



Review

# Improving Crop Productivity and Ensuring Food Security through the Adoption of Genetically Modified Crops in Sub-Saharan Africa

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**Abstract:** The food security challenge is one of the most topical issues of the 21st Century. Sub-Saharan Africa (SSA) is the least food-secure region, and solutions are constantly being sought to alleviate the problem. The region's exponentially growing population is in dire need of affordable and nutritious food. The "Gene Revolution" (genetic engineering) presents opportunities in which food security can be ensured in SSA. Genetic modification (GM) has potential to solve myriad problems currently being experienced in SSA agriculture, hence improving yields and reducing the costs of production. Most of the SSA countries have a precautionary stance towards GM crops; thus, only a handful of countries have approved the commercialized production of transgenic crops. The lack of understanding and sound knowledge about the GM system is reflected in the formulation of policies and regulatory frameworks for biosafety and their implementation. There is need to conscientize the policymakers and the public about the general principles of genetic engineering for better decision making. Considering the multiple beneficial aspects demonstrated by transgenic crops it will not be prudent to ignore them. The versatility of GM technology makes it adaptable to the food crisis in SSA.

**Keywords:** genetic modification; food security; Sub-Saharan Africa; transgenic crops; genetic literacy



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## 1. Introduction

Sustainable development goal number 2—Zero Hunger—is premised upon ensuring enough and quality nutrition for the entirety of the world's population [1]. Achieving this goal is not without challenges. In the wake of climate change and burgeoning population, this becomes an uphill task. The most affected region in terms of food security is Africa, particularly Sub-Saharan Africa (SSA) [2]. Sub-Saharan Africa ranks highest on the Global Hunger Index (GHI) (Quaye et al., 2012). Genetic modification (GM) has the potential to address the malnutrition challenges being experienced in Sub-Saharan Africa (SSA).

South Africa, which has been commercially growing GM food crops for more than 20 years (since 1998), is a classic example of how genetic engineering (GE) can be a solution to this food conundrum sweeping across SSA [3]. Though most of the neighboring countries are food-scarce, the nation has been resilient and even exports some grain in the region. The fact that more than 80% of the maize (*Zea mays*) grown in South Africa is Bt maize clearly unravels the strategic move to ensure food availability for the nation's populace, whose staple diet is maize [4]. Moreover, when the fall armyworm (*Spodoptera frugiperda*) spread to Africa in 2016, South Africa did not suffer much damage since Bt maize has considerable

resistance to this pest [5,6]. In East Africa, Kenya serves as an example of the progressive decision of adopting Bt cotton. In 2018, the President lifted a ban on the cultivation or importation of GM crops except for conducting confined research trials [7]. This was driven by the conscious decision to revamp the national textile industry, hence contributing to the growth of the economy. This move of granting the cultivation of Bt cotton was well-received by farmers and proves to be a promising venture [8]. Other Eastern African nations can tap into the Kenyan experience and adopt GM crops as well. The development of an insect-resistant GM cow-pea variety in Nigeria is a milestone reached [7,8]. This is an illustration that African seed producers can develop indigenous GM crop varieties, thus contributing to food security.

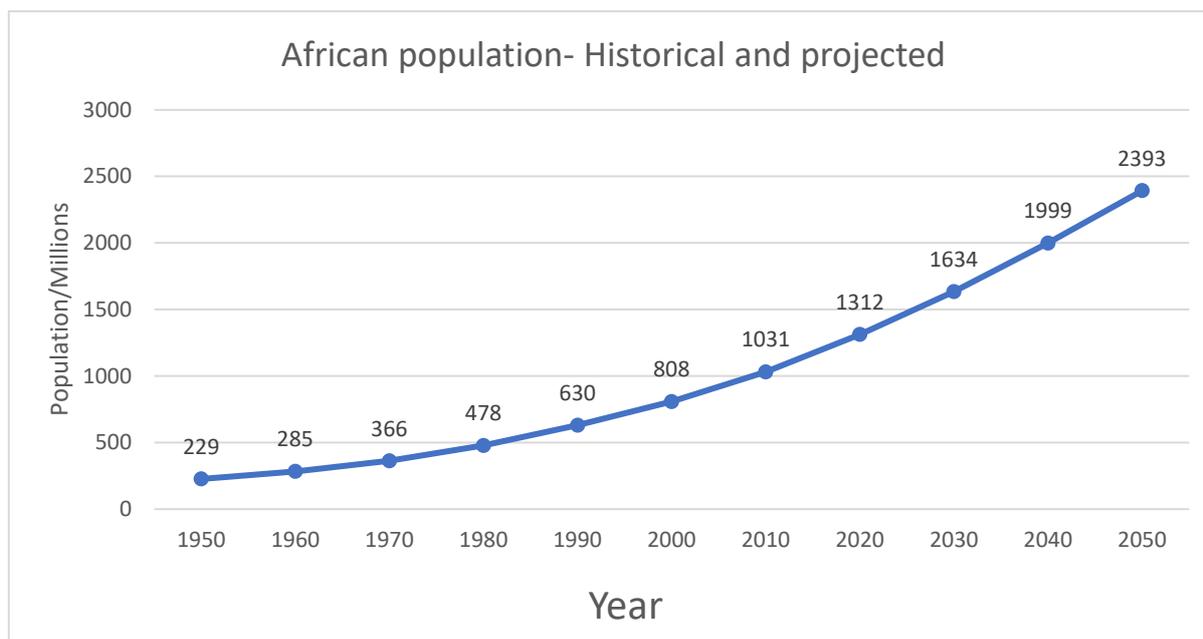
The peer-country effect is significant in shifting the precautionary stance towards GMOs. When Burkina Faso decisively began trials of Bt cotton, neighboring West African countries involving Nigeria and Ghana followed suit, passing GMO legislation and embarking on confined field trials (CFTs) [9]. Should this trend continue, this will mark the beginning of the “Gene Revolution” in Sub-Saharan Africa, a path leading to food security. Genetic modification can be applied to effectively offset the challenges faced by the area in producing food. The system has been applied in plants for more than 30 years and has proved to be immensely beneficial [10].

With the current state of affairs, African farmers cannot compete effectively on the global market with American and Asian producers who enjoy the economic advantages that come with the use of GM crops [11]. As the cost of production reduces and higher yields are achieved as a result of using pest-resistant varieties, the farmers gain leverage to compete on the basis of price on the global market. The same cannot be said for the SSA farmers who are riddled by high costs of production as well as low yields due to pests and diseases. Adoption of GM technology across the region will be a turning point in SSA agriculture.

## 2. Ensuring Food Security for the Growing Population

Africa’s population is growing exponentially. Figure 1 shows the African population growth curve highlighting both the historical and projected growth from 1950–2050. The growth pattern shows a doubling of the population in every 30 years (generation). In the period 1950–1980, the population more than doubled by 20 million people, from 227 million to 478 million, sequentially more than doubling with 75 million to 1 billion and 31 million people in 2010 (after 30 years). In the 70 years that have ensued from 1950–2020, the African population has increased 5.7 times (almost 6-fold). There is need to ensure that the level of food production keeps up with the burgeoning population. However, the most affected in terms of food security are the people settled in Sub-Saharan Africa. About 25% of the SSA population (approximately 240 million people) are undernourished [2].

In SSA, the food consumption rate is fast outpacing the production rate, resulting in high importation levels to offset the deficit. Bazuin et al. [11], reported that the import levels for rice, one of the important cereal crops in the region, are rising at a rate of about 8.4% annually, translating to 20% of the aggregate world rice imports. This, therefore, demonstrates that improving production of strategic food crops is a matter of great urgency. The subsistence approach towards agricultural production coupled with use of less advanced cultivars not adapted to the current abiotic and biotic phenomena has resulted in poor yields. It is logical that farming methods that lower yields require more arable land for production of the same amount of food [8].



**Figure 1.** African population growth curve. Source: The graph was constructed using data from African Economic Outlook 2015.

