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Nigeria cotton farming revolution: Role of transgenic cotton (Bt cotton) in revitalization of the cotton farming situation

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Abstract
Cotton (*Gossypium* spp.) is an important economic crop and the largest source of textile fiber in the world. Cotton is an important rare economic success story in Sub-Saharan Africa and a major source of foreign exchange earnings in more than 15 countries of the continent and is a crucial source of income for millions of rural people. Over the years, Nigeria cotton production declined due to pest infestation and other related factors. The discovery of *Bt* cotton and it success cultivation inspired the revitalizations of the comatose cotton farming system leading to the development of Nigeria's two homegrown *Bt* cotton varieties: MRC 7377 BG 11 and MRC 7361 BG 11. The cotton has been genetically modified to include a gene from *Bacillus thuringiensis* to combat insect attack. Environmental impact assessment shows Nigeria *Bt* cotton is safe and possible strategies towards sustainability, improvement of the recorded success and the fiber quality were also suggested. Here, an outlook of Nigeria cotton revolution is presented and the role of transgenic cotton (*Bt* Cotton) in revitalization of the cotton farming situation is discussed. The paper highlights challenges facing cotton sectors in Nigeria and even in Africa and demonstrates how reform in the sectors is the key to sustaining growth, improving competitiveness and reducing rural poverty. It provides national and regional policy makers with a number of recommendations based upon the observable lessons of past reform programs.

Keywords: Nigeria, *Bacillus thuringiensis* Bt, Bt cotton, cotton fibre, genetic engineering

Introduction

Cotton (*Gossypium* spp.) is an important economic crop and the largest source of textile fiber in the world. Tetraploid upland cotton (*Gossypium hirsutum* L.) is a globally important crop grown primarily for its fiber, and its production is a vital part of the economy, politics, and society in many countries (Yu *et al*., 2012). Cotton is a plant known majorly for its cellulose abundant fiber. Cotton is a soft and fluffy staple fiber that grows in the boll or a protective capsule around the seeds. It is a shrub belonging to the plant family *Malvacea* and the genus *Gossypium* which comprises of 50 species (45 diploids 2n =2×=26; and 5 tetraploids 2n= 4×=52, Fryxell *et al* ., 1992). Out of the 50 *Gossypium* species, four have been domesticated, including two tetraploid species, *i.e.*, *Gossypium hirsutum* 'Upland cotton' and *Gossypium barbadense* 'Pima or 'Egyptian cotton', which are the most cultivated species (Mehboob-ur-Rahman *et al.,* 2011), and two diploids: *Gossypium arboreum* 'Tree cotton' and *Gossypium herbaceum* (Rajasundaram *et al* ., 2014). Cotton is considered as the foremost commercially important fiber crop and is deemed as the backbone of the textile industry (Vajhala, 2012) [35].

Cotton is still a rare economic success story in Sub-Saharan Africa. While the continent's share of the world's agricultural trade fell by about half from 1980 to 2005, its share of world cotton exports more than doubled. Cotton is a major source of foreign exchange earnings in more than 15 countries of the continent and is a crucial source of income for millions of rural people. "Organization and Performance of Cotton Sectors in Africa" provides an in-depth comparative analysis of the outcomes of the reforms that have been implemented in Sub-Saharan cotton sectors and of the linkages between sector organization and performance.

Historically, cotton is native to tropical and subtropical regions around the world including the America, Africa and Asia. The greatest diversity of wild cotton species is found in Mexico, followed by Australia and Africa (Colleen, 2005) [4]. Cotton has been spun, woven, and dyed since prehistoric times. It clothed the people of ancient India, Egypt, and China. Hundreds of years before the Christian era, cotton textiles were woven in India and their use spread to the Mediterranean countries and beyond (Colleen, 2005) [4]. Cotton has been used for millennia in the confection of fabric, with the earliest known use dating from 12,000 years B.C. in Egypt, and remains today the most widely used textile fiber. Numerous synthetic fibers, such as polyesters, acrylics, polyamides, and polypropylenes, have entered the market over the past 50 years, due to the excellent fiber quality and eco friendliness, cotton has still maintained its strong consumer demand worldwide that cotton textiles represent more than half of the global textile market, and the demand is expected to continue.

