Hybrid *Bt* cotton: a stranglehold on subsistence farmers in India

Andrew Paul Gutierrez

Cultivation of long season hybrid and GMO Bt-hybrid cottons is unique to India. The hybrid technology prevents seed saving, requires annual purchases of high cost seed that leads to sub optimal planting densities. These factors contribute to stagnant low yields and to increases in insecticide use that induce new pests that are increasingly resistant to insecticide and Bt toxins. Subsistence farmers growing rainfed Bt cotton in south and central India have been particularly affected by this hybrid technology.

Pure line high-density short-season (HD-SS) rainfed cotton varieties are available or in development that would greatly increase yields, reduce yield variability, decrease costs of seed and insecticides and increase profits. The high costs of Bt hybrid seed make the technology incompatible with the HD-SS applications. The article questions why pure line HD-SS technology has not been implemented in India.

Keywords: *Bt* cotton, hybrid seed, high density short season cotton, farmer suicides.

THE severe economic and social problems in Indian cotton gained national and international attention as the number of suicides among cotton farmers surged, especially in Maharashtra and Telangana where rainfed cotton dominates and, in Andhra Pradesh[1]. The increase in suicides began after the introduction of hybrid cotton and insecticides in the late 1970s and increased after 2002 with the introduction of costly transgenic (i.e. genetically modified) F1 hybrid *Bt* cottons (*Gossypium hirsutum*) expressing endotoxins of the soil bacterium *Bacillus thuringiensis* for control of lepidopteran pests[1]. By 2012, more than 1100 *Bt* hybrid varieties of variable quality were planted on 95% of the cotton area. Two factors underpin much of the development of *Bt* cotton in India: (a) seeds from F1 hybrid plants are fertile but are not saved for planting because they produce variable phenotypes and, (b) hybrid cotton is grown only in India, while fully fertile pure-line varieties of *G. hirsutum* cotton are the norm worldwide.

Hybrid long season varieties of cotton were introduced purportedly to increase yield and quality, but it also ushered in an increased use of insecticides and fertilizers[2]. As has occurred worldwide, pesticide use in cotton (and other crops) induces outbreaks of non-target pests[3]. In India, insecticide use induced serious outbreaks of the so-called 'American' bollworms (*Helicoverpa armigera*) that proved more destructive and difficult to control than the original target pest; the native cotton pink bollworm (PBW; *Pectinophora gossypiella*). Indian hybrid *Bt* cotton was introduced starting in 2002 to solve the insecticide-induced bollworm problem and to control pink bollworm[1]. Although hybrid *Bt* cotton provided initial relief, it has failed as resistance to the *Bt* toxin(s) is developing in pink bollworm and bollworm[4–9]. Resistance management[10] with refuges of non *Bt* cotton was not possible on small Indian holdings, and resistance to the *Bt* toxin(s) became inevitable. In addition, by 2013, insecticide use in Indian cotton reached pre-2002 levels, new pests not controlled by the *Bt* toxin were induced (e.g., whiteflies, plant bugs, mealy bugs), acceptance of *Bt* hybrid cotton reached >95% (Figure 1) and, pure line

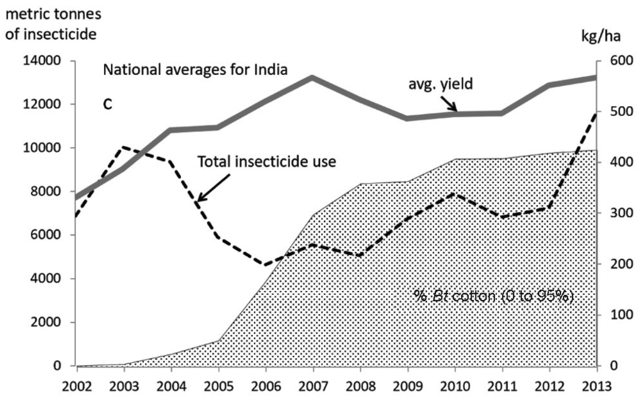

Figure 1. A summary of average national yield, insecticide use and *Bt* cotton adoption in India[11].