The sustainable development goals have a provision for ensuring food security as well as promoting improved nutrition across the world. The inverse relationship of a growing population and dwindling agricultural productivity puts SSA at greater risk of food insecurity [1]. One of the problems posed by the exponential population growth is the pressure it exerts on production resources such as land; for example, the most fertile regions in SSA tend to be highly populated and in a paradoxical way, this leads to the degradation of those environments [1,12]. The high population densities in productive areas of the region are directly proportional to the farm sizes, generally small landholdings of 2–5 hectares. The small fragmented landholdings combined with poor production methods or agricultural practices set the yields on a downward trajectory. Having poor yields means that the farmers need more land to produce sufficient food or make enough income to invest in their agricultural enterprises [13,14].

The growing rate of urbanization in a region that relies mostly on subsistence farming aggravates the situation. The subsistence-smallholder farmers characterize SSA with the surging demand for food in the urban setups, thus driving food prices upwards [2,11,15]. Moreover, the small landholdings are divided between food-crop production and export-crop production. To augment their incomes, most SSA farmers grow cash crops such as tobacco, cotton, coffee, etc., and therefore there is not much land left for sufficient food production [1].

Transgenic plants can help in addressing this food-security conundrum. The GM crops, which offer multiple advantages such as disease and pest resistance, high nutrient-use efficiency, enhanced water-use efficiency, herbicide resistance, improved shelf-life and better nutritional composition can be an effective solution [16]. This provides an opportunity to employ a holistic approach towards the many facets of this problem instead of trying to find individual modus operandi of approaching each aspect. Moreover, with the right policies put in place and adequate investment, this is a very expeditious way of turning things around.

### 3. Bio-Fortified Transgenic Food Crops to Curb Malnutrition

Genetic modification is also a vehicle for micronutrient intervention, i.e., fortification, supplementation and dietary diversification [17]. This offers the means to address the malnutrition challenges debilitating the SSA population. The Africa Bio-fortified Sorghum

is one such initiative that is at an advanced stage towards developing sorghum varieties with high levels of vitamin A, iron and zinc using biotechnology tools [18]. This will contribute immensely to solving the problem of vitamin A, iron and zinc deficiency in SSA. The deficiency of those elements is associated with blindness, and therefore biotech can contribute positively towards the well-being of the people [18,19].

Another important project designed to tackle the problem of malnutrition in SSA is the Bio Cassava Plus initiative [20]. Cassava is a vital source of carbohydrates for more than 250 million Africans [21]. Incorporating important mineral elements such as iron and zinc, which are deficient in the SSA population, can ameliorate the humongous problem of malnutrition [22]. The use of supplements in the form of tablets is costly and less practical for the resource-poor populace. Hence, biofortification serves a more pragmatic alternative. The genetic transformation approach has enabled the augmentation of zinc content in the cassava tubers of variety 60,444 widely grown in West Africa by overexpressing an Arabidopsis ZIP plasma membrane zinc transporter [21].

Biotechnology tools can effectively bring about quality and nutritious foods for the whole region. Methods such as gene stacking are of great importance in developing crops that have multifunctional phenotypic characteristics [23,24]. For example, the variety 60,444 used as the background cultivar in the Bio Cassava Plus is susceptible to Cassava Mosaic Disease (CMD); therefore, inasmuch as attention was given towards improving the nutritional aspect of the crop, disease resistance and shelf had to be considered seriously as well [21].

#### 4. Coping with Climate Change and Environmental Challenges

The climate-change challenge is a reality and has wreaked havoc in SSA agriculture. Most of SSA agriculture is rain-fed, and thus the erratic rainfall patterns experienced in the last couple of decades have seriously exacerbated the situation. Though some seed production corporations in the region are making efforts towards the development of drought-resistant varieties for strategic crops such as maize, rice and wheat, the classical approach to plant breeding takes long to come up with a new variety. Incorporating genetic engineering in the breeding programs will accelerate the rate at which drought-resistant varieties are produced. This is made possible by the fact that GE involves a few genes, unlike millions of genes as in the case of conventional breeding [10].