Nigeria is the most populous and economy rich country in Africa as well as a major contributor to Africa economy. Cotton has significant impact on its economy growth. This review presents Nigeria cotton farming, and the challenges posed by textile industries as a result of lack of improved cotton seeds. Further, the invention of *Bt* cotton and its mechanism of action which provides solutions to the numerous challenges and set back seen in cotton farming in the previous years were also reviewed with much emphasis on the Nigeria cotton farming situation and success of *Bt* cotton.

General uses of cotton fiber

The cotton fiber is used in the textile industry and today, the world uses more cotton than any other fiber, processing and handling of cotton generates many business opportunities. All parts of the cotton plant are useful. The most important is the fiber or lint, which is used in making cotton clothes. Linters provide cellulose for making plastics and other products, are also incorporated into high quality paper products and processed into batting for padding mattresses, furniture and automobile cushions (Colleen, 2005) [4]. The left over from the cotton milling can also be used to feed livestock (ruminant animals). Cotton lint can be refined into cotton wools which are used as absorbent cotton. Several consumer goods are made from cotton which includes coffee filters: for making archival papers, for fish nets and book binding etc.

The constant increase in demand of cotton as against other manufactured synthetic fiber have been attributed to its natural comfort, performance, appearance, versatility, and the product and fabric development or the basis of price, quality, comfort, soft and unique spinning characteristics across a wide range of textile products. This spurs comparison of cotton fiber with other fibers. Firstly cotton fiber when compared with other plant fiber has the purest form of cellulose. Nearly 90% of the cotton fiber is cellulose. All plants consist of cellulose, but to varying extents. Bast fibers such as flax, jute, ramie and kenaf from the stalks of the plants are about three-quarters cellulose. Wood, both coniferous and deciduous, contains 40–50% cellulose, whereas other plant species or parts contain much less cellulose. The cellulose in cotton fiber is also of the highest molecular weight among all plant fiber and highest structural order “highly crystalline and oriented” (You-Lo Hsieh, 2016) [39]. Compared cotton fiber to animal fiber (wool) cotton fibers have no surface scales and are softer than wool. Further compared cotton fiber to the synthetic fibers, the entirety cotton fiber is a flat, twisted ribbon, with 50 to 100 convolutions per inch. The fiber has no sharply cut ends with a soft touch or feel. The fiber is environmentally friendly at the processing level unlike the synthetic fibers that cause environmental havoc. Cotton, with this high quantity, quality and structural order of the most abundant natural polymer, is viewed as a premier fibre and biomass with highest demand to the textile industries and the consumers. With the advancements in spinning technologies, the textile industry is placing an increasing emphasis on fiber quality for manufacturing. Premium prices are given for fiber with increased length, fineness, uniformity and strength. Improvements in fiber quality with the selection of longer staple varieties and introduction of new crop management techniques have met with limited success; however, all these could be linked to many countries enormous interest in the cotton plant of which in this review, Nigeria is specifically considered.

History of Cotton farming in Nigeria

For a long time, cotton farming was one of the major agricultural produce notable to Nigerians GDP. The value and importance of cotton to Nigerians was beyond local use only, but also for export, cotton farming was booming as government continues to support with about 24 states involved in cotton farming.

