



Biotech Cotton - Relevance For Africa

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Since 1996, biotech cotton has been significantly influencing cotton production systems in major cotton growing countries across the globe. In 2017, insect resistant *Bacillus thuringiensis* based *Bt*-cotton comprised 74.9% of the total global biotech cotton area and herbicide tolerant (HT) cotton comprised the rest. While Asian countries adopted only *Bt*-cotton, industrialised countries such as Argentina, Australia, US, Brazil, Mexico and South Africa adopted both *Bt* and HT cotton. Until 2017, three countries in Africa (South Africa, Burkina-Faso and Sudan) grew biotech cotton. Three more African countries — Nigeria, Swaziland and Ethiopia — approved *Bt*-cotton in 2018. Further, Malawi, Kenya and Cameroon are conducting multi-location trials of *Bt*-cotton and are likely to approve *Bt*-cotton soon.

In Africa, HT cotton was approved in South Africa and trials are underway in Cameroon. As in Asia, the relevance of biotech cotton in Africa would be more for the IR trait and less for the HT trait. Biotech cotton has been grown for 10-20 years in major cotton growing countries, notably India and China, which have small-scale farming systems similar to those in Africa. Impacts of biotech cotton have been wide ranging across different countries. Africa has the advantage of learning from the experiences of the world.

This article attempts to provide a short summary of the global status of biotech cotton with reference to the relevance for African countries.

Biotech Crops — Global Status

Biotech cotton, transgenic cotton and genetically modified cotton are synonyms. China was the first country in the world to commercialise a biotech crop: 'virus-resistant to-

bacco'. In 2017, 24 countries grew biotech crops on 189.8 million hectares. More than 90% of the global biotech area is in just five countries (Argentina, Brazil, Canada, India and USA). More than 99.0% of the global biotech area is under just four crops — soybeans: 50.0%; maize 31.0%; cotton: 13.0% and canola: 5.0%

Biotech Cotton — Global Status

So far until October 2018, biotech cotton has been approved for commercial cultivation in 19 countries (listed below).

In 2017, biotech cotton was cultivated by 13 countries in 24.07 million hectares, which comprised 80.0% of the global cotton area. More than 94.0% of the global biotech cotton area is located only in five countries: India (47.4%), USA (19.1%), Pakistan (12.5%), China (11.5%) and Brazil (3.9%). In 2017, the share of biotech cotton was 84% to 100% in major cotton growing countries such as Australia (100%), Argentina (100%), Brazil (84%), China (96%), India (93%), Pakistan (96%) and USA (96%).

Two traits: HT cotton and *Bt*-cotton

There are only two traits available in biotech cotton: Insect resistance (mainly *Bt*-cotton) and herbicide tolerance (HT). Argentina, Australia, Brazil, Colombia, Mexico, Paraguay, South Africa and USA approved *Bt*-cotton and HT cotton. Developing countries such as India, Burkina Faso, China, Pakistan, Myanmar and Sudan approved only *Bt*-cotton and have not approved HT cotton as yet. In 2017, the share of *Bt*-cotton in the global biotech cotton area was 74.9%, with 3.5% under HT cotton and 21.6% under *Bt*+HT cotton.

Year	Countries	Year	Countries
1995	USA	2005	Brazil
1996	Mexico	2007	Paraguay
1997	Australia & China	2008	Costa-Rica
1998	Argentina & South Africa	2009	Burkina-Faso (Currently under ban)
2002	India	2010	Pakistan & Myanmar
2003	Colombia	2012	Sudan
2004	Japan	2018	Nigeria, Ethiopia & Swaziland

Genetically engineered HT cotton varieties were developed as follows:

