	40.3	62.4	32.8	68.8	54.7	62.4	32.8	50.2	48.5
26–70	163.6	198.1	199.1	186.9	85.9	104.0	104.5	98.1	287.6	251.6	312.9	284.0	147.1	131.92	165.3	148.1
71–120	178.1	184.8	157.2	173.4	143.4	148.8	126.5	139.6	86.4	153.8	54.7	98.3	34.1	111.2	54.7	66.7
121–150	129.8	113.9	140.7	128.1	68.2	59.8	73.9	67.3	10.0	0.0	0.0	3.3	10.0	0.0	0.0	3.3
Total (0–150)	602	620.4	627.2	616.5	338.6	351.5	346.0	345.4	446.4	438.2	436.4	440.3	253.6	275.92	270.2	266.6

Note: DAP, days after planting.

useful for making a valid assessment. The consumptive water use of cotton varied with the length of the growing season, temperature, and sunshine hours. Sivanappan (2004) reported that the consumptive water use was 700–750 mm in north India. The recorded consumptive water uses (338.6–351.5 mm) of this trial were comparatively less. The cotton crop was sown in the month of April (peak summer); it continued to grow up till September in the northern states of India and was subjected to high evaporative demand, thereby resulting in high consumptive water use. The recommended growth seasons (August to January) in the trial region (Tamil Nadu, India) were falling under winter when the evaporative demand is less, resulting in less use of consumptive water. Higher performance was observed in the season of 2007–2008 in all entries including Bt and non-Bt hybrids and straight variety (LRA 5166) because of less moisture stress during the critical period (boll development) of plant growth. In the other experimental seasons (2006–2007 and 2008–2009), effective rainfall (34.1 mm in 2006–2007 and 54.7 mm in 2008–2009) received was less and the crop faced severe moisture stress during the boll development periods (71–120 DAP), affecting crop growth severely and finally reducing the yield. Blaise (2011) reported that apart from climatic reasons, soil moisture stress in critical periods of crop growth is a major factor responsible for low crop productivity. Sankaranarayanan et al. (2011a) reported that higher seasonal rainfall was positively correlated with better crop growth and realization of higher yield in Bt cotton. When sufficient moisture deficits occurred, the lint yield of dryland plants was reduced by 25%, primarily because of a 19% reduction in the number of bolls (Pettigrew 2004).

Growth attributes

Bt effect

The growth and development have a direct bearing on the reproductive efficiency and seed cotton yield. Growth characters observed at 90 DAP and at harvest revealed significant variation with respect to the number of bolls in Bt versus non-Bt, and Bt recorded a mean of 19.6 and 22.3 bolls per plant while it was only 12.3 and 16.5 bolls in non-Bt, respectively (Table 2). Numerically 18.5% higher number of squares was observed in Bt in comparison to non-Bt at 90 DAP. The damage caused to the fruiting bodies by insect pest was relatively low in Bt hybrids. This resulted in higher number of bolls with Bt hybrids (Singh et al. 2007). The other growth character e.g. LAI was higher with non-Bt in both stages (28.6% higher at 90 DAP and 32.3% higher at harvest) as compared to Bt. The non-Bt hybrids exhibited more vegetative growth and recorded significantly more number of functional leaves leading to higher LAI. The same trend was observed with respect to dry matter production and plant height with non-Bt hybrids, which registered 11.3% higher dry matter production and 5.9% and 8.8% higher plant height, respectively, at 90 DAP and at harvest. Sankaranarayanan et al. (2011b) recorded higher LAI and dry weight with MECH 162 non-Bt than MECH 162 Bt. The Bt hybrid plants were shorter by 7% with 10.8% reduced LAI over those of non-Bt hybrids (Rekha 2007). As the growth of cotton advanced towards the grand growth of boll development phases, the growth rate in terms of plant height was reduced in transgenic Bt cotton (Tayade & Dhoble 2012). Venugopalan et al. (2009) reported that the introduction of the Bt gene has altered the morphological, phenological, and physiological characteristics of these introgressed cultivars. Apparently change in morphoframe of the plants following incorporation of Bt gene resulted in dwarf plants with less vegetative growth. Mayee et al. (2004) reported that all the transgenic Bt cotton hybrids were short statured than their

Table 2. Plant growth characters at 90 DAP and at harvest of Bt and non-Bt hybrids (pooled means).

