Production and Adoption of Transgenic Crops in Sub-Saharan Africa

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Author’s contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

ABSTRACT

Food insecurity is high in sub-Saharan Africa. It has been estimated that 29 out of the 40 low income countries and countries with the highest rates of malnutrition are found in this region. Therefore, increasing agriculture productivity in sub-Saharan Africa is a priority and utilization of scientific and technological advances could enhance agricultural productivity. While the use of transgenic crops has been floated as one of the key solutions, to this effect, the region has continuously experience low levels of adoption compared to other regions. This paper reviews the state of production and adoption in sub-Saharan Africa, with an in-depth explanation of factors that may have led to low adoption levels. Furthermore, biosafety measures meant to regulate production and utilization of transgenic crops have also be discussed.

Keywords: Food insecurity; transgenic crops; cereal yield; economy.

1. INTRODUCTION

Agricultural is a predominant sector in sub-Saharan African economies, contributing about 15 percent of the average regional Gross Domestic Product (GDP) [1]. In spite of its central role in the region’s economy, agricultural performance has continuously remained low causing food insecurity in the region [2]. In fact, food security in sub-Saharan Africa (SSA) has progressively reduced since 1970 with the proportion of malnourished population reaching...
30% in 2017 primarily due to low cereal yield and high reliance on grain imports (Fig. 1).

While, it is acknowledged that extreme poverty rates have declined from 54 percent in 1990 to 41 percent in 2015, in the sub-Saharan Africa, the number of extreme poor, increased by 136 million people during the same period, i.e. from 277 to 413 million [3]. More than 57% of the population in the sub-Sahara cannot afford the cost of a healthy diet [4]. Furthermore, it has been identified that 29 out of the 40 low income countries and countries with the highest rates of malnutrition are found in sub-Saharan Africa. [5].

In addition, the performance of agriculture as a major foreign exchange earner in sub-Saharan Africa has not been satisfactory. It’s imperative to note that since the sub-Saharan region is not a single unit and economic issues vary spatially and temporally, the major cause of low productivity, leading to lower income is expected to vary. However it’s generally agreed that the low productivity is attributed to both biotic and abiotic stress as well as poor agronomic practices [6,7]. On the other hand, it’s lately been argued that the low productivity in sub-Saharan Africa can be traced back to interference by external forces, which focused production on a few export or introduced crops [7]. This subsequently, interrupted the advancement of adaptable local economic growth, built on traditional livelihood strategies leading to low crop productivity.

At the moment sub-Saharan Africa faces the greatest food security risk. By 2050 its population is expected to increase 2.5-fold and the demand for cereals (regions staple food) is expected to approximately triple to meet this projected change in population [8]. However the current production prospects particularly levels of cereal consumption, already depend on substantial imports thus meeting the intended target (tripled cereal production) is most unlikely [8]. Therefore, increasing agriculture productivity in sub-Saharan Africa is a priority and it’s imperative that scientific and technological advances should be employed to mitigate or eliminate the factors that have continued to keep agricultural productivity at very low levels [9].

Some policy-makers within the region have considered transgenic crops as a potential technology to enhance agricultural productivity. In the same vein, pro- transgenic crop activists have advocated that the technology is a solution to mitigate the ever increasing risk of hunger and malnutrition in sub-Saharan Africa. It is expected that transgenic crops could easily be adopted in the region as they have been scientifically proven to be effective. Of course this is debatable as non-transgenic crop advocates, prefer promotion of good agricultural practices to utilization of transgenic crops [10].

Transgenic crops, also referred to as genetically modified organisms (GMO’s) are genetically engineered crops that have been developed by molecular modification through the insertion of foreign genetic materials [11]. Genetic engineering speeds up the process of generating new varieties and increases the variety of genes which can be inserted into a particular plant. The inserted gene sequence (transgene) may come from another unrelated organism, or completely different species. However, the use of transgenic crops come with perceived risks that probably could have prevented or slowed down its adoption and utilization. This paper reviews the perceived risks of modern biotechnology, and further on provides an overview of factors affecting adoption of transgenic crops in sub-Saharan Africa. Furthermore, biosafety measures meant to regulate production and utilization of transgenic crops are also reviewed.

2. STATUS OF PRODUCTION OF TRANSGENIC CROPS IN SUB-SAHARAN AFRICA

The magnitude of the uproar on resistance to adoption, generally depends on type of transgenic crop. Generally, non-eatable transgenic crops such as cotton tend to get adopted relatively easily compared to eatable ones. Maize being the most important eatable stable crop in sub-Saharan Africa [13,14], attracts a great upheaval when it comes to adoption and utilization of its transgenic product. Popular maize transgenic crops are insect, drought and herbicide resistant. Among the non-eatable transgenic crop, boll-worm resistant cotton is the most popular [15,16]. World over, in 2019, the commercialization of biotech crops, occupied 190.4 million hectares, planted by up to 17 million farmers in 29 countries [17]. The production of transgenic crops is however low in sub-Saharan Africa. Lately, only six sub-Saharan African nations: Estwatini, Nigeria, Malawi, Ethiopia, Sudan, and South Africa have permitted utilisation and commercialisation of transgenic crop. Besides these developments, significant progress in transgenic crop research
3. HINDRANCES TO LOW ADOPTION OF TRANSGENIC CROPS

From what has been discussed earlier, it is clear that food insecurity is high in the sub-Saharan African region. Interestingly, despite these facts, this region has been slow in adopting transgenic crops despite the technology being suggested as an African solution in resolving challenges of food insecurity. It’s argued that such a scenario is unacceptable as hunger and malnutrition is a serious concern in the region. It is believed that such modern technologies will improve crop productivity [10]. In this section, attempts are made to review factors that may have lead or contributed to low production and adoption of transgenic crops.

3.1 Religious Beliefs, Cultural and Ethical Concerns

Traditional beliefs and ethical concerns have played a role in slowing the adoption of transgenic crops by portraying it as abominable. Robinson [21], noted that beliefs, habits and rituals are attached to religion and culture and are so deeply rooted that there is instant approval or disapproval of transgenic products. Some sectors believe that transfer of genes across species boundaries e.g. bacteria to crop, is tantamount to ‘playing GOD’ and that is unacceptable [22]. However, some sections argue that whatever gene is incorporated into a host genome, is in fact an equivalent version of the original and its development is not a contravention of religious beliefs and ethical concerns [22]. Despite this differences in opinion, it’s agreeable that religious and ethical concerns have contributed to slowing down the adoption and utilization of transgenic crops in the sub-Saharan Africa [22]. In certain areas culture belief has taken up a significant role in opposing adoption of transgenic crops. In the meeting of experts and activists which took place in the northern city of Tamale, in Ghana, in 2018, it was reaffirmed that cultural beliefs hinders or slows down adoption of transgenic crops [23]. In certain places, cultural beliefs are seen as being tied to agriculture and practice and it is believed that transgenic seeds cannot be accepted by ancestors if planted and sacrificed [23].
### Table 1. Global area of biotech crops in 2018 and 2019: by Country (million hectares)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>USA*</td>
<td>75</td>
<td>71.5</td>
</tr>
<tr>
<td>2</td>
<td>Brazil*</td>
<td>51.3</td>
<td>52.8</td>
</tr>
<tr>
<td>3</td>
<td>Argentina*</td>
<td>23.9</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>Canada*</td>
<td>12.7</td>
<td>12.5</td>
</tr>
<tr>
<td>5</td>
<td>India*</td>
<td>11.6</td>
<td>11.9</td>
</tr>
<tr>
<td>6</td>
<td>Paraguay*</td>
<td>3.8</td>
<td>4.1</td>
</tr>
<tr>
<td>7</td>
<td>China*</td>
<td>2.9</td>
<td>3.2</td>
</tr>
<tr>
<td>8</td>
<td>South Africa*</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>9</td>
<td>Pakistan*</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>10</td>
<td>Bolivia*</td>
<td>1.3</td>
<td>1.4</td>
</tr>
<tr>
<td>11</td>
<td>Uruguay*</td>
<td>1.3</td>
<td>1.2</td>
</tr>
<tr>
<td>12</td>
<td>Philippines*</td>
<td>0.6</td>
<td>0.9</td>
</tr>
<tr>
<td>13</td>
<td>Australia*</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>14</td>
<td>Myanmar*</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>15</td>
<td>Sudan*</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>16</td>
<td>Mexico*</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>17</td>
<td>Spain*</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>18</td>
<td>Colombia*</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>19</td>
<td>Vietnam*</td>
<td>&lt;0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>20</td>
<td>Honduras</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>21</td>
<td>Chile</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>22</td>
<td>Malawi</td>
<td>…</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>23</td>
<td>Portugal</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>24</td>
<td>Indonesia</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>25</td>
<td>Bangladesh</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>26</td>
<td>Nigeria</td>
<td>…</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>27</td>
<td>Eswatini</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>28</td>
<td>Ethiopia</td>
<td>…</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>29</td>
<td>Costa Rica</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>191.7</td>
<td>190.4</td>
</tr>
</tbody>
</table>

sub-Saharan countries are written in bold (Source: ISAAA [17])

### Table 2. Evaluation of favourable prevailing environment for adoption and utilisation of transgenic crops

<table>
<thead>
<tr>
<th>Enabling Environment</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Strong</td>
<td>Republic of South Africa</td>
</tr>
<tr>
<td>Strong</td>
<td>Ethiopia, Ghana, Kenya, Nigeria, Sudan</td>
</tr>
<tr>
<td>Medium</td>
<td>Botswana, Malawi, Mali, Namibia, Tanzania, Uganda, Zambia, Zimbabwe</td>
</tr>
<tr>
<td>Weak</td>
<td>Burkina Faso, Cameroon, Cote d’Ivoire, Madagascar, Mauritius, Mozambique, Rwanda, Senegal</td>
</tr>
<tr>
<td>Very Weak</td>
<td>Angola, Benin, Burundi, Chad, CAR, Congo, Djibouti, DRC, Eritrea, Gambia, Equatorial Guinea, Gabon, Guinea, Guinea Bissau, Lesotho, Liberia, Niger, Somalia, South Sudan, Swaziland, Togo, Sierra Leone</td>
</tr>
</tbody>
</table>

(Source: Ochieng and Ananga [2])

### 3.2 Multinational Companies Dominating Sub-Saharan Africa’s Food Production

The cost of developmental knowledge and release of genetically modified variety has to a larger extent led to seed multinational companies to patent seed products [24]. Consumer advocates, on the other hand are worried that patenting these new plant varieties may cause a rise in the price beyond what small scale farmers can afford in sub-Saharan Africa [25,26]. Thus there is a perceived likelihood that multinational companies can ultimately dominate the market in
the supply and production of seed in sub-Saharan Africa. Such perceptions have contributed to a slow response to adoption, spearheaded by non-transgenic crop advocates [27].

3.3 National Stance and Policy on Transgenic Crops

Sub-Saharan Africa is characterized by a mosaic of national policy positions on genetically modified technology. This ranges from those which can be considered to be permissive to those which are more pre-cautionary and ultimately to those which are prohibitive to the adoption of genetically modified crops or food [28,29]. For example in 2002, Southern Africa suffered a critical shortage of food. However the government of Zimbabwe and Zambia refused USA food aid as a result of being genetically modified despite being in a serious famine [30]. In another scenario, Namibia cut off all maize trade with South Africa in 2004 because the latter grew transgenic crops [31]. It can therefore be assumed that the speedy adoption or acceptance across countries in sub-Saharan Africa may to a large extent depend on national policies and government will in these countries. A lack of domestic institutional capacity and political will plays a major role as pro-transgenic governments are usually at a political risk due to anti-transgenic crop campaign by civil society and media [32]. Evaluation of favourable policies on adoption and utilisation of transgenic crops across selected countries in sub-Saharan Africa may be to a large extent depend on national policies and government will in these countries. A lack of domestic institutional capacity and political will plays a major role as pro-transgenic governments are usually at a political risk due to anti-transgenic crop campaign by civil society and media [32].

3.4 Biotic Resistance

The concern about antibiotic resistance (AR) genes which are transferred alongside the gene of interest in transgenic crops have been debated for over a period of time. It is believed that AR genes may be present in the finished products and these may lead to health challenges if they are transferred to gut bacteria in humans or if they are transferred to disease causing bacteria in the gastrointestinal tract (GIT). However, it has been established that there is a low probability for GIT gene transfer to occur and studies have shown no evidence of horizontal GIT gene transfer [33,34]. Thus biotechnology-derived foods have been suggested to be as safe and nutritious as their conventional counterparts [35].

3.5 Insurance on Crop Failure and Policy on Marketing

Insurance on crop failure and policy on marketing tend to have a cross cutting effect on conventional, organic and transgenic (biotechnological) crop production. These play a role in initiation of interest to invest or engage in agricultural activities and ultimately to employ developed technologies in agriculture such as the use of transgenic crops. In sub-Saharan Africa, crop failure due to drought and floods is more apparent. However, insurance and other forms of protection against natural disasters are rare or ineffective in the region [36].

Furthermore more, despite the high variability and inadequacy of rainfall in sub-Saharan Africa, investment in irrigation is inadequate [37]. Interestingly, the irrigated area in SSA, extending over six million hectares, makes up just 5 percent of the total cultivated area. Two-thirds of this area is located in three countries: Madagascar, Sudan and South Africa [38]. When compared to other selected regions, the proposition of irrigated to total cultivated area being 37 percent in Asia and 14 percent in Latin America [38].

In addition, policy responses on marketing in the region are largely unpredictable and ad hoc in nature, thus creating market uncertainty [36]. For example the price and selling control policies are largely unpredictable between and within season and thus discouraging investments and involvement in agriculture production. These policies are viewed as supporting consumers at the expense of producers (farmers) [36].

3.6 Potential Environmental Risks and Health

Transgenic crops have been perceived to have the potential to cause a variety of health and environmental impacts. Under this section selected transgenic crops associated with environmental risks and health are reviewed. To start with, consider a herbicide trade name Round-up, with an active ingredient glyphosate. Generally, an active ingredient glyphosate inhibits the enzyme, 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) and thus disrupts the production of chorismate-derived aromatic amino acids and secondary metabolites in the schematic pathway leading to death [39,40]. However, with regards to herbicide resistance crop a cloned and mutated EPSPS gene was inserted that encodes for a modified enzyme that resist the inhibition of glyphosate (Fig. 2)
They are however concerns that pollen from herbicide resistant maize may end up pollinating closer related grass species creating super weeds [41]. Thus such weeds cannot be killed with herbicides. Elsewhere over 24 species of weeds have been reported to be glyphosate resistance, stressing that the need to overcome such negative effects cannot be overemphasized [42]. However its being argued that weed resistance is particularly developed due to herbicide application rather than gene transfer [43].

The notion of utilizing Genetic use restriction technologies (GURT's) or terminator genes was earlier on in the 1990’s suggested as a remedy to avoid such concerns. It was argued that their application would be further useful for preventing undesired transgenic flow and obtaining specific agronomic/economic benefits. Therefore, the number of patent applications on terminator transgenes started to increase in the late 1990s, reaching the peak in 2006 but declined, thereafter, due to the ban of these technologies [43]. The perception that GURT's or terminator genes were just a tool to compel farmers to depend on multinational corporations’ seed monopolies led to its ban. Another environmental concern relates to the use of insect resistance transgenic cotton (Bt cotton). It’s believed in some circles that Bt cotton also eliminates non target beneficial insects such as bees and butterfly besides the bollworm [44]. Bt cotton posses Cry 1Ac gene of Bacillus thuringiensis and encode for the toxic crystal δ - endotoxin protein which kills the bollworm. It’s hypothesised that this protein does not affect non target insects [45]. Advocates for transgenic crops advises that the toxin only binds to specific receptors in the gut wall of the bollworm which later on dissolves the gut wall that ultimately leads to the death of the bollworm [45]. As earlier alluded, it’s also believed that transgenic crops may produce new harmful allergens and toxins to humans and unintended environmental organisms. [35]. It should be noted that even though allergens are proteins in nature, only a few proteins are allergic [46], implying that that there is low probability of obtaining allergens in transgenic food. However, despite these assuring facts, safety measures should first be undertaken on transgenic product before it’s accepted. In this regard, a transgenic crop is compared to its parental non transgenic crop for evaluations of possible allergens, to ensure its safety to human, animal and environment [33]. I must expound that these biosafety approaches are not done haphazardly but rather follow agreed systematic approaches. Details of biosafety adherence for transgenic organisms are discussed in detail in the next section.
4. APPLICATION OF BIOSAFETY AS A MEANS OF REGULATING UTILIZATION OF TRANSGENIC CROPS

At a policy level, the general outcry concerning a potential source of harmful effect of transgenic crops did not fall on deaf ears. On 29 January 2000, the Conference of the Parties to the Convention on Biological Diversity adopted a supplementary agreement to the Convention known as the Cartagena Protocol on Biosafety [47]. The protocol, sets out a comprehensive regulatory system for ensuring the safe transfer, handling, and use of living modified organisms (LMOs) subject to transboundary movement. It was agreed that transgenic products should be assessed using precautionary approach to ensure their safety [47]. Such an approach seeks to protect not only biological diversity from the potential risks of genetically modified plants but also animals. Hence adopted a combined terminology known as LMOs. The protocol establishes an Advance Informed Agreement (AIA) procedure for ensuring that countries are well informed before agreeing to the import or acceptance of a particular transgenic crop [48]. It ensures the safe handling, transport and use of LMOs resulting from modern biotechnology that may have adverse effects on biological diversity, taking into account the risks to human health.

4.1 Monitoring and Implementation of Biosafety

Monitoring and implementation of biosafety measures are comparatively more difficