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Explaining contradictory evidence regarding impacts of genetically modified crops in developing countries. Varietal performance of transgenic cotton in India

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SUMMARY

A study of the commercial growing of different varieties of *Bacillus thuringiensis* (Bt) cotton compares the performance of growing official and unofficial hybrid varieties of Bt cotton and conventional (non-Bt) hybrids in Gujarat by 622 farmers. Results suggest that the official Bt varieties (MECH 12 and MECH 162) significantly outperform the unofficial varieties. However, unofficial, locally produced Bt hybrids can also perform significantly better than non-Bt hybrids, although second generation (F_2) Bt seed appears to have no yield advantage compared to non-Bt hybrids but can save on insecticide use. Although hybrid vigour is reduced, or even lost, with F_2 seed the Bt gene still confers some advantage. The F_2 seed is regarded as 'GM' by the farmers (and is sold as such), even though its yield performance is little better than the non-GM hybrids. The results help to explain why there is so much confusion arising from GM cotton release in India.

INTRODUCTION

Cotton is a very important crop in India and the introduction of genetically modified (GM) varieties that can enhance performance could have major benefits to Indian farmers and their livelihoods. India grows around 8–9 million hectares of cotton each year, accounts for approximately 0·25 of the world's total cotton area (0·16 of global cotton production) and contributes 0·30 to the value of output of Indian agriculture. Insect pests are a major limiting factor to cotton output, especially bollworms (Lepidoptera). Cotton covers 0·05 of cropped area, but consumes 0·52–0·59 of all pesticides in India (Kuruganti 2003). In March 2002 the Indian government permitted commercial cultivation of genetically modified *Bacillus thuringiensis* (Bt) cotton. The Bt gene (Cry1Ac) is derived from a soil-borne bacteria, *Bacillus thuringiensis*. It was transferred into cotton varieties by Monsanto in the United States and produces a protein that is toxic to bollworms. When a bollworm eats a part of the plant, the protein acts on the gut of the bollworm to prevent it feeding and the bollworm dies after around 2 days.

Bt cotton has now been produced in India for two seasons and there has been considerable debate and conflicting views regarding its agronomic performance and whether Bt varieties have financial benefits for Indian farmers (Friends of the Earth International 2004). Previous studies have shown potential gains to producers from growing Bt cotton in a number of (developing) countries (James 2002; Baffes 2004; FAO 2004), and trial data from India has reinforced this (Qaim & Zilberman 2003). Indeed, Bt cotton is currently grown not only in the USA and Australia, but also in Argentina, China, Colombia, Indonesia, Mexico and South Africa, as well as India.

Gujarat State is situated on the west coast of India and covers an area of 2 million km^2, 0·062 of the total area of the country. Agriculture forms a vital sector of the Gujarat economy. It provides food grains for the State population, raw materials for most of the agro-based industries and employs over 0·5 of the

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population (World Bank 2003). A characteristic feature of the state's agriculture is its cropping pattern, which is dominated by cash rather than food crops, particularly cotton and tobacco. Cotton yields in Gujarat are the highest in the country. In 2004, cotton was planted on 1·75 million hectares in Gujarat and produced 0·32 of India's cotton output (Singh 2004).

There are two species of cotton grown in Gujarat: *Gossypium hirsutum* and *G. arboreum*. Most of the cotton grown is an intra-*hirsutum* hybrid, with the remainder being planted to improved (non-hybrid) *hirsutum* and *arboreum* cultivars. There are two 'official' Mahyco-Monsanto Bt cotton hybrids grown in the state – MECH-12 and MECH-162. Popular non-Bt varieties are Bunny, Tulsi, NHH-44 and JK-666.

Reports from India regarding the economic performance of Bt cotton have been mixed, with some claiming benefits for Bt growers while others claim that they are actually worse off compared with growers of non-Bt cotton (Shiva & Jafri 2003). There are various explanations for this inconsistency. If Bt varieties are reported as faring worse than conventional varieties, there is the obvious conclusion that the Bt gene is not conferring any significant advantage, perhaps because the bollworm pressure is not high enough to make a difference. This, in essence, is the position of the anti-GM groups. There are more complex variants of the same theme. For example, it could be argued that sucking and foliage-eating pests are significant problems, but, because of poor training and advice, Bt growers do not spray against these and hence yields (and profits) are reduced.