	90 DAP						At harvest							
	Plant height (cm)		LAI		No. of bolls		Plant height (cm)		LAI		No. of bolls		DMP (kg ha^{-1})	
Hybrids	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt
RCH2	71.4	74.5	1.6	2.0	19.9	10.5	87.5	90.9	1.7	2.7	21.6	13.3	3705	3938
RCH20	79.6	83.9	1.7	2.2	19.6	13.0	90.6	105.5	2.1	3.6	19.9	14.3	4320	4909
RCH708	81.3	87.6	3.0	3.8	19.2	13.3	102.9	109.5	3.2	3.9	25.3	17.9	4505	5102
Mean	77.43	82	2.1	2.7	19.6	12.3	93.7	102.0	2.3	3.4	22.3	16.5	4177	4650
LRA 5166		67.9		1.3		8.5		98.2		1.3		19.5		3979
	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%
Bt	3.8	NS	0.3	0.5	2.5	5.1	5.3	8.1	0.4	0.9	2.5	5.1	210	426
Bt x hybrids	6.6	NS	0.52	1.1	4.2	NS	7.6	NS	0.7	NS	3.9	7.9	363	NS
Genotypes	6.3	12.7	0.51	1.0	4.0	8.0	7.3	NS	0.6	1.2	3.6	7.3	336	682

Notes: LAI, leaf area index; DMP, dry matter production; SEd, standard error of difference; CD 5%, critical difference (=LSD, least significant difference).

non-Bt counterparts. The retention of the early formed bolls by the inbuilt protection of Bt gene in Bt hybrids favoured the utilization of more photosynthates for the nourishments of bolls which indirectly suppressed the vegetative growth in Bt hybrids. Conventional non-Bt hybrid, because of absence of Bt gene, was susceptible to frequent boll worm attacks thereby losing the early formed square and bolls; this produced more vegetative growth because of less competition for partitioning of photosynthate by reproductive growth.

Genotypes

Statistical analysis revealed that genotypes varied significantly with respect to growth attributes viz., plant height (90 DAP and at harvest), LAI (90 and at harvest), bolls (90 DAP and at harvest), and dry matter production (at harvest) due to genetic makeup. The straight variety (LRA 5166) had recorded the significantly least plant height (67.9 at 90 DAP and 98.2 cm at harvest) and LAI (1.3 at 90 DAP and 1.3 at harvest) (Table 2). Dong et al. (2007) reported that the cotton hybrid (H01) had higher LAI and leaf weight per plant, and was superior to parents (straight varieties). Amongst genotypes (both Bt and non Bt version of RCH2 'intra *G. hirsutum*', RCH20 'intra *G. hirsutum*', RCHB 708 'inter specific *G. hirsutum* x *G. barbadense*', and *G. hirsutum* variety 'LRA 5166') tested in the trial, the interspecific non-Bt hybrid (RCHB 708) recorded significantly higher plant height of 87.6 and 109.5 cm, leaf area index of 3.8 and 3.9, at 90 DAP and harvest respectively, and dry matter production of 5102 kg ha^{-1}. Similar findings were observed by CSM (2006). Heitholt (1995) found that okra leaf type (*G. barbadense*) cultivars yield more bolls and dry matter production (DMP). The increase in DMP might be attributed to improved foraging ability of RCHB 708 Bt with better assimilation capacity which helped the plants in increasing the plant height and larger number of branches that finally exhibited significant improvement in DMP as already reported by Moursi et al. (1976).

Yield attributes

Bt effect

Bt genotypes performed significantly higher pooled means per plant: seed cotton yield (77.7 g $plant^{-1}$), bursted bolls (20.9) compared to non-Bt: seed cotton yield (50.7 g $plant^{-1}$), and bursted bolls (12.3). The boll weight was slightly higher in Bt over that in non-Bt (Table 3). The yield attributes of mean Bt hybrids increased at a rate of 53.3%, 42.2%, and 8.6%, respectively, in yield, number of bursted bolls, and boll weight per plant in comparison to non-Bt hybrids. The increased seed cotton yield per plant in Bt hybrids might be attributed to better fruiting efficiency, efficient source sink relationship, balanced vegetative growth, early maturity, bigger boll size, and retention of higher number of bolls over their non-Bt counterpart.

Genotypes

Amongst the genotypes tested, significantly higher yield (89.0 g) and harvested bolls (27.2) per plant were recorded in RCHB 708 Bt, while the boll weight (4.18) was significantly higher in RCH 20 Bt. The interspecific hybrid (*G. hirsutum* x *G. barbadense*, RCHB 708 Bt) is known for vigorous vegetative and reproductive growth except boll weight in comparison to intra G. *hirsutum* hybrids (RCH2 and RCH20).