S.No	HT Cotton	Transgene/protein	Source	Mode of action
1	Glufosinate resistant cotton (Bayer)	Bialaphos resistance (bar) phosphinothricin N-acetyltransferase (PAT)	<i>Streptomyces hygroscopicus</i>	Acetylates the free amino group of glufosinate to inactivate it
2	Glyphosate resistant cotton (Monsanto and Bayer)	' <i>epsps</i> ' gene encoding '5-enolpyruvulshikimate-3-phosphate synthase'	<i>Agrobacterium tumefaciens</i> CP4 strain	Overexpression of the <i>epsps</i> gene in HT cotton neutralizes the toxic effects of the herbicide glyphosate
3	Dicamba resistant cotton (Monsanto)	<i>Demethylase</i> gene codes for a dicamba mono-oxygenase (DMO) protein	<i>Stenotrophomonas maltophilia</i>	Demethylates dicamba to the herbicidally inactive metabolite DCSA
4	2,4-D resistant cotton (Dow)	'Aryloxyalkanoate dioxygenase-12' (<i>aad-12</i>) gene	<i>Delftia acidovorans</i>	Alpha ketoglutarate-dependent dioxygenase activity inactivates 2,4-D herbicide
5	Isoxaflutole resistant cotton (Bayer)	p-Hydroxyphenylpyruvate dioxygenase (hppd) enzyme	<i>Pseudomonas fluorescens</i> strain A32	Reduces the specificity for the herbicide's bioactive constituent
6	Bromoxynil resistant cotton (not in use)	<i>Nitrilase</i> gene	<i>Klebsiella pneumoniae</i> subsp. <i>Ozaenae</i>	Inactivates bromoxynil

HT Cotton

Herbicide tolerant cotton contains genes derived from micro-organisms or maize and has the ability to survive specific herbicide applications which kill weeds. HT-cotton cultivars are now available for tolerance to six different herbicides namely, glyphosate, glufosinate, dicamba, 2,4-D, Isoxaflutole and bromoxynil (HT not in use). HT cotton is more of necessity in industrialised countries that either do not have adequate manpower for manual or mechanical weeding or these processes are uneconomical through mechanical means.

Bt-cotton

Bt-cotton is a potent technology for almost season-long control of bollworms. *Bt*-cotton provides benefits until insect resistance becomes a problem. *Bt*-cotton controls only lepidopteran larvae (caterpillars). The target insects across the world are: bollworms, *Helicoverpa armigera*, *Heliothis virescens*, and *Helicoverpa zea*; pink bollworm *Pectinophora gossypiella*; spotted bollworms, *Earias* spp., the red bollworms *Diparopsis* spp., the tobacco caterpillar *Spodoptera litura* and a few semi-loopers and hairy caterpillars.

A soil bacterium, *Bacillus thuringiensis* (*Bt*) is known to produce proteins which act as oral toxins. When consumed the proteins perforate the mid-gut membranes and cause mortality in 2-4 days after consumption. So far, insect resistance in biotech cotton has been almost completely based on seven *Bt*-toxins, Cry1Ac, Cry1Ab, Cry1C,

Cry1F, Cry2Ab, Cry2Ae And Vip3a. Though cowpea trypsin inhibitor (CpTi) protein was also deployed in insect resistant biotech cotton in China, the area under cultivation appears to be negligible.

The first-generation *Bt*-cotton, Bollgard, Ingard etc., was based on a single gene *cry1Ac*. The second-generation biotech cotton was Bollgard-II (*cry1Ac+cry2Ab*); Wide-strike (*cry1Ac+cry1F*); Twin-link (*cry1Ab+cry2Ae*); *Bt*-III (*cry1+cry2+vip3A*) and *Bt*+HT (*epsps*).

Economic benefits from *Bt*-cotton can arise from higher yields due to effective protection from lepidopteran larval damage and from savings due to reduced insecticides for bollworm control.

***Bt*-cotton & HT cotton technology developers**

1. Monsanto company, USA
2. Bayer crop science, Germany
3. Dow Agro Sciences LLC, USA

***Bt*-cotton technology developers**

4. Syngenta, Switzerland
5. Metahelix life sciences Pvt. Limited, India
6. JK Agri genetics Pvt. Limited India
7. Cotton-Sericulture Department, Myanmar

Insect resistant cotton (*Bt* and Protease inhibitor) technology developer

8. Chinese Academy of Agricultural Sciences (CAAS), China

Insect resistance to *Bt*-cotton and weed resistance to herbicides

Two bollworm species, namely, *Helicoverpa zea* (in the USA) and the pink bollworm *Pectinophora gossypiella* (in India) have developed resistance to Cry2Ab and Cry1Ac toxins in *Bt*-cotton.

Glyphosate resistance was recorded in 13 weed species each in USA and Australia and 8 each in Argentina and Brazil. The main glyphosate resistant weeds are: *Amaranthus palmeri*, *Conyza canadensis*, *Amaranthus tuberculatus*, *Ambrosia artemisiifolia*, *Ambrosia trifida*, *Kochia scoparia* and *Lolium perenne*. The weed species *Lolium perenne* was found to be resistant to glyphosate and glufosinate in the USA.

Relevance of Biotech Cotton for Africa

The main bollworms in Africa are: the cotton bollworm, *Helicoverpa armigera*, the Spotted bollworms *Earias insulana*, the Sudan bollworm, *Diparopsis watersi* and the red bollworm, *Diparopsis castanea* spp., The pink bollworm *Pectinophora gossypiella* is a serious pest mostly in southern and east African countries. *Bt*-cotton was reported to be highly effective in controlling bollworms, which are known to cause maximum damage to the crop. *Bt*-cotton can be a useful pest management technology for Africa wherever bollworms cause serious economic losses despite the implementation of IPM.

Cotton bollworms are major pests of cotton, mostly dominated by the cotton bollworm *Helicoverpa armigera* and the pink bollworm *Pectinophora gossypiella*. There are anecdotal evidences coupled with a widespread belief in Asia that *H. armigera* which was an 'inconsequential pest of cotton' prior to 1981, emerged as a major pest of cotton in India and Pakistan only after the introduction of synthetic pyrethroids which were meant to control the pink bollworm and cotton leaf worm *Spodoptera litura*. Therefore, it would be important for African countries to consider conducting scientific studies with massive reduction of pyrethroid usage to examine if this would reduce *H. armigera* infestation on cotton. Bollworm problems can be reduced to a greater extent by growing short season (140-150 days) varieties to create asynchrony between a short 'reproductive phase window' and the bollworm infestation peaks. Further, recently introduced insecticides such as spinosad, emamectin benzoate, chlorantraniliprole etc., are effective in bollworm management. However, if none of these strategies work, *Bt*-cotton could be effective. Nevertheless, IPM would play a major role in the management of the wide spectrum of pests with or without *Bt*-cotton, because *Bt*-cotton controls only bollworms and not sap-sucking pests.

Current Status of Biotech Cotton in Africa

So far insect resistant biotech *Bt*-cotton has been approved in six countries in Africa, namely, South Africa, Burkina-Faso (currently banned), Sudan, Nigeria, Swaziland and Ethiopia. In addition, herbicide tolerant trait was also approved in South Africa. Malawi, Kenya and Cameroon are conducting multi-location trials of *Bt*-cotton. Cameroon is also considering herbicide tolerant traits for approval.

Following is the status of biotech cotton in Africa:

- **South Africa:** Biotech *Bt*-cotton was approved for commercial planting in 1998. South Africa approved *Bt*-cotton and HT cotton. Cotton was cultivated in 137,000 hectares in 1998. However, cotton area started declining subsequently due to drought and other factors, to a meagre 5000 hectares by 2009. Cotton was cultivated in 37,000 hectares in 2017 with almost all of it being biotech cotton.
- **Sudan:** Sudan approved *Bt*-cotton in 2012. As of now, all *Bt*-cotton is based on the single gene *cry1Ac*. Initially one variety called Seeni 1 was approved and two hybrids from India, Hindi 1 and Hindi 2 were approved in 2015. About 75.0% of the cotton area is under irrigated conditions. The private sector seeds comprise 31.0% of the cotton acreage. The Government of Sudan signed an agreement with China's Agriculture Ministry to plant 500,000 hectares of cotton in the Gezira region in the 2017/18 season. Sudan grew cotton in 194,000 hectares with 99.0% under *Bt*-cotton.
- **Burkina-Faso:** *Bt*-cotton was approved in 2009 and spread to about 65% of the area in 2015. Burkina Faso approved the two gene (*cry1Ac* + *cry2Ab2*) based Bollgard-II. The cotton bollworm, *Helicoverpa armigera* and the Sudan bollworm *Diparopsis watersi* were effectively controlled. However, the use of technology was suspended in 2016 following complaints of increasing short fibres and inferior fibre quality.
- **Nigeria:** *Bt*-cotton multilocation trials were conducted by Monsanto Agriculture Nigeria Ltd for seeking approval for commercial release. The two gene (*cry1Ac* + *cry2Ab2*) based Bollgard-II was approved for commercial cultivation in July 2018.
- **Ethiopia and Swaziland:** Multilocation trials with *Bt*-cotton were conducted by Ethiopia Institute of Agricultural Research (EIAR). The single gene *cry1Ac* based *Bt*-cotton (event-1) developed by JK Agrigenetics India was approved for commercial cultivation in June 2018.
- **Zimbabwe, Uganda and Senegal:** Reports indicate that trials were conducted but results and status of regulatory approvals for commercial cultivation are unknown.