However, if it is hypothesized that the Bt gene does help address a serious potential loss from bollworm then what other explanations could account for reports of poor performance of Bt varieties relative to non-GM? To begin with it should be noted that most cotton varieties in India are hybrids, and as such if seed is saved then the performance the following season may not be as good. Indeed, the high cost of Bt varieties does provide a motive for farmers to save seed. However, if the Bt gene is heterozygous in the hybrids then F_2 seed will not carry the Bt gene in all segregants and so some of the seed will not confer resistance to cotton bollworm. Therefore, farmers planting F_2 seed will lose hybrid vigour and, if from a Bt variety, could have patchy bollworm resistance in the field. Yield performance will be a complex interplay between these two factors. The extent to which farmers save cotton seed in India is presently unknown, but if asked it is likely that farmers will still refer to such F_2 seed as 'GM'.

There are two different categories of Bt cotton in India. One category comprises 'official' varieties (MECH-12 and MECH-162) in the sense that they are produced by Monsanto, the owner of the Bt gene patent, and have been sanctioned for use by the Indian government. The other category is the 'unofficial' varieties in the sense that the Bt gene was inserted into the genetic background of a range of varieties without Monsanto's permission and these varieties are not sanctioned by the Indian government for commercial use. Monsanto claim that the unofficial varieties will not perform as well as the official ones because breeders of the unofficial varieties have not taken into account the genetic background into which the Bt gene has been inserted, and have not backed up their work with extensive field testing. More complicated still is the fact that the genetic backgrounds of the unofficial seeds can be quite varied, hence it is more accurate to refer to them as a complex of varieties rather than a single one. Indeed, the company that releases unofficial Bt cotton seed in Gujarat sells both the F_1 (the cross of two inbred lines) and F_2 (second generation after hybridization) seed. Therefore when opponents of the technology talk of 'GM' are they referring to official or unofficial versions? Also, is it F_1 or F_2 (farmer saved or unofficial variety purchased from a company)?

While the situation is complex, and different groups hold up different sets of evidence typically based upon their own trials or surveys, now that data based on the commercial growing of Bt cotton (and not just from field trials) are emerging it should be possible to draw some tentative conclusions. The present paper presents the findings of research relating to a sample of 626 farmers growing different conventional and Bt cotton varieties under real commercial field conditions in Gujarat, India during 2003. The aim was to provide some answers to the questions raised above by comparing the official Bt varieties released by Monsanto with unofficial varieties sold in the state. It is the first such study of its kind in India, and one of the few in the world. Unlike previous Indian studies (Naik 2001; Qaim & Zilberman 2003), it analyses commercial field data rather than trial plot data.

For the purposes of the current study, a hypothesized ranking of the varieties is as follows (best performing varieties on the left) on an assumption that the Bt gene is conferring an advantage in the study area:

$$\text{Official varieties} > \text{unofficial } F_1 > \text{unofficial } F_2 > \text{non-GM cotton}$$

Official (MECH) varieties would do best based on Monsanto's assertion regarding adequate testing of the product, and F_2 seed purchased from the company producing unofficial GM cotton would do worse than F_1. It is arguable whether F_2 should be better or worse performing than the non-GM control. Here it is assumed that the Bt resistance will outweigh the benefits from hybrid vigour. It is also assumed that the MECH and unofficial varieties (F_1 and F_2), as well as any farmer-saved seed from Bt cotton, would be referred to as 'GM'.

MATERIALS AND METHODS

A personal interview survey of cotton farmers in Gujarat was undertaken just after the 2003/04 harvest season during December 2003 and January 2004. Respondents were randomly sampled from farmers growing cotton across six districts of Gujarat (obtained from a list from seed suppliers). The distribution of districts was chosen to reflect different agroclimatic regions of the state. A draft questionnaire was designed and pre-tested, and based on the pre-test findings a final questionnaire was drafted and taken onto farms by trained and experienced agricultural extension workers. In-depth personal interviews of farmers were carried out using this questionnaire. The questionnaire was structured into four main sections to collect information on:

(i) personal and socio-economic details about the farmer and his family (e.g. education, gender, family members involved in farming, etc.). These were included so as to allow a check for the assumption that the more skilful (experienced) farmers or those with better resources (available labour or better land for example) are those more willing to adopt new technologies.
(ii) the pattern of land holding (e.g. land owned or leased, crops grown, etc.)
(iii) cotton cultivation practices (e.g. cotton varieties planted, cotton yields, output prices and use of inputs such as seed, fertilizer, sprays and labour)
(iv) farmer's attitudes, experiences and knowledge concerning Bt cotton (including detailed questions about their use of pesticides).