Table 3. Yield attributes (pooled means) and seed cotton yield as influenced by Bt and non-Bt hybrids.

	Yield (g per plant)		No. of bursted bolls per plant		Boll weight (g) per boll		Seed cotton yield (kg ha^{-1})							
							2006–2007		2007–2008		2008–2009		Mean	
Hybrids	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt
RCH2	65.0	42.0	17.2	11.9	3.8	3.6	1006	410	1893	1478	1287	889	1395	926
RCH20	79.0	47.0	18.3	11.3	4.4	4.0	1380	440	2408	1724	1494	838	1761	1001
RCH708	89.0	63.0	27.2	17.6	3.3	3.0	1380	980	2853	2228	1518	837	1917	1348
Mean	77.7	50.7	20.9	14.7	3.8	3.5	1255	610	2385	1810	1433	855	1691	1092
LRA 5166		45.0		14.2		3.0		1080		2180		937		1399
	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%
Bt	8	16.3	2.6	5.3	0.3	NS	88.0	196	143	319	47.1	105	168	342
Bt x hybrids	12.3	25.0	4.1	8.3	0.4	NS	150	335	252	562	83.0	185	242	492
Genotypes	10.4	20.9	3.7	7.4	0.5	0.8	140	320	234	511	80	168	222	447

Note: SEd, standard error of difference; CD 5%, critical difference (=LSD, least significant difference).

Seed cotton yield

Bt effect

The results revealed that Bt hybrids produced significantly higher seed cotton yield i.e. 1255, 2385, and 1433 kg ha^{-1}, respectively, in the seasons of 2006–2007, 2007–2008, and 2008–2009 as compared to non-Bt hybrid, which registered the seed cotton yield of 610, 1810, and 855 kg ha^{-1} (Table 3, Figure 1). Yield reductions observed were 51.4%, 24.1%, and 40.4% in non-Bt during the seasons 2006–2007, 2007–2008, and 2008–2009, respectively. The early boll setting and higher photosynthesis rate of Bt hybrids resulted in less physiological boll shedding and higher yield with Bt hybrids. The relation for the increase in yield with early boll setting was indicated in earlier studies (Qaim & Zilberman 2003). Bt cotton showed remarkable contribution to the doubling of cotton yield in rainfed condition. On average, Bt cotton hybrid increased the cotton yield from 400–500 to 800–1000 kg ha^{-1} (Mayee & Choudhary 2013). Ansingkar et al. (2005) found that Bt cotton hybrids recorded significantly higher yield over their non-Bt counter parts as well as the local checks. Similar findings were also reported by Nehra et al. (2004) and Srinivasalu et al. (2006). Ramasundaram et al. (2004) made a survey and reported that low pest infestation in Bt cotton resulted in its higher yield (1170 kg ha^{-1}) compared to the conventional hybrid (972 kg ha^{-1}). Performance of Bt hybrids versus non-Bt hybrids at Nanded (Maharashtra, India) revealed that on average 48.5% higher seed cotton yield was realized with Bt over non-Bt (Deosarkar et al. 2004). Thus, retaining the early formed bolls by preventing bollworm attack, the genetically transformed cotton helps in retaining a larger number of reproductive parts and consequently higher seed cotton yields in Bt genotypes. Conventional non-Bt hybrids were attacked frequently by bollworm complex and got rid of the early formed squares and bolls and thus, were low yielders. The results conveyed that the advantage of Bt cotton under low rainfall situation was more pronounced and varying (of course with genotypes).

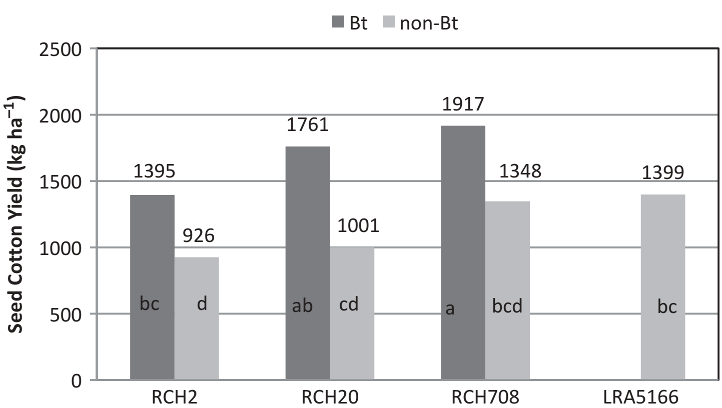

Figure 1. Mean seed cotton yield (kg ha^{-1}) of Bt and non-Bt hybrids and variety (CD (0.05) = 447 kg ha^{-1}). Means with the same letter in bars are not significantly different at the 5% probability level.

Genotypes

All the Bt hybrids included in the experiment yielded significantly higher over their non-Bt counterparts. The pooled results revealed that yield reductions to the extent of 50.6%, 75.9%, and 42.2% were observed in non-Bt hybrids of RCH 2, RCH 20, and RCHB 708, respectively, over the corresponding Bt versions of the same hybrids (Table 3, Figure 1). The varied performance of Bt cotton genotypes was also reported by Dong et al. (2006). They observed that the indigenous Bt hybrid (SCRC 15) showed better performance than the introduced Bt hybrid (33 B) and the indigenous Bt variety (SCRC 16). Amongst the genotypes, RCHB 708 Bt significantly produced higher seed cotton yield of 1380, 2853, and 1518 and 1917 kg ha^{-1}, respectively, in 2006–2007, 2007–2008, 2008–2009 seasons and pooled mean and because of its better suitability and adoptability to the region (*G. barbadense* zone). Dong et al. (2007) reported that the F1 Bt hybrid H01 (K0215 × K643) exhibited the greatest heterosis in yield and protein content, and lint yield were increased with an average of 12.2% and 9.0% as compared to the parents (K0215 and K643), respectively; and the yield advantage of hybrid cotton can be attributed to the improved source–sink relationship and flow of more photosynthate to the reproductive parts. The Bt hybrid (H*Bt*C) has been widely adopted by farmers in southern China, while Bt variety (*Bt*C) had been rejected due to its low yield potential (Dong et al. 2004). However, the hybrid RCHB 708 Bt showed less yield advantage (42.6%) over non-Bt counterpart amongst other Bt hybrids due to high reproductive growth habit of interspecific hybrid that helped to produce higher number of squares, flowers, and bolls which compensated the loss to some extent due to boll worms at early stages. The results further revealed that RCHB 708 Bt had been planted with 50% population (22,222 plant ha^{-1}) of the straight variety (LRA 5166) (44,444 plant ha^{-1}), but registered significantly higher seed cotton yield because of the fact that RCHB 708 Bt produced 10%, 91.2%, and 97.7% higher boll weight, bursted bolls, and single plant yield, respectively, than LRA 5166, thus finally resulting in enhanced performance. The conventional non-Bt variety (LRA 5166) registered less biometrics, yield attributes, and single plant yield. However, regarding seed cotton yield of the hybrids RCH 2Bt and RCH 20 Bt compared to LRA (1080, 2180, 937, and 1399 kg ha^{-1}, respectively, in 2006–2007, 2007–2008, 2008–2009 seasons and pooled mean), the higher population (two-fold times) (44,444 plant ha^{-1}) kept in LRA 5166 than Bt and non-Bt hybrids (22,222 plant ha^{-1}), had effectively compensated the less plant yield in LRA 5166. Amongst seasons, the higher performance of LRA 5166 observed in the 2007–2008 season might be due to less boll worm incidence; and the economic threshold level (ETL) reached only once but in the other seasons (2006–2007 and 2008–2009) the boll worm reached ETL twice during the cropping season.

Quality parameters

Bt effect

The increase in productivity alone could not benefit the cotton growers as the quality of cotton fibre is the primary concern for fetching higher price (Sreenivasan 2004). Cellulose synthesis in cotton fibre influences the fibre morphological and structural features, which in turn influences the physical, tensile, and mechanical parameters of fibres. Analysis of the fibre in the abovementioned trial showed that quality parameters viz., seed index, lint index, ginning percentage (GP), 2.5% span length, maturity ratio, uniformity ratio, micronaire, fibre elongation, and fibre quality index were no different in Bt versus

Table 4. Quality parameters as influenced by Bt and non-Bt hybrids (pooled means).