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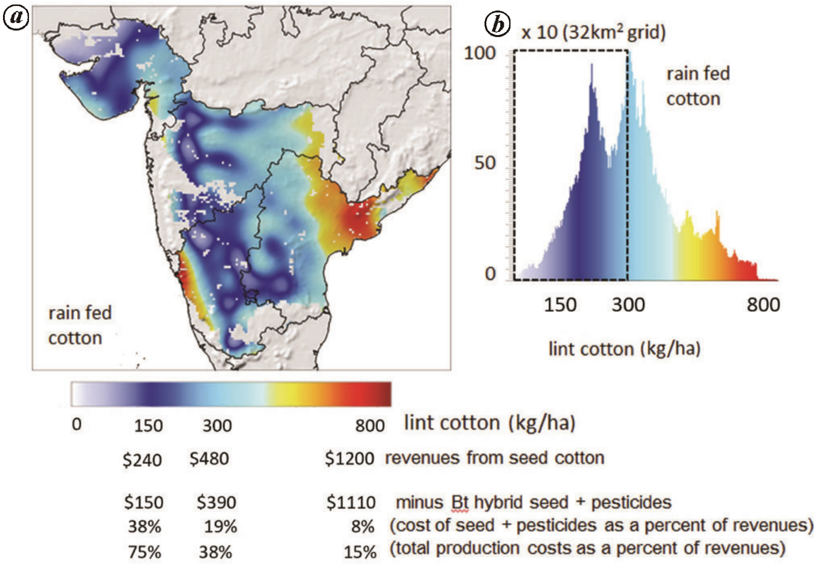

Figure 2. A regional bioeconomic summary of simulated average rainfed *Bt* cotton production in south central India: ***a***, Geographic distribution of prospective cotton yields; ***b***, Frequency histogram of area and kg/ha of lint cotton[1,11].

varieties largely disappeared from the market[1,11,12]. These developments launched Indian cotton farmers onto the insecticide[3] and hybrid biotechnology treadmills[1,11]. However, despite the new technology, yields in India plateaued starting 2007 (ref. 11) (Figure 1) and continue to be far lower than in Australia, China and USA, and less than half of those in some developing countries in west Africa[12].

A partial budget for cotton production based on simulation studies illustrates the plight of a subsistence farmer in Maharashtra producing an average lint yield of 300 kg lint per hectare (~850–900 kg/ha seed cotton) under rainfed condition at the recommended planting density of 2–2.5 plants m^{-2} (Figure 2; scaled to 2.5 plants m^2). (Note that seed cotton is what farmers harvest, and lint cotton is the fibre after ginning and is roughly 30–35% by weight of seed cotton.) At 850 kg/ha of seed cotton yield, the costs of insecticide and *Bt* cotton seed plus the cost of production are ~38% of total revenues resulting in a net income of 82 US cents per day per ha (i.e. ($480 × 0.62)/365). Assuming no land preparation and harvesting costs, farmer income would still be only $1.07 per day. As an important aside, a simple change in planting density to say 4–5 plants m^{-2} using the current varieties could increase yield by 35–40%, but unfortunately seed costs for hybrid *Bt* cotton seed ($69/hectare at 2 plants m^{-2}) would increase about 2–2.5-fold cancelling much of the gain. The use of sub-optimal planting densities likely contributes to the observed yield stagnation.

In the annual gamble of the monsoon, subsistence farmers face uncertain rains and yields with a combination of fixed high cost of hybrid *Bt* cotton seed, continued insecticide use against induced new pests, and often high usury costs of 5–10% per month to fund the technologies. These and other factors increase eco-social distress (and likely suicides), especially in Maharashtra and Andhra Pradesh[1]. Undoubtedly, the rainfed hybrid *Bt* cotton-insecticide driven system is not sustainable for economic, ecological and social reasons. However, despite unpredictable rains, there are more sustainable alternatives for rainfed cotton[13].