After rejection of incomplete forms a total of 622 farmers were included in the analysis. For the most part the farmers only grew one plot (field) of cotton planted to a single variety, but four respondents had plots of Bt (official or unofficial) and non-Bt and for these farmers both plots were included in the analysis. The random nature of the sample resulted in different sample sizes of plots for those growing official and unofficial hybrids as well as those not growing Bt cotton. The total number of cotton plots included in the analysis was 626, 306 of which were planted to official (MECH) hybrids, 169 planted to unofficial hybrids and 151 plots of 'non-Bt'.

The data collected were coded where necessary before analysis. For example, 'education level' was coded from 1 (no education) to 7. The use of cotton inputs by farmers is expressed in terms of farmer expenditures on the main input categories – seed, manure, inorganic fertilizer, insecticide (for bollworm, sucking pests and others), irrigation and labour (for spraying and harvest). This is done:

(i) to allow a diversity of products, with different active ingredients in the case of insecticides, to be aggregated together into single categories of input, and
(ii) to gain a measure of the effect of the different varieties on the cost and profitability of cotton production for the different cotton varieties.

Analysis was with SPSS using the General Linear Model approach to analysis of variance, and mean separation was via Duncan's Multiple Range Test ($P \leqslant 0{\cdot}05$). The varieties were compared in terms of the variables presented in Table 1.

In order to provide further information on the factors governing production multiple regression was performed on the logarithm of yield per acre (dependent variable) and plot area (acres) and expenditure on a range of inputs (seeds, farmyard manure, inorganic fertilizer, bollworm insecticide, sucking pest insecticide, other insecticide such as seed dressing, irrigation and variety). Some of the variables are complex. For example, 'seed cost' is related to both the hybrid planted (Bt hybrids are generally more expensive than non-Bt) and seed rate. None of the labour terms were included in the model. Each variety was analysed separately using a 'stepwise' regression approach, with the cut-off point set at 0·1. Separate analysis was employed on the a priori assumption that varieties may have different responses to the various inputs.

RESULTS

The results of the analysis of variance and Duncan's Multiple Range Test are shown in Table 1. In terms of age of respondent, education level, household size, number of household members involved in farming and cotton plot area there is no significant difference between the five varieties. This is suggestive, but by no means conclusive, of evidence for sampling not being biased towards older/younger or less/more educated farmers, or towards small/larger households or those with low/high labour availability. It is well established that more skilful farmers tend to be those more willing to adopt new technologies such as Bt cotton. While the characteristics recorded in the survey suggest that there are no significant differences between the farmers in terms of availability of household labour, age (proxy for experience) or education (proxy for skill with new technologies), there is still the possibility that Bt hybrids were adopted by farmers able to achieve higher yields even with non-Bt cotton. Therefore, it is possible that some of the differences in Table 1 could reflect differences in ability or available resources rather than variety.

In terms of yield, Bt MECH 12 has by far the highest mean yield (kg/acre) of any of the cotton varieties, followed by Bt MECH 162. The unofficial

Table 1. *Comparison between four different types of Bt and non-Bt cotton*

	Bt varieties						
	Mech 12	Mech 162	F_1	F_2	Non-Bt	*P*	SD
Age of the respondent (years)	41·7	42·3	44·1	43·0	40·2	>0·05	11·82
Education level	3·65	3·62	3·4	3·52	3·52	>0·05	1·43
Household size	7·06	6·81	6·86	6·13	6·15	>0·05	3·2
Family members in farming	3·36	3·26	3·48	3·15	3·1	>0·05	2·61
Plot area (acre)	3·09	3·45	4·13	4·19	3·75	>0·05	3·55
Yield (Kg/acre)	832	726	691	601	606	<0·001	471
Response	+37%	+20%	+14%	−5%	–		
Price (Rp/Kg)	23·6	24·1	23·0	23·8	22·7	<0·001	0·93
Revenue (Rp/acre)	19658	17537	15851	14291	13762	<0·001	11130
Response	+43%	+27%	+15%	+4%	–		
Costs (Rp/acre)							
Seed cost	1610	1627	924	1265	535	<0·001	214
Farmyard manure cost	706	754	646	587	756	<0·001	283
Total inorganic fertilizer	1120	1935	1729	1437	921	<0·001	657
Total labour fertilizer	448	313	325	339	332	<0·05	414
Insecticide costs							
Bollworm cost	971	477	522	734	1955	<0·001	204
Sucking pest cost	1528	1472	1724	1178	1557	<0·001	461
Other insecticide cost	292	188	3	123	210	<0·001	198
Total insecticide costs	2791	2136	2250	2035	3723	<0·001	558
Harvest labour cost	2439	1913	2161	1745	1301	<0·001	1998
Irrigation	1838	2347	2685	2388	2440	<0·001	843
Total cost	10950	11025	10719	9794	10007	<0·001	2731
Response	+9%	+10%	+7%	−2%	–		
Gross margin (Rp/acre)	8707	6512	5132	4497	3755	<0·001	10317
Response	+132%	+73%	+37%	+20%	–		
Sample size	151	155	87	82	151		

Error degrees of freedom in ANOVA = 621.
Percentage response is expressed relative to the non-Bt hybrid.