	Seed index		Lint index		GP (%)		2.5% span length (mm)		Micronaire (μg $inch^{-1}$)		Strength (g tex^{-1})		FQI	
Hybrids	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt
RCH2	9.8	9.5	5.8	5.7	37.1	37.3	30.2	29.4	4.3	3.9	22.6	22.2	330.0	332.0
RCH20	10.0	10.0	5.7	5.8	36.5	36.5	29.9	30.1	4.3	4.1	22.6	21.9	325.0	327.0
RCH708	11.5	12.0	5.6	5.8	32.8	32.5	34.7	34.4	3.8	3.7	23.5	25.8	417.0	463.0
Mean	10.4	10.5	5.7	5.8	35.5	35.4	31.6	31.3	4.1	3.9	22.9	23.3	357.3	374.0
LRA 5166		9.3		5.3		36.4		28.5		4.4		22.0		298.0
	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%
Bt	0.6	NS	0.5	NS	0.9	NS	0.4	NS	0.05	NS	0.5	NS	13.9	NS
Bt x hybrids	1.0	NS	0.8	NS	1.5	3.0	0.7	1.3	0.09	0.17	0.9	NS	21.6	43.8
Genotypes	0.9	1.8	0.7	NS	1.4	2.8	0.6	1.2	0.08	0.16	0.8	NS	18.2	36.6

Note: GP, ginning percentage; FQI, fibre quality index; SEd, standard error of difference; CD 5%, critical difference (=LSD, least significant difference).

non-Bt (Table 4). Yadav et al. (2012) reported no difference in micronaire, 2.5% span length, immature fibre content, neps and maturity ratio at final stage of fibre development. Similarly, Ethridge and Hequet (2000) could not find differences in micronaire, uniformity ratio, strength, and elongation measured in high volume instrument as a result of transgenic technology.

Genotypes

Amongst genotypes tested in the trial, RCHB 708 non-Bt registered significantly highest seed index (10.5 g), optimum micronaire (3.9), strength (23.3 g tex^{-1}), and fibre quality index (374) (Table 4); it was, however, at par with the corresponding isogenic lines (RCHB 708 Bt). Mayee et al. (2004) reported that the differences in fibre quality parameters amongst Bt hybrids were attributed to the existence of genotypic difference among the hybrids. Similar findings were also reported by Gurumurthy (1993). The genotype (RCHB 708 non-Bt) is an F1 hybrid between *G. hirsutum* x *G. barbadense,* and *G. barbadense* is known for its high-quality amongst cotton species. The exceptional fibre length, strength, and fineness of *G. barbadense* over the largely grown upland cotton of *G. hirsutum* was reported by Saha et al. (2004).

Soil nutrient status and nutrient uptake

The influence of Bt cotton hybrid cultivation on the soil pH, EC, available N, P and K status revealed that none of the tested genotypes significantly influenced the soil pH, EC, available N, P and K status of soil (Table 5). Hosmath et al. (2004) found that the organic carbon content, EC, and pH were not significantly influenced by Bt and non-Bt cotton. The seed cotton yield harvested from different hybrids was less than the potential one because of soil moisture limitation imposed upon by low rainfall situation. This might have not created an imbalance in the nutrient status of soil majorly. The available soil nutrients and the application of the total recommended level of NPK (90:19.6:37.3 kg ha^{-1}) were sufficient for the Bt hybrids under low rainfall situation. Amongst the genotypes tested, the highest N uptake (142.0 kg ha^{-1}) was estimated with RCHB 708 non-Bt. The conducive climate for *G. barbadense* cotton of the zone favoured the higher growth of ELS hybrids (RCHB 708 non-Bt), because of the absence of Bt gene in non-Bt version of RCHB 708 resulting in higher vegetative growth and dry matter thereby resulting in higher N uptake.

Economic analysis

The economic analysis revealed that the Bt hybrid incurred higher mean cost of cultivation (Rs 16,582 ha^{-1}), gross return (Rs 46,870 ha^{-1}), net return (Rs 28,818 ha^{-1}), benefit cost ratio (2.6), per day productivity (11.1 kg day^{-1}), and per day profitability (Rs 190 day^{-1}) (Table 6). Bt hybrids increased the mean cost of cultivation, gross return, net return, benefit cost, ratio per day productivity, and per day profitability to the extent of 8.9%, 53.9%, 107.6%, 44.4%, 65.7%, and 120.9%, respectively, over non-Bt hybrid. The higher yield realized in Bt hybrids caused higher picking cost but also higher economic return. Conversely, Bt hybrids were effective in controlling the boll worms, thereby reducing the plant protection cost. But the cost advantage related to less plant protection in Bt hybrids was offset by higher picking cost ultimately leading to higher cost of cultivation with Bt. Dong et al. (2004) observed that reduced pesticide application and

Table 5. Nutrient uptake of cotton plants (kg ha^{-1}) and soil available nutrients (kg ha^{-1}) after harvest as influenced by Bt and non-Bt hybrids (pooled means).