Major insect pests in Africa

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- **Malawi:** *Bt*-cotton trials were conducted by LUANAR, DARS, Monsanto, Quton and general environmental trial approvals were granted. Variety registration trials are under consideration.
- **Kenya:** Conditional approvals for environmental release to conduct National Performance Trials (NPTs) were granted. *Kenya* Agricultural and Livestock Research Organisation (*KARLO*) and Monsanto are conducting the trials.
- **Cameroon:** Trials with insect resistant and herbicide resistant biotech cotton were conducted by Bayer Crop Science and application for environmental release is under consideration.

Impact of Biotech Cotton

Insect resistant *Bt*-cotton and herbicide tolerant HT-cotton exercised a strong influence on cotton production in more than three-fourth of the global cotton area. Both technologies are different in their own way. *Bt*-cotton effectively controlled the major bollworm insect pests in all the countries where it was introduced. Several research publications show that biotech cotton had a significant initial impact in effectively controlling bollworms thereby reducing the usage of chemical pesticides used for bollworm control at least over the first five to six years after introduction in most countries. But, subsequently, in some countries, pesticide usage increased for the control of *Bt*-resistant bollworms and new insect pests that were unaffected by *Bt*-toxins. Studies pointed out that increase in the usage of insecticides may have been due to two main factors.

1. Insect pest species that were not affected by *Bt*-toxins in biotech cotton increased progressively over the years, due to reduction in insecticide applications for bollworm control on *Bt*-cotton. Thus, minor pests, such as mirid-bugs, mealybugs, thrips etc., which would otherwise have been controlled by the bollworm-insecticides, emerged as major pests, warranting insecticide applications for their control.
2. Bollworm adaptation to *Bt*-toxins enabled them to survive on biotech *Bt*-cotton to various degrees in different countries, necessitating the usage of insecticides. Pink bollworm resistance to *Bt*-cotton in India is a striking example, where insecticide usage is increasing due to bollworm resistance.

Insecticide usage has been increasing constantly over the past 10 years in India, Pakistan, China, Brazil and USA for the control of thrips, whiteflies, mealybugs, pink bollworms and recently also for the cotton bollworm infestation. Insecticide use for boll weevil control is a major concern in Brazil. Enhanced use of herbicides to control resistant weeds in USA and Brazil is an emerging concern. Thus, there has been a rising trend in the usage of insecticides and herbicides in all the top five cotton growing

countries over the past 10 years.

This predicament presents major concerns on the following fronts.

- Increased crop damage
- Declining yields
- Enhanced production risks
- Enhanced usage of pesticides
- Increased cost of production
- Increased ecological and environmental hazards

Beyond doubt, biotechnology has influenced cotton production systems in major cotton growing countries. But, a critical analysis of innovations in the past two decades points out that the pace of technological developments in the past ten years did not match those of the preceding ten years. The *cry1Ac* gene in *Bt*-cotton that was released in 1996, represented the first arsenal continues to be the main source of resistance to bollworms even after 20 years of continuous deployment. The other genes *cry1Ab*, *cry1C*, *VIP3Aa*, *cry1F* and *cry2Ab* played their role in bollworm management, but were not superior to *cry1Ac* in controlling bollworms. Further, there is no scientific evidence to show that the new biotech cotton events developed recently are in any way superior to the previous ones.

Recommendations for Africa Based on Global Experiences

Biotech cotton will be a useful technology provided the following diligent measures are considered

Africa needs basic yield enhancement technologies first

Cotton yields in Africa have been low and stagnant for about 30 years. What Africa needs is basic technologies that can enhance yields. For yields to be increased, the current dependence on multi-monopodial plant types and long duration low density planting needs to be changed first to be replaced with short-season compact-architecture varieties cultivated in high density planting systems. *Bt*-cotton or HT cotton are only plant protection or weed control technologies and have nothing to do with yield enhancement.

Examine the need

- Explore the options for *Bt*-cotton only where bollworms cause serious economic losses and IPM strategies are ineffective. Bollworms can also be effectively controlled by ecological methods and through Integrated Pest Management (IPM). For example, two strategies, namely, short-season cotton varieties plus avoidance of synthetic pyrethroid insecticides have the potential to significantly reduce bollworm infestations. *Bt*-cotton would be economical only if boll-

worms are a big menace and cannot be controlled by any other strategies.

- Explore the option for HT cotton if labour availability is a serious constraint and if selective herbicides are unavailable or target-specific herbicide application is not possible. HT cotton renders farms dependent on the usage of specific herbicides.