F_1 hybrids have relatively high yields per acre compared with F_2 and conventional varieties but much less than the official Bt seed. These differences are substantial (14, 20 and 37% increase over non-Bt for F_1, MECH 162 and MECH 12 respectively) and statistically significant. As discussed above, some of this difference may be due to the more skilful farmers or those with better resources (e.g. land) adopting the technology. However, the rank order of the yields appears to bear out the hypothesis.

It would also appear that the price of cotton is higher for the Bt varieties compared with the non-Bt, perhaps reflecting a better quality of cotton and less staining caused by bollworm. A higher yield combined with a higher price generates significantly higher revenue for the Bt plots, and the percentage increase compared to non-Bt varied from 4 to 43%. Indeed, the ranking of revenue is that predicted in the hypothesis: MECH 12 > MECH 162 > F_1 > F_2 > non-Bt.

Unsurprisingly, seed costs/acre are highest for the MECH Bt varieties due to the relatively high cost of the seed, although seed costs for the F_2 seed are relatively high even when compared with the F_1 hybrids. Conventional, non-Bt seed costs are the lowest of all. The remainder of the cost data produce a rather complex picture of ranking between the varieties. With regard to insecticides, the use and costs of bollworm spray is highest for the conventional varieties and much lower for all the Bt varieties, particularly the official MECH 162 variety (followed by the unofficial F_1 hybrids). The cost of sucking pest sprays is highest for the F_1 hybrids and lowest for the F_2 seed. Inorganic fertilizer costs are highest for farmers growing the MECH 162 seed and lowest for the conventional varieties while irrigation costs are highest for the F_1 hybrids, lowest for MECH 12 and at a similar level for the remainder. Overall, the MECH varieties have the highest costs per acre associated with them, followed by F_1 hybrids and

Table 2. *Results of a stepwise regression analysis of cotton yield (log of Kg/acre, dependent variable) against logarithm of plot area (acres) and input expenditures (Rp/acre)*

	Bt varieties									
	MECH 12		MECH 162		F_1		F_2		Non-Bt	
Constant	6·752		6·804		6·77		2·491		−1·982	
Plot area	−0·452	$P<0·001$	−0·421	$P<0·001$	−0·49	$P<0·001$	−0·384	$P<0·001$	−0·364	$P<0·001$
Seed		$P>0·05$		$P>0·05$		$P>0·05$		$P>0·05$		$P>0·05$
Manure		$P>0·05$		$P>0·05$		$P>0·05$	0·094	$P<0·001$		$P>0·05$
Fertilizer		$P>0·05$		$P>0·05$		$P>0·05$		$P>0·05$		$P>0·05$
Bollworm insecticide	−0·32	$P<0·05$		$P>0·05$		$P>0·05$	0·84	$P<0·01$	1·28	$P<0·05$
Sucking pest insecticide	0·39	$P<0·01$		$P>0·05$		$P>0·05$		$P>0·05$		$P>0·05$
Other insecticide	−0·093	$P<0·05$		$P>0·05$		$P>0·05$	−0·41	$P<0·01$	−0·21	$P<0·001$
Irrigation		$P>0·05$		$P>0·05$		$P>0·05$		$P>0·05$		$P>0·05$
R^2 (adjusted)	0·38		0·23		0·21			0·28		0·34
Sample size	151		155			87			82	151

Cut-off point for the stepwise analysis is 0·1.

then conventional varieties, with F_2 seed having the lowest per acre costs.

When considering the profitability for farmers of growing the different varieties (i.e. (yield × price) − input costs, where only variable inputs that vary directly with output are considered), farmer profitability per acre is considerably greater for MECH 12 than for MECH 162 – the two official Bt varieties. The increase in gross margin of MECH 12, MECH 162 over the non-Bt varieties was 132 and 73% respectively. However, it should be noted that this sizable difference is largely a function of their increased yield (hence, increased revenue) rather than reduced costs. The F_1 hybrids are the next best performers in terms of profit (37% increase over non-Bt), followed by F_2 seed (20% increase over non-Bt).