The alternation of drought and floods in SSA has seriously affected productivity on the fields and even led to the worsening of land degradation [4,25]. Arable land is under threat from erosion and desertification. Figure 2 indicates a rift in a Kenyan field leading to the formation of gullies. Some water bodies are shrinking, hence affecting water supply for farming activities. The temperature increases across the globe create conducive breeding conditions for most crop pests [26]. This increases pest populations and genetic variability. Moreover, water-stressed plants are more nutritious for insect pests [27]. Dehydration in such plants results in the concentration of amino acids favored by the pests. The insects instinctively target water-stressed plants. A whole field of moisture-deprived plants is highly predisposed to pest attack. Healthy lush plants of certain species produce secondary metabolites that they secrete in defense against pest attack. Unfortunately, drought-affected plants, due to the lack of moisture, fail to produce enough amounts of this sap and therefore succumb to attack. The pests, upon finding such susceptible hosts, release pheromones signaling other insects of their species to also come prey on the crop [27]. The crop succumbs to attack as the pest population thrives. The pest migration trends show that in the near future a great many invasive insect species will migrate from the temperate regions to Africa as result of temperature increases. Insects that are ectothermic thrive well in high-temperature environments that favor their metabolism and increase their longevity [28].

To cope with these challenges, GE can be used to expeditiously develop with high water-use efficiency (WUE) as well high nutrient-use efficiency (NUE). Such varieties are able to survive harsh environmental conditions and maintain significantly high yields as

they channel much of the water and nutrients they take up towards biomass production. Li et al. [29], did a meta-analysis of data from 130 publications and discovered that genetic transformation led to increased NUE of three strategic food crops (maize, rice and wheat).

The use of herbicide-tolerant GM crops such as roundup ready maize and soybean comes with indirect environmental benefits by enabling no-till/zero-till farming [30]. This has the potential advantage of stabilizing the soil profile as well as maintaining the soil structure in erosion sensitive areas of SSA, for instance the East African Rift region where gully erosion is rampant [31].



**Figure 2.** A rift in a Kenyan field leading to the formation of gullies. Source: CNN Africa.

There are environmental concerns that the Bt proteins produced by GM crops may affect economically beneficial insects such as bees. The GM crops have very high selectivity; they are not harmful to non-target organisms or insects. The proteins they produce affect specific pest families. Only the insects that have receptors that can recognize in their intestinal walls can be affected [32]. Therefore, bees and other beneficial insects are not susceptible.

### **5. Genetic Modification an Alternative Management Strategy for Fall Armyworm**

The arrival of the fall armyworm (FAW) on the African continent in 2016 resulted in a chaotic state of maize fields across SSA [33]. Maize is a staple for the majority of the SSA population, and hence the impacts of the FAW on the crop had adverse reverberations felt across the whole region. Some surveys that were conducted in 2017 revealed that yield losses of 45% and 40% were experienced in Ghana and Zambia, respectively [34]. Consequently, the effect was felt at the household level. Finding worthwhile solutions to this emerging problem cannot be overemphasized [33].

Resistance breeding is one of the components inherent in integrated pest management, and GE (genetic engineering) can be an effective tool to attain this object. Host resistance as a pest management strategy is highly suited to the production models used in this region, since most farmers cannot afford to buy the pesticides required to control this pest. This will achieve twin objectives simultaneously, i.e., reducing production costs coupled with high yields.