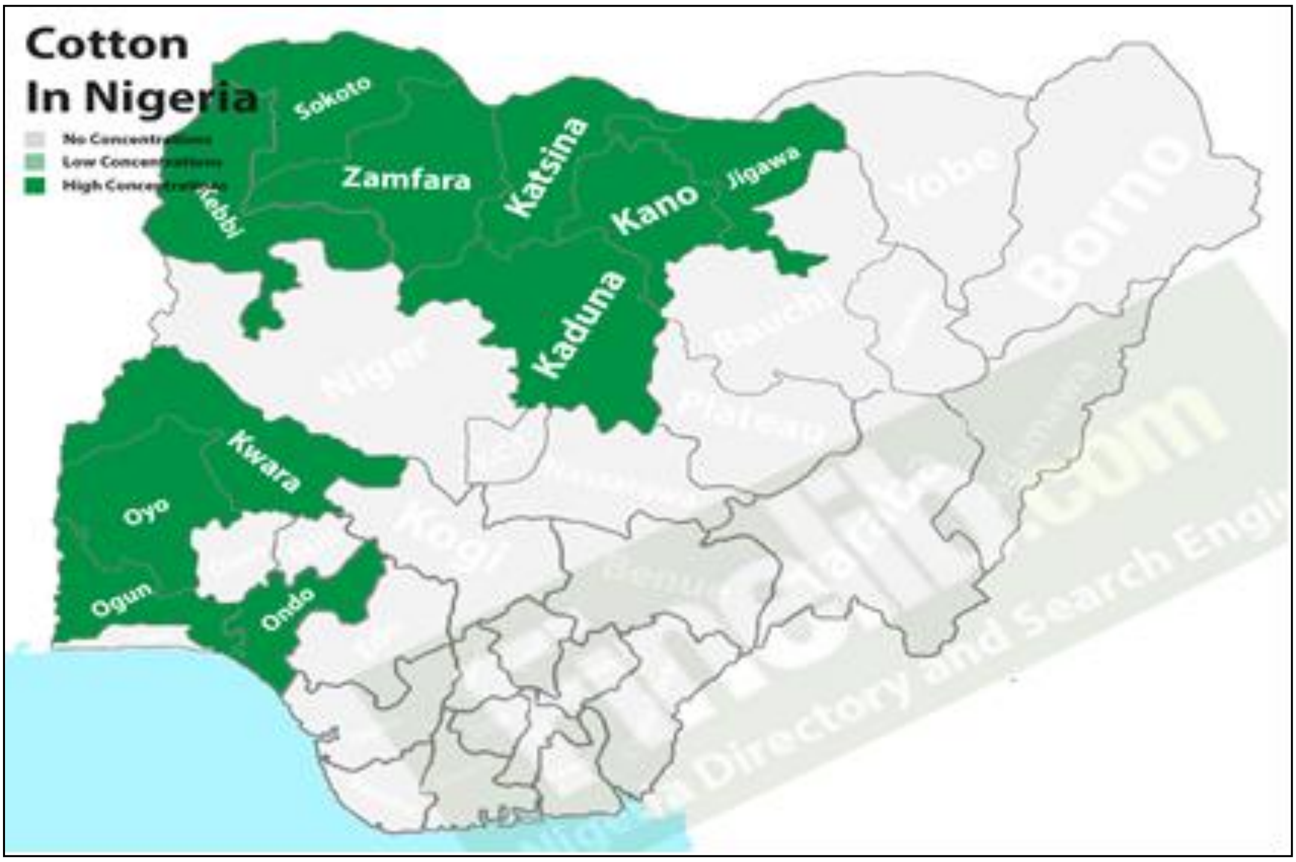

Fig 1: Nigeria cotton producing states (Since 1903)