Further analyses were undertaken to explore the relationship between output (yield), plot area and expenditure on various inputs (seed, fertilizers, insecticides and irrigation). The results of 'stepwise' regressions for each of the five varieties are shown in Table 2. Values of R^2 are not high, varying between 0·21 and 0·38, but the models do show statistically significant relationships between cotton yield per acre and some variables. Values of the intercept on the yield axis are in an order that broadly agrees with the hypothesis, with the lowest intercepts for non-Bt and F_2 cotton. For all five models there is a statistically significant negative relationship between yield per acre and plot size, showing that the smaller plots have the higher cotton yields, probably because of more intensive management. The use of bollworm insecticides increases yield per acre for the non-Bt and F_2 hybrids, while for F_1 and MECH 162 there was no significant effect. This fits the hypothesis given that non-Bt and indeed F_2 would be expected to have susceptibility to bollworm and hence yield should respond to the use of bollworm insecticide. F_1 and MECH 162 would be expected to have some resistance to bollworm and have less of a response to bollworm insecticide. Interestingly the bollworm insecticide coefficient is negative for MECH 12, and it is not immediately apparent why this should be so. While the use of bollworm insecticide may have no positive effect on the yield of a bollworm resistant hybrid it should not reduce it, and this result may warrant further research. Expenditures which were also significant in the models include farmyard manure (F_2; positive response), other insecticides (non-Bt, F_2, MECH 12; negative response) and sucking pest insecticide (MECH 12; positive response). Positive and differing responses to farmyard manure and sucking pest insecticide are readily explained. Given a presumably high level of bollworm resistance in MECH 12, sucking pests may well become the most limiting factor and hence sprays against these pests would significantly boost yields. However, a negative yield response to 'other insecticides' for three of the varieties is interesting and, as with the negative response of MECH 12 to bollworm insecticide, this requires further investigation.

DISCUSSION

The results would appear to support the view of a benefit from growing Bt cotton, especially the official

Bt cotton varieties, and the findings help to explain the differing reports as to the performance of Bt cotton under commercial farm conditions in India. The official Bt varieties are found to generally outperform both unofficial Bt varieties and non-Bt varieties in terms of both yield per acre and profitability for farmers. Although the unofficial Bt varieties generally outperform conventional varieties, they appear to perform far less well than the official Bt cotton crops. The advantage of, and indeed main incentive, for farmers to use the unofficial Bt varieties is that the cost of seed for these varieties is lower than that for the seed of the official Bt varieties. The poor performance of the F_2 compared with F_1 was expected due to the loss of hybrid vigour and loss of some bollworm resistance, but it is interesting to note that F_2 still outperforms, at least in terms of profitability, the non-Bt varieties. This provides some evidence as to the importance of bollworms given that benefits can accrue even from the F_2 where the Bt gene may not be present in all of the seed. Therefore, if asked the apparently simple and logical question 'does Bt cotton do better than the non-Bt varieties' the answer would have to be a mix of 'yes' and 'no' depending upon what Bt varieties are used to make the comparison and what is meant by 'better'.

The findings highlight a major problem in assessing the performance of GM crops, particularly in developing countries when it is combined with another commonly used technology such as hybrid vigour. Where there are a number of GM varieties, some of which have been indigenously developed, these varieties need to be considered separately and each one considered on its own individual merits. The high cost of GM seed does encourage seed saving, although with cotton this is not an easy task given the need to separate the lint from the seed. Unfortunately, such situations make it easy for those opposing the technology to select GM varieties that perform relatively badly (such as the F_2 saved seed in the present study) and hold them up as examples of the failure of genetically modified crops to benefit farmers.

However, it is important to remember that the research reported here relates to just one state (Gujarat is the main state to date that has seen substantial documented plantings of unofficial Bt cotton varieties) and one growing season in India, where both official and unofficial varieties of Bt cotton were grown. It is clear from regional analyses covering a number of other Indian states that there is geographical variation in the performance of varieties. However, over two seasons there is evidence to suggest that across Indian states the legal Bt varieties have performed better than any other cotton varieties both in terms of yield and profitability for Indian farmers (Mahyco 2003; AC Nielsen 2004). This is shown by farmer attitudes to the Bt varieties. A survey of over 3000 farmers in India (AC Nielsen 2004) found that 0·9 of farmers using official Bt seed in 2003 intended to purchase official Bt seed again in 2004, whilst 0·42 of non-Bt farmers intended to purchase Bt varieties in 2004.

The Indian government has been concerned about the use of unauthorized Bt cotton varieties (Jayaraman 2001) and is currently taking action to prevent the use of unauthorized cotton seed in Gujarat (AgraFood Biotech 2004). It is clear that GM crop varieties must be individually assessed as to their merits on a case-by-case basis, given the large variation in performance across varieties, and that both growers and observers should be made aware of the varietal differences.

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