Lessons can be learned from the major maize producers in the world, the United States, Brazil, Argentina and Canada, where transgenic resistance has been the most effective against FAW [35]. Moreover, transgenic resistance has been proven to provide

better protection of the crop than native resistance [6]. Native resistance provides significant but minimal protection. This means that the varieties recommended by maize breeders on the fundamentals of native resistance will not bring forth a level of protection as that of transgenic plants. Though there are Africa specific FAW haplotypes not synonymous with the known American populations, native resistance in the African maize gene pool is nonexistent [5,6,33]. The advantage of using transgenic host plant resistance as an FAW management strategy has been demonstrated in South Africa (SA), the only African country where Bt maize has been approved for production [36]. The transgenic variety MON89034 has exhibited satisfactory resistance to FAW, and hence transgenic host resistance is currently the most effective control strategy in South Africa, although the country's cooler subtropical climate may also have been unfavorable to the pest problem there. Botha et al. [5] carried out some studies in SA to evaluate the resistance of existing Bt maize. The study demonstrated that the Cry 1A.105 + Cry 2Ab2 proteins produced by the Bt maize were effective in causing considerable larval mortality of nine FAW populations. These Cry proteins may also be genetically engineered with others such as Vip3Aa20, which is potent against FAW, helping manage the insect resistance to Bt maize [37–39]. Based on these results, the approval of Bt maize in other countries in the SSA can reduce the impacts of this pest on the staple crop of the region. Consequently, the whole region will be food secure, thus improving the quality of livelihoods.

## 6. CRISP-R Technology: Viral Disease Management Applications

The climatic changes currently prevailing are synonymous with the development of epidemics in the fields. Food security in SSA is under serious threat from viruses from the following families: Geminiviridae, Potyviridae, Tombusviridae, Closteroviridae and Nanoviridae [40]. A novel and effective way of dealing with these viruses is the use of clustered regularly interspaced short palindromic repeats (CRISP-R). This biotechnological tool allows for targeted mutagenesis of the viruses in planta. Ali et al. [41], used CRISP-R to target TYLC in *Nicotiana benthamiana*, and this significantly reduced or attenuated disease symptoms. This demonstrates that CRISP-R can be used to develop plants that are resistant to DNA viruses. This is a faster way of incorporating resistance genes in plants than conventional breeding, in which a donor plant would have to be found, then cross with the cultivar of interest, select individuals that possess the desired traits and carry out back-crossing.

Genetic engineering offers a wide range of tools that can be used against plant diseases, especially viral diseases that are cumbersome to control using chemical methods [40]. It is quite unfortunate that all these promising technologies with potential in significantly reducing the impacts of pests and diseases in SSA are not approved for use in most nations within the region.

## 7. Reducing Postharvest Losses through GM Technology

One of the problems faced by the smallholder SSA farmers is that of postharvest losses (PHLs). The region experiences aggregate (comprehensive for all crops) PHLs as high as 37% and 20% for cereals that form the basis of the staple diet [42]. Moreover, the high temperatures being experienced across the region as a result of climate change aggravate the situation, increasing the losses since most loss-causing agents (pests and pathogens) thrive in warm temperatures. This threatens food security and incomes of the farmers [43]. Therefore, practical solutions are needed to contain this situation.

GM crops can be a way of solving this problem. Genetic engineering can be employed to retard the activity of cell-wall degrading enzymes. Furthermore, GM technology can be used to interfere with ethylene production, thus slowing the senescence process and reducing the chances of infection by opportunistic pathogens [44]. RNA antisense provides another avenue of regulating the genes that code for fruit ripening [45]. Gupta et al. [46], overexpressed the oat (*Avena sativa*) arginine decarboxylase (AsADC) gene in tomato to

accumulate polyamines and increase shelf-life. The transformed plants had better shelf-life and enhanced levels of vitamin C and lycopenes.

### 8. Approaches to Reduce Selection Pressure by Transgenic Crops

Just like any other method that relies on the use of toxins to kill pests and pathogens, pest resistance to transgenic crops has been reported [3,35,47]. Several strategies are being developed to cope with this phenomenon, for instance, gene stacking, use of refuge crops and mixing Bt seed with non-Bt seed [48].