Leading Indian agronomists have proposed that adoption of pure-line high density short-season (HD-SS) varieties of rainfed cotton could more than double current yields and, would avoid heavy infestations of pink bollworm, thus reducing insecticide use and pesticide disruption[14–16]. HD-SS cotton is not a new technology, as before the advent of *Bt* cotton, high yielding pure-line HD-SS varieties were developed in California during the mid-1990s for control of the invasive PBW in irrigated desert cotton (Figure 3)[13]. After its invasion in the mid-1970s, PBW caused massive damage in California cotton during the 1976–1987 period, leading to massive use of insecticides that induced massive outbreaks of bollworm (*Helicoverpa zea*) and budworm (*Heliothis virescens*), defoliators and whitefly and, bankruptcy; not unlike what occurs in India. Control of PBW was achieved starting in 1988 when mandatory adoption of pure line HD-SS cotton was introduced that required early harvesting to prevent formation of dormant overwintering pupae followed by plowing for stalk destruction to kill residual overwintering pupae[13]. These practices short-circuited the pest's life cycle. Implementation of HD-SS cotton required teaching farmers how to implement the technology and weaning them off heavy insecticide use (and ecological disruption). By 1993, high yields of equivalent quality

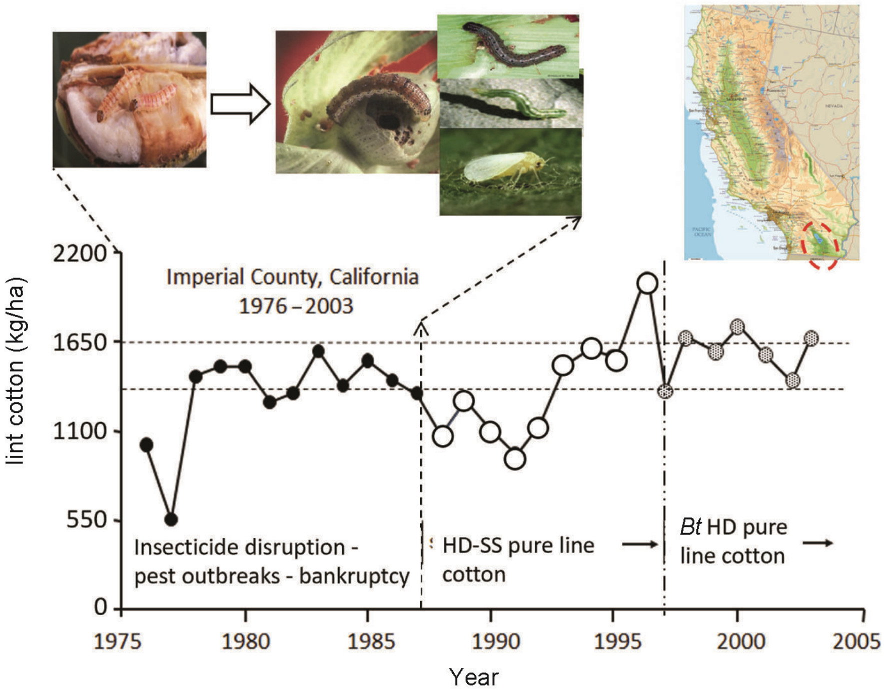

Figure 3. Production phases in response to the invasive pink bollworm in irrigated desert cotton in Imperial County in southern California: period of ecological disruption (●; 1976–1987), the transition to short season high density pure line cotton (○; 1988–1996) and the adoption of high density pure line *Bt* cotton (●; 1997 – present) (data courtesy of the Imperial County Agricultural Commissioner).

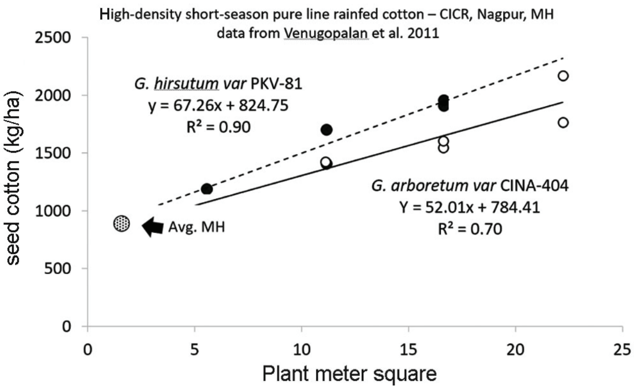

Figure 4. Seed cotton yields: average for Maharashtra for current hybrid *Bt* cotton (●) and, field density trials of (●) *G. hirsutum* and (○) *G. arboretum* high-density short-season pure line cottons at CICR, Nagpur, India[13,15].