The peak period of cotton production in Nigeria was 1976/77 when about 453,126 bales (183.43kg/bale) were produced. In the 1970s, the textile industry was Nigeria's second highest employer. At its peak from 1970–1990, it comprised about 130 modern factories and supported numerous other ancillary firms, providing about 350,000 direct jobs and 1.2 million indirect jobs according to the Nigerian Textiles Manufacturing Association. However, about 60 percent of the cotton raw materials were sourced locally thereby supporting agriculture, 25-30 percent of its production was exported according to the Central Bank of Nigeria's 1995 annual report. Today only about 33 factories remain standing and the local cotton industry is drowsy, production started to decline due to price fluctuation, pest infestation and other related problems. By 1983/84, only 69,000 bales were produced, while the demand was about 531,000 bales, which might have been satisfied through importation. Production in Nigeria is mainly from three cotton zones, namely, the northern zone (60%), eastern zone (10%) and southwest zone (30%). Production is dominated by small scale farmers; with farm sizes ranging from 3-5 ha all under rain fed ecologies. Seed cotton yield range from 0.6-1.5 tons per ha, and about 98 percent of the cotton grown locally belongs to *Gossypium hirsutum* and *G. barbadense* of 2 percent. Cotton story, value and farming changed in Nigeria as at the time interest was shifted to oil (1970-1980s). There was heavy decline in cotton farming for lack of fertilizer, frequency use of spray, lack of competitive price and market, and no improved seeds to replace the conventional ones. Pests and diseases were identified as the great threat to cotton production. The productivity of cotton crop worldwide is severely hampered by the occurrence of pests, weeds, pathogens apart from various environmental factors (Vajhala, 2012) [35]. The most important group of insects in terms of economic costs is the bollworm, which causes discoloration of the cotton lint, and automatically represents a serious decline in quality and substantial reduction in price. Aphids, bacteria blight (*Xanthmonas malvacearum)* are also examples of insects that affect cotton yield. Other causes of poor crop yield have been attributed to late planting and adverse weather condition. However as a result of the oil boom in Nigeria together with the outlined constraints, Government interest on agricultural sector generally declined. These general problems on agriculture posed severe effect on the cotton industries which have up to that time played an important role in the economy. Unfortunately, this decline has remained since that time and total production remains far below the national requirements of the textile and the oil mills. Furthermore, decline in cotton farming is increasing annually from 4% in 1980s to recently no significance in the economy. Cotton farming system in Nigeria is not different from usual worldwide common planting and harvesting methods. Restoring the cotton glory back in Nigeria has however became a subject of serious concern to every Nigerian. Nigeria Textile Manufacturers (2016) said "Genetically Modified insect protected (*Bt*) Cotton can play an immense role in restoring attraction to cotton farming as well as reviving and repositioning the textile sector in the country". The lack of confidence by participants across the cotton value chain over the years restricted the much-needed investment, so it is the most important to input in the industry "the cotton crop". Genetically Modified insect protected "(*Bt*) cotton" could improve cotton lint quality, farmers benefit and yields increase due to reduced insect-pest damage, the release and commercialization of *Bt* cotton could be related to successes recorded about the *Bt* cotton in other countries**.**

Bt cotton Breakthrough

The success of *Bt* cotton can be traced as far back as 1901, Shigetane Ishiwatari firstly isolated the bacterium *Bacillus thuringiensis* (*Bt*) as the cause of the sotto (sudden-collapse) disease (Maureen & Mike, 2010). In 1911, Ernest Berliner isolated bacteria that had killed a Mediterranean flour moth and rediscovered *Bt*. He named it *Bacillus thuringiensis* after the German town Thuringia where the moth was found. Berliner (1915) reported the existence of a crystal within *Bt*. Hannay, Fitz-James and Angus (1956) found that the main insecticidal activity against lepidopteran (moth) insects was due to the parasporal crystal. With this discovery there came increased interest in the crystal structure, biochemistry, and general mode of action of *Bt*. Success reports were started from 1958, the US commercialized *Bt*, *Bt* was registered as a pesticide to the EPA (1961). Use of *Bt* increased in 1980 when insects became increasingly resistant to the synthetic insecticides, the scientists and environmentalists became aware that the chemicals were harming the environment. Organic *Bt* affects specific insects and degrades rapidly in the environment. Until 1995, it became feasible to move the gene that encodes the toxic crystals into a plant. The first genetically engineered plant "Corn" was registered with the EPA. During this same period, cotton was facing serious harm by the pressure of Tobacco Budworms, Cotton Bollworms, and Pink Bollworms. In 1995, attacks from these pests reduced US cotton yields over 4% and over a quarter billion dollars' worth of cotton. At this important point, biotechnology came into develop such a strain of cotton which could be resistant to the most common pests which cause large losses worldwide. *Bt* cotton was introduced into US agriculture in 1996. The contribution of *Bt* cotton brought the significant decrease in the cost of pesticides applied and a big boost in the amount of cotton produced, which was reflected in the reduction of cotton prices in the US between 1996 and 1998. The Cotton Bollworm, which was controlled using *Bt* technology in US, was the very dangerous pest worldwide. Traditionally, the Cotton Bollworm has been combated by the use of pesticides. However, in developing nations like India, there is a huge cost of using large amounts of pesticides, which typically cannot be afforded by marginal farmers. *Bt* cotton was developed with the intention of reducing the amount of pesticides, reducing the cost of growing cotton and reducing the environmental impact of heavy pesticide usage. *Bt* cotton developed by Monsanto (USA) quickly became widespread since the first commercial release in US and China in 1996, followed by its introduction in India in 2003.