Gene stacking is the introgression of multiple genes either simultaneously or sequentially in a genome [24]. This method has vast potential in delaying pest resistance in GM crops and follows the same pattern as the use of different modes of action in chemical pest control. Gene stacking allows for a highly effective and durable form of resistance than monogenic technology in transgenic plants [47]. This also improves polygenic agronomic traits. Genetic engineering is advantageous in carrying out gene stacking over conventional breeding since the latter may lead to linkage drag [24]. Gene-stacking technology has progressed over the years, and methods such as Gene Assembly in Agrobacterium by Nucleic acid Transfer using Recombination Technology (GAENTRY) have been developed that can carry multiple genes and transform plants successfully [49]. McCue et al. [50] used the GAENTRY system to stack 8 genes with different phenotypical functions including herbicide resistance, insect resistance and anthocyanin accumulation in the potato crop (*Solanum tuberosum*).

Another way of delaying insect resistance to Bt crops is the use of refuge crops which are susceptible to pest attack. This reduces the selection pressure and promotes the survival of homozygous susceptible individuals [51]. The susceptible members of the gene pool will then mate with those carrying the resistance genes, leading to heterogeneity and thus delaying the build-up of a resistant population [48].

### 9. GE a Breeding Tool Not the Source of Problems

In most SSA countries the general view is that GMOs are potentially injurious to the environment and hence are treated with a great deal of mistrust [11]. The government authorities managing the enforcement of biosafety regulations and supervising the investigation trials tend to be bureaucratic and unnecessarily drag the process towards final approval [9]. Genetic modification is a means to an end. It is a tool for producing various genomic combinations just like conventional breeding. The environmental potential hazards cited by the anti-GMO lobbyists are a result of the plant traits bred for, not due to the method of breeding used. A classic example is that of herbicide tolerance, a phenomenon which also exists naturally since some plants are tolerant to one or more herbicides; it is not GE that is responsible for the interspecific breeding that occurs between the crop with the resistant gene but the trait bred for [52].

Therefore, the crop trait is of concern and not the method used to develop such genotypes. This aim can be reached by other breeding methods which may be laborious and time-consuming. Hence, emphasis should be put on the crop traits to be developed in a particular transgenic plant. There is need for a balanced view towards the GM crops. They can also contribute positively to sustainable development in the SSA in the same manner that has uplifted the livelihoods of resource-poor farmers in Asia and Latin America [53].

### 10. Reconciling the Environmental Concern Discourse with Naturally Occurring Transgenic Plants

In SSA as in Europe, the rationale behind the precautionary attitude to GM crops is predominantly the potential environmental hazards they may bring about. The use of the term, “Frankenstein foods”, reveals peoples’ thoughts about the nature of GM crops. It has to be understood that there are naturally occurring transgenic plants. Horizontal gene transfer is existent in nature, and about 7% of dicotyledonous plants are naturally transformed [54].

Horizontal gene transfer (HGT) is a process whereby genetic material is exchanged between distantly related genomes [55]. The mechanisms by which it occurs in eukaryotes are not fully understood and there are two schools of thought that can be used to explain this phenomenon. The first hypothesis is that pollination between the two genomes will not lead to regular fertilization but may cause some chromosomal disruptions, for example, chromosome fragmentation. The second theory proposes that the transfer of genetic material is facilitated by vectors such as bacteria, viruses and insects [55].

Research has demonstrated that the action of the *Agrobacterium tumefaciens* in nature gives rise to naturally occurring genetically modified plants [54]. The bacterium introduces its plasmid, i.e., part of its DNA, into the plant cells, resulting in the transformation of the plant. Naturally occurring transgenic food crops have been discovered, such as sweet potato (*Ipomea batatas*), banana (*Musa* spp.), tea (*Camelia sinensis*), etc. [54]. This means that even if artificial genetic transformation is not carried out, transgenic plants will still be produced. The unravelling of such information to the public would serve to dispel the skepticism and GMO phobia.

### 11. Promoting Genetic Literacy

The general populace needs to have adequate information and sound appreciation of genetic principles so as to make sustainable choices [56]. The basis of carrying out scientific research in any discipline is to reveal truths unknown to mankind. It is very important for policymakers to make pieces of legislation from a truth-guided standpoint. The word GMO (genetically modified organisms) has been associated with many negative connotations. Ironically, though negative attitudes are expressed towards the GMOs, there is very little public awareness on the subject [57].