Preference for short-season cultivars (varieties)

Emphasis must be placed on the development and deployment of short season cultivars to reduce the 'bollworm-vulnerable window'.

Curb usage of synthetic pyrethroids

Synthetic pyrethroid usage must be reduced as much as possible to curtail any possible 'bollworm-resurgence effect'.

Choice of elite local cultivars

If *Bt*-cotton is to be deployed, locally adapted elite varieties must be used as recurrent parents for the conversion into biotech cotton.

Proper introgression of transgenes

Plant breeding techniques to introgress the biotech traits into locally adapted varieties must be carried out diligently by carrying out the whole process of introgression breeding and selection in the same agro-eco regions of cultivation. The methodology of plant breeding for proper selection of progeny from segregating populations over progressive generations to achieve homozygosity for the *Bt* genes and homogeneity for economically important traits in the cultivars is extremely important. The wisdom and role of local scientists such as plant breeders, agronomists, entomologists etc., must be respected at all times and used in the entire process of developing *Bt*-cultivars to ensure adaptability and sustainability of the biotech technologies.

Stacked genes for insect resistance management

If *Bt*-genes are to be deployed, to ensure sustainable and durable performance of *Bt*-toxins, it is always better to introduce all the available *Bt*-genes as a stack in a single simultaneous introduction. This can significantly delay insect resistance development to the toxins. For example, introduce the three gene based *Bt*-cotton (*cry1Ac+cry2Ab2+VIP3Aa*) at a go, instead of introducing *cry1Ac* followed by *cry1Ac+cry2Ab* after a few years and thereafter *cry1Ac+cry2Ab2+VIP3Aa* after a few more years.

Open-pollinated cultivars must be preferred over hybrid varieties

Private seed companies prefer to sell hybrid seeds because

farmers would have to buy fresh hybrid seeds every season. Farm saved seeds from a hybrid-crop cannot be used for sowing in the subsequent season. High yields (1000 to 2500 Kg/ha) have been obtained by major cotton growing countries such as USA, Mexico, Brazil, Turkey, Uzbekistan, China and Australia by growing open pollinated varieties in contrast to low yields of 500 Kg/ha in India wherein >95% of the area is under hybrid *Bt*-cotton. Hybrid cotton varieties are less sustainable compared to open-pollinated cultivars. Hybrid seed production is expensive, cumbersome and labor-intensive. Majority of the cotton hybrids are designed to produce a large number (40-100) of bolls per plant which leads to longer duration and a larger crop canopy that warrants low crop densities. Hybrid seeds are expensive and are planted at low crop densities which also necessitates longer duration for high yields to be realized. A long duration crop becomes more vulnerable to insect pests, moisture stress and nutrient deficiencies, thereby leading to crop management problems, production uncertainties and yield risks. There is hardly any robust evidence to show that hybrid seeds provide higher yields in a shorter time frame as compared to open-pollinated varieties. Further the seeds harvested from a hybrid crop cannot be reused for subsequent sowing to raise a homogenous crop. Hybrid crop demands more fertilizers to maintain hybrid vigour that also leads to more foliage and higher pest infestation, thereby warranting more pesticide usage. Because of the longer duration, hybrid cotton can lead towards potential problems of pink bollworms, bacterial blight and mealybugs. In the interest of long term sustainability, hybrid cotton must be scrupulously avoided in Africa especially in rainfed regions.

Minor insect pests can become concerns

Secondary insect pests are expected to assume the status of major pests generally due to overall reduction in insecticide usage for bollworm control in *Bt*-cotton. Experience in India shows that 1.15 kg insecticide per hectare was used prior to the introduction of *Bt*-cotton. The usage decreased initially in the first five years to 0.5 kg/ha but increased again to 1.2 kg/ha by 2014, mainly due to the need for insecticides to control secondary pests.

Do not neglect IPM and IRM

Bt-cotton must be considered only as a component of overall Integrated Pest Management (IPM) and not as an independent pest management strategy all by itself. Experience shows that indiscriminate deployment of *Bt*-cotton and HT cotton with scant regard to the principles of IPM and insect resistance management (IRM) leads rapidly to severe pest problems and *Bt*-resistant target pests. Compliance with regulatory guidelines holds the key to sustainability. Resistance in target pests to *Bt*-cotton and development of resistant weeds to herbicides, are inevitable eventualities that get accelerated in the wake of poor compliance of resistance management strategies.