Appendix 1. Pure line non-*Bt* HD-SS varietal trial data on kg seed cotton/ha: data reproduced from Venugopalan *et al.*[15]

Plants/ha	Anjali	CNH120MB	PKV-81	NISC-50	CCH-724
New world: *Gossypium hirsutum* → kg/ha seed cotton					
55000	502	1030	1200	1056	679
111000	847	976	1714	890	843
111000	853	1138	1418	1103	681
166000	966	1250	1921	1016	864
166000	796	1289	1967	1052	835
Plants/ha	AKA-07	CINA-404	PA-255	PA-08	JK-5
Desi: *Gossypium arboretum* → kg/ha seed cotton					
111000	1163	1430	1259	1090	1223
166000	1349	1550	1595	1318	1452
166000	1456	1610	1349	1455	1151
222000	1815	2173	1625	1509	1842
222000	1419	1772	1226	1479	1734

NB: Plants m^{-2} = plants/ha/10,000.

and high profits returned under HD-SS cotton, saving the desert cotton industry in California. However, despite this progress, industrial farmers rapidly switched to pure line *Bt* varieties of cotton when they became available in 1997 because it was easier to implement and in the absence of resistance to *Bt* toxins, provided good control of PBW. In addition, with greatly reduced insecticide use, bollworm, budworm and other induced secondary pests receded to their former non-pest status. In industrial irrigated cotton, the price of pure-line *Bt* cotton was an acceptable cost of production. But what part, if any, of the HD-SS cotton technology is suitable for Indian conditions?

Pure line high yielding non-*Bt* HD-SS rainfed varieties of new world *G. hirsutum* and native desi *G. arboreum* have been developed in India[15,16] (e.g., Figure 4; data reproduced in Appendix 1) by scientists at the Central Institute for Cotton Research (CICR), Nagpur. CICR field trials at different densities in 2010 were conducted under 1005 mm of rainfall that accrued over 53 days. The *G. hirsutum* pure line non-*Bt* HD-SS variety PKV-081 produced an average of 1944 kg of seed cotton/ha at

16 plants m^{-2}, whereas the pure line non-*Bt* HD-SS *G. arboreum* variety CINA-404 yielded an average of 1,973 kg/ha at 22 plants m^{-2}. The importance of plant density on yield (for any variety) is seen in Figure 4 and in the appendix data. Seed cotton yields in the two non-*Bt* rainfed cottons were about half those in irrigated cotton in southern California but, they were about 2.2 times the current average yield of long season *Bt* hybrids in Maharashtra. Mean seasonal rainfall at Nagpur is 760 mm (ref. 15) with a coefficient of variation (CV) of about 35–40%. The amount and timing of rainfall affects annual yields and variability[15], but the shorter season for HD-SS cotton enables it to better utilize the rainfall thereby reducing yield variability[13]. Across the south-central states of Andhra Pradesh, Gujarat, Karnataka and Maharashtra, the relationship between rainfall and CV is mm rainfall = $4267e^{-0.04CV}$, $R^2 = 0.69$ (ref. 1). Equally important, the HD-SS varieties would largely escape PBW infestation as they germinate with the monsoon rains of mid-June, after most of the adult emergence from overwintering PBW pupae has occurred. The short season length of less than 150 days is also unfavourable for PBW buildup. These attributes would reduce insecticide use (and secondary pests such as bollworm), allow seed saving, increase yields and profits, and reduce indebtedness[13–16]. Research on pure-line HD-SS cotton in India continues but is not well documented in the literature[16]. However, endorsements of the technology by CICR research scientists are found in presentations[17,18] and no doubt in CICR annual reports.