With the advent of social media, unverified information spreads at an alarming rate. Gone are the days when people relied on mainstream media for information. In this era, people are constantly bombarded by information flows, some of which are not true. Unfortunately, very few people filter the information they receive and verify its authenticity. It is easy for anti-GMO lobbyist groups to spread incorrect information and set up anti-GMO campaigns supported by masses of people [58]. This is a wake-up call to the science community to bring the science to the consumer (information user). People need to be properly educated on the issues regarding genetic engineering and other related technologies. Research has revealed that pro-GMO discourses tend to be science-based and backed by facts from conducted studies, whilst the anti-GMO discourse is predominantly non-scientific and sentimental [59].

### 12. Development of Policy Frameworks That Capacitate Biotechnology Advancement

There is need for institutionalization of sound biosafety regulatory frameworks, investment and infrastructural provision for biotechnology in Africa [25]. Policy and institutional challenges contribute to the plummeting agricultural productivity in SSA. The resultant food scarcity translates to economic disadvantages as prices of food commodities surge, leaving millions of people vulnerable to starvation and malnutrition.

Kamanga et al. [60], proposed the establishment of the African Biotech Coalition (ABC), where all stakeholders, be it in the private sector or public sector, collaborate on biotechnology projects taking place on the continent. The coalition will have shared objectives such that all the parties involved speak with one voice, thus presenting a coherent argument and clear position to the people. This will also become instrumental in communicating the ends being sought by the various biotech projects carried out. The majority of the population is not well-informed about the GMOs, and hence the coalition can also take the initiative to educate the public through various communication channels [61].

Both public and private entities championing the use of GM crops in SSA need to apply the participatory model where the farmers do not feel as if they are at the peripheries but are an indispensable part of the projects [58]. This dispels the conservative attitudes that farmers in the region usually express towards new technologies and methods.

Politicians and the public are not highly involved in scientific development and technological advances. The GMO discourse in SSA is dominated by non-governmental organizations (NGOs) that supposedly represent the rural folk and are mostly left-wing and anti-GMO whilst the scientists and academicians are pro-GMO. The farmers who are the final consumers of these technologies and products are generally not informed about genetic engineering [62].

The level of investment towards biotechnology projects is very low in SSA. There is need to engage the private sector to invest in the development of GM crops across the continent. One of the reasons for this state of affairs is the lack of well-structured policy frameworks that are effectively implemented and not arrayed as frothy rhetoric. Investors need to be sure about the intricacies of the operations and regulations before they get involved. Regrettably, the ambiguity surrounding the GM crop policy in Africa is dissuasive to investors. The snail pace at which biotechnology projects are handled as well as the general precautionary stance are perceptible to the financiers and potential partners hence keeping them aloof. Clear policies and regulatory frameworks need to be established and genuinely enforced, therefore boosting investor confidence and make the projects flourish. In the industrialized nations, the biotechnology space is generally dominated by the private sector, which generates huge revenues [62]. Moreover, the private sector, unlike state institutions, has the robustness that is needed to commercialize innovations at a brisk pace.

### 13. Conclusions

The disquisition boils down to the fact that the confluence of multiple factors such as exponential population growth, climate change, migration of invasive pests, small landholdings, post-harvest losses and poor farming methods increase Sub-Saharan Africa's vulnerability to hunger and starvation. Sub-Saharan Africa's agriculture needs technologies that can improve productivity and profitability. This can only be attained by taking a paradigm shift and not cumulative change. The adoption of GM technology in the region will ameliorate most of the challenges currently bedeviling agricultural productivity and consequently food security. The growing of GM crops will not only tackle the issue of food security but will also contribute towards higher incomes for farmers and stimulate economic growth. Promoting genetic literacy among the politicians and the public is vital in removing the ambivalent attitude towards GMOs. The region needs to invest more towards biotechnological projects and invite the private sector to the party so as to accentuate the pace of development. It is, however, important to monitor the use of this technology for sustainable development.

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