Bt cotton success report

Transgenic plants expressing insecticidal Bt proteins alone or in conjunction with proteins providing tolerance to herbicide were revolutionizing agriculture (Shelton *et al* ., 2002). Transgenic cotton carrying the insect-resistant *(Bacillus thuringiensis: Bt toxin)* genes have proven efficacious in conferring Lepidopteran resistance in cotton. For instance, Kenya uses to produce 20,000 bales of cotton every year against a demand of 140,000, meaning they have to import the deficit. As the National Performance Trials for *Bt* cotton was completed, with *Bt* they can produce up to "260,000 bales". Like other countries, pests attack was the main reasons and caused cotton growing and textile industry abandoned, but *Bt* cotton was reviving them. In China, using historic data beginning in the 1950s there was a gradual increase in the cotton yield until late 1970s decline, due to bollworms infestation and resistance to chemical pesticides. The 1999 and 2000 production survey (Pray *et al*, 2001; Pemsel *et al*., 2005; Wang *et al* ., 2008) [38], *Bt* cotton continued to do well and increase yield in the northeast China (Yellow river) and Central (Yantze river) cotton zone after the introduction and spread of *Bt* cotton. In Sudan, *Bt* cotton was adopted in 2012 after the constitution of the National Biosafety Council. Only one variety, named Seini, was released for commercialization (Naglaa, 2013) [20]. Seini is a Chinese *Bt*-cotton genotype (*G. hirsutum*) carrying the *Cry1A* gene from *Bacillus thurengenesis* (*Bt*); a hybrid CN-C01 against bollworms was approved for commercial production by the Chinese National Authority in 2004. *Bt* cotton out-yielded the non-*Bt* varieties more than 5-6 times evaluated in open field trails in six environments in Sudan. *Bt* cotton contributed to a reduction in the damage caused by sucking insects and in the improvement of cotton quality by limiting stickiness. The cost of cotton insecticides and application for non *Bt* cotton cost $892 per hectare, reducing to $586 for *Bt* cotton, a savings of about 35%. The net profit for farmers from cultivating *Bt* cotton was estimated to reach $405 per hectare. South Africa began plant *Bt* cotton in 1998. The adoption rate continued to increase and the *Bt* cotton coverage reached 95% in 2007 (James, 2007). *Bt* cotton was adopted by large-scale farmers and smallholders in South Africa. Besides the economic benefits, the number of insecticide sprayings related to *Bt* cotton plantings had decreased with a beneficial impact on the environment (Morse *et al* ., 2006) [18]. Following a multi-year slump, the Philippines cotton industry was anticipating a renaissance through the help of an innovative, science-based crop. The introduction of the *Bt* cotton variety revived the local cotton industry according to Edison Rinen (Phil FIDA). While farmers usually get maximum of two tons per hectare in planting non-*Bt* cotton, five to six tons per hectare is attainable with *Bt* cotton. India ranks third in global cotton production after US and China, and with 8-9 million hectares grown each year, India accounts for approximately 25% of the world's total cotton area and 16% of global cotton production (Barwale *et al*, 2004) [1]. However, a major limiting factor to both cotton production and quality in India was damage due to insect pests, especially bollworms. Following the release of *Bt* cotton in India, it had a higher yield than non-Bt types and required less insecticide which can be expensive and labour intensive for application (Barwale *et al* ., 2004; Bennett *et al* ., 2004; Morse *et al* ., 2005; Naik, 2001; Pemsl *et al,* 20004; Qaim & Zilberman, 2003) [1, 2, 19]. *Bt* cotton also tends to have a better quality from less damage and staining from bollworm attack. (Barwale *et al* ., 2004; Bennett *et al* ., 2004; Morse *et al* ., 2005; Naik, 2001; Pemsl *et al*., 20004; Qaim & Zilberman, 2003; Uma *et al*., 2016) [1, 2, 19]. Burkina Faso, in collaboration with Monsanto, two regional Bolgard II varieties were generated and commercialized in 2008 (Vitale & Greenplate, 2014) [37] from the introduction of biotech crops in 1996, 175.2 million hectares of biotech crops were grown globally. In 2013, genetically engineered cotton was grown on 33.1 million hectares in 15 countries around the world (most of it in India, China, Pakistan and US). In 1997, China became one of the first countries to commercialize *Bt* cotton followed by India. China and India now have developed their own *Bt* cotton hybrids. All these probably could be summed as the catalyst to Nigeria interest in *Bt* cotton commercialization for the revitalization of her cotton farming.