	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
Hybrids	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt
RCH2	105.6	103.7	17.4	19.0	61.1	53.9	155.9	157.1	7.6	7.5	915.6	910.6
RCH20	118.2	128.1	20.2	22.6	67.4	82.1	156.9	159.0	7.3	7.8	891.5	919.8
RCH708	130.8	142.0	21.6	23.9	73.9	72.1	169.3	161.4	7.2	7.6	908.1	896.5
Mean	118.2	124.6	19.7	21.8	67.5	69.4	160.7	159.2	7.0	7.6	905.1	909.0
LRA 5166		94.8		18.4		58.2		150.9		7.7		884.1
	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%
Bt	7.1	NS	1.2	NS	6.9	NS	6.3	NS	0.44	NS	14.86	NS
Bt x hybrids	10.4	21.1	2.0	NS	12.4	NS	9.6	NS	0.70	NS	23.33	NS
Genotypes	9.6	19.4	1.9	NS	11.1	NS	8.8	NS	0.65	NS	21.08	NS

Note: SEd, standard error of difference; CD 5%, critical difference (=LSD, least significant difference).

Table 6. Economics of cultivation of Bt and non-Bt hybrids (pooled means).

Hybrids	Cost of cultivation (Rs ha^{-1})		Gross return (Rs ha^{-1})		Net return (Rs ha^{-1})		B.C ratio		Per day productivity (kg ha^{-1}-day^{-1})		Per day profitability (Rs ha^{-1}-day^{-1}y)	
	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt
RCH2	14,975	14,630	33,480	22,224	18,505	7594	2.2	1.5	10.0	6.2	132	51
RCH20	16,805	15,005	45,786	26,026	28,981	11,021	2.7	1.7	11.7	6.3	193	69
RCH708	22,378	20,110	61,344	43,136	38,967	23,026	2.7	2.2	11.6	7.7	236	149
Mean	18,053	16,582	46,870	30,462	28,818	13,880	2.6	1.8	11.1	6.7	190	86
LRA 5166		16,995		32,177		15,182		1.9		9.3		101
	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%	SEd	CD 5%
Bt	813	1652	2580	5246	4009	8152	0.01	0.2	0.8	1.6	20.7	42
Bt x hybrids	1431	2910	4598	9351	6989	14,212	0.14	0.28	1.3	2.6	37.3	76
Genotypes	1306	2640	4206	8501	6524	13,186	0.12	0.26	1.2	2.4	34.6	70

Note: SEd, standard error of difference; CD 5%, critical difference (=LSD, least significant difference).

saving of labour resulted in a two-fold increase of net return in Bt cotton than conventional cotton. Weir et al. (1998) conducted an economic analysis of bollgard cotton compared to conventional cotton and concluded that bollgard is superior in enhancing monetary return. Economics of Bt cotton cultivation assessed by Prasad Joshi et al. (2011) indicated that the total cost of cultivation was maximum for Bt, but Bt cotton has registered 31% higher yield and 151% higher net return (the net additional benefit being Rs 18,429 ha^{-1}) (Kiresur & Ichangi 2011).

Economic analysis revealed that the introduction of Bt gene into non-Bt hybrid increased the net return to the extent of 143.7%, 163.0%, and 69.2% in RCH 2, RCH 20, and RCHB 708, respectively. Amongst the genotypes tested, RCHB 708 Bt was assessed having the highest gross return (Rs 61,344 ha^{-1}), net return (Rs 38,967 ha^{-1}), and per day profitability (Rs 236 ha^{-1}). The enhanced return is justified in that the higher yield realized by climatic suitability of the zone for *barbadense* along with Bt effect in addition to the inbuilt superior quality parameters fetched higher market price which resulted in higher return with RCHB 708 Bt. The non-Bt straight variety, LRA 5166, registered better economic return than the non-Bt version of RCH2 and RCH20 but less compared to the rest of the genotypes.

Conclusions

On-station trial conducted in a sandy clay loam soil during 2006–2007, 2007–2008, and 2008–2009 seasons revealed a superior growth behaviour and yield performance of Bt hybrids over non-Bt hybrids even in scanty rainfall areas where the crop suffered moisture stress during the early period and again during the boll development phase. Amongst the hybrids, RCHB 708 Bt out-yielded the others even though the total dry matter production in non-Bt hybrids was higher.

Acknowledgements

The authors duly acknowledge the facilities and support provided by Project Coordinator and Head and The Director, CICR, Nagpur, Maharastra, India.

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