Hybrid HD-SS *Bt* cotton can be developed, but hybrid seed production is labour-intensive and costly. At current prices for hybrid *Bt* seed (~\$69/ha at 2 plants m^{-2}), costs to achieve appropriate HD-SS densities would be more than six times higher (>\$415 ha^{-1}). Hence, unless hybrid seed costs are greatly reduced, hybrid *Bt* cotton is not a viable economic option for HD-SS development. In contrast, pure line seed for HD-SS is relatively inexpensive and it can be saved and replanted. HD-SS *Bt* pure line varieties of cotton are widely grown in USA, Australia and other developed economies, but legal constraints (threats of law suits) prevent industrial farmers with large land holdings from replanting saved seed. But this is not a viable option for preventing seed saving by millions of Indian farmers with small land holdings. In India, hybrid cotton fills the gap as it prevents seed saving and provides a viable solution for the seed industry obviating intractable legal enforcement issues[1,11].

Hence, the obvious question is why weren't pure line HD-SS high yielding varieties adopted in India? Why did the regulators in Government ministries allow the hybrid technology to flourish and HD-SS technologies to languish despite their high yield potential?[14] Weren't Government ministries and regulators sufficiently informed on the HD-SS technology to make sound decision in the public interest? What is strikingly obvious is that the hybrid technology is at the heart of the Indian cotton debacle as it limited in the name of profits, the development and implementation of alternate technologies at the expense of the farming community and the public good. What is difficult to know is what role bureaucracy, conflicts of interest and, commercial greed played in the cotton economy of India where poor farmers have grossly incomplete information and, have little say in the development and distribution of product developments to meet their needs[19]. An excellent review of the pros and cons of the debacle that is Indian cotton concluded that the increase in suicides was due to the cultivation of hybrid *Bt* cotton[1,20]. In light of the available HD-SS option, recent legal challenges in the Supreme Court of India to the hybrid GM technology are instructive and need to be heeded by Government ministries. In a Counter Affidavit in the Delhi High Court in 2015 (WP(C) No. 12069)[21], the Union of India (i.e. the Indian Government) unequivocally linked farmer suicides with the failure of *Bt* cotton and its very high costs. Paragraph 5 of the 2016 counter affidavit to the seed industry states:

> 'That the impugned price control order was promulgated with the objective of regulating the maximum sale price of cotton seeds in India inclusive of various hybrid varieties of cotton seeds including *Bt* cotton seeds and it was done in the interest of the farmers to make the cotton seeds available at fair prices. The farmers across the country have been financially burdened due to the increasing prices of the *Bt* cotton seeds. In addition to the prices of the cotton seeds, the famers also have to spend on pesticides and other resources to make the crop more pest resistant and high yielding. This results in escalated expenses. As a result, there is very less margin of profit for the farmers. Since *Bt* cotton seeds is the major seed used by cotton farmers, a farmer succumbs to the pressure to use the best seed available in the market even when he might not have the means to cultivate such a crop. Consequently, in case of a crop failure, the farmers incur enormous debts in view of the loans taken to cultivate such *Bt* cotton crop. In the event of failure to raise a profitable yield, the farmers end up piling up huge debts which in turn has caused a rise in farmers' suicides across various cotton growing states.'

Signed:
Rajendra Kumar Trivedi
Deputy Commissioner (Seeds), Government of India,
Ministry of Agriculture and Farmers Welfare

This paragraph is an excellent summary of the underlying issues raised in this paper and previous papers. The most straightforward solution for stable cotton production in India is for Government agencies to foster (*reward*) HD-SS pure line cotton variety development and enable the distribution of the seed and relevant agronomic information. But there needs to be an oversight committee of unconflicted international experts to assure that the agronomic and economic comparisons of HD-SS pure line varieties and current hybrid *Bt* varieties are done in a rigorous scientific manner – sham comparison must be exposed as they threaten the livelihood and the very lives of millions of subsistence Indian cotton farmers – *custodiet ipsos custodes* indeed[20]. Finally, recent calls by industry and its clients to extend implementation of the hybrid technology in aubergine (brinjal, eggplant) and mustard and likely other crops in India will only mirror the disastrous implementation of the failed hybrid *Bt* technology in Indian cotton and, will only serve to tighten the economic hybrid technology noose on still more subsistence farmers for the sake of profits.

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Received 10 August 2018; accepted 27 August 2018

doi: 10.18520/cs/v115/i12/2206-2210