Nigeria *Bt* cotton success report

Genetically engineered cotton varieties, expressing *Bacillus thuringiensis cry* genes, proved to be highly successful in controlling the bollworm complex. Various other candidate genes responsible for resistance to insect pests and pathogens, tolerance to major abiotic stress factors such as temperature, drought and salinity, have been introduced into cotton via genetic engineering methods to enhance the agronomic performance of cotton cultivars (Vajhala, 2012) [35]. This technology has solved the challenges pose to cotton farming in many countries including Nigeria. In 2018, the transgenic cotton was commercialized as the first genetically modified crop to boost the textile industry in Nigeria Two homegrown cotton varieties: MRC 7377 BG 11 and MRC 7361 BG 11 were developed by Mahyco Nigeria Private Ltd. in collaboration with the Nigeria Institute for Agricultural Research (IAR). Nigeria's new *Bt* cotton was suitable for cultivation in all of Nigeria's cotton growing zones and produced 4.1 to 4.4 tonnes per hectare compared to the local variety, which yields just 600 to 900 kilograms per hectare. In addition to the pest-resistant traits, they offer early maturity, fiber length of 30.0 to 30.5 millimeters, fiber strength of 26.5 to 27.0g/tex (tenacity) and micronaire (strength) of 3.9 to 4.1. The new varieties have saved farmers the trouble of contending with the local conventional variety, which is no longer accepted at the international market. Nigeria *Bt* cotton has proven safe, no negative impact on both the environment and health of the consumers. The bollgard cotton reduced cotton production costs and insecticide use for the control of tobacco budworm (*H. virescens*), cotton bollworm (*H. zea*), and pink bollworm (*P. gossypiella*) (Perlak *et al*, 1990; Perlak *et al*., 2001) [21, 22]. Agronomic traits, fiber quality, and seed composition remain unchanged in the transgenic cotton. However, negative effects from a transgene may exist. For example, in the case of Roundup Ready Flex cotton, a 14-location field study in 2002 showed that transgenic Coker 312 had reduced overall boll (4.56 vs. 4.70 g /boll) and seed size (9.56 vs. 9.83 g 100/seed), and micronaire (3.76 vs. 3.88 units), as compared with its nontransgenic Coker 312, although these differences were within the variation common for commercial cotton. Other fiber quality traits including length, strength, and elongation were not changed (Horak *et al*, 2007). According to the reports on "several food safety and risk assessment studies of *Bt* cotton", it is confirmable that *Bt* cotton hybrids pose no obvious toxic effects on non-target species. The analysis of Bt protein in the soil indicated that Cry1Ac protein are degradable without negative environmental impact. Further evaluation of the impact of GM protein leached by roots of GM cotton on the soil microflora showed that there was no significant difference in population of microbes and soil invertebrates between both samples. Food safety assessments have shown that nutrient composition analysis of proteins, carbohydrate, oil and calories also disclose no obvious difference in the *Bt* and non *Bt* cotton seed, this was observed after comparison of animals fed with *Bt* and non *Bt* cotton seed thus, supporting the campaign that *Bt* cotton is as safe as the conventional cotton in almost every ramification. From the observed and documented successes of *Bt* cotton left for Nigeria is to keep long what they have started. Sustainability strategies therefore became the issue of serious concern. As earlier reported, the majorly grown cotton species in Nigeria is the upland cotton (*Gossypium hirsutum*), researches have advance enough on *G. hirsutum* thus, the development of Nigeria cotton data-base will help to sustain the technology as it has done in US and China. Undoubtedly, *Bt* cotton will promote Nigeria to produce a quantity of high quality cotton, propelling it to a place of leadership in the continent's textiles industry (Gakpo, 2018). Nigeria *Bt* cotton success and Nigeria's decision to commercialize *Bt* cotton has revived hopes for the novel variety in Ghana. Science-focused civil society groups are confident, Nigeria's move will serve as a good role model and push players in the agricultural space to resume work on processes to make *Bt* cotton available to farmers in Ghana (Gakpo, 2018). Nigeria's green lighting of *Bt* insect resistant cotton and cowpeas may spur Africa's acceptance of GMOs (Steven, 2019)

Conclusion

Among others, the major drawback of cotton domestication is the lack of genetic diversity. This lack of genetic diversity is observed more in *Gossypium hirsutum* (Mehboob-ur-Rahman *et al*, 2011). *Gossypium hirsutum* is the major Nigeria cultivated cotton which as a result of many challenges in the past faded. Advancement in cotton genetics '*Bt* cotton' paved way to revitalization of cotton farming and the textile industry. However, more on the sustainability of the *Bt* cotton success and development of improved program to avoid reoccurrence of the initial set back and reappearance of undesirable trait in the future. The development of resources could be tagged 'Nigeria cotton genome resources' to enhance research on Nigeria cultivated cotton, which will necessitate fast improvement is substantial. Recall, Nigeria cotton in addition to the pest-resistant traits, they offer early maturity, fiber length of 30.0 to 30.5 millimeters and fiber strength of 26.5 to 27.0g/tex (tenacity) and micronaire (strength) of 3.9 to 4.1. The price received for cotton is dependent on the quality of each bale of cotton and long, uniform, strong, fine and mature cotton fiber provides better returns to growers and opens more market opportunities for premium fabrics. The Nigeria cotton fibre strength is within average, the micronaire quality is within Grade 5 compared to Australian cotton with good strength and micronaire (Grade 6 and Grade 7 respectively). The Nigeria cotton length is also shorter compared to Austrian cotton that is above 30mm. Therefore, approaches towards improving these qualities are necessary. The approaches include integration of the majority of crop management factors would increase/optimize yield and fiber quality. However, biotechnology approach would always be better to improve and sustain effective fiber quality, which has been pointed as the primary focus for spinning mills in Nigeria. Improved cotton yields and fiber quality have continued to be realized through modern biotechnology-based plant breeding. There are adequate genetic resources available for innovative cotton breeders to make more progress, but new tools being offered by modern molecular technologies will achieve those gains more efficiently (Greg *et al*, 2014). Advances in fiber quality science have been made in cotton biotechnology by improving the understanding of fiber development process that contribute to fiber quality through gene discovery, genome mapping, identification of linked molecular markers and key functional genes. Combining traits of GM cottons can also contribute to the sustainability of the successes already recorded. Currently we target to genetically improving the fibre quality of *Gossypium hirsutum* which is the dominated cotton species in Nigeria. The genes from known and documented high quality fibre producing are identified by bioinformatics. Success of the research may bring about the integration of it approaches towards improvement and sustainability of home (Nigeria) grown cotton fibers. This genetic engineering approach will confer useful agronomic and fiber traits qualities and lower the cost of production, improve yield and promote environmentally friendly farm practices. Several genes for stress resistance and fiber modifications are being tested in various laboratories. New genes for insect and herbicide resistance are being sought as well. A strategy to modify fiber using metabolic pathway engineering to produce aliphatic polyester compounds is under development too. Particle bombardment technology has been developed to introduce and test genes in elite varieties of cotton, without the need for regeneration or other tissue culture practices and backcrossing. These developments will lead to improved agronomical and fiber traits in cotton and enable the industry to expand its market share in the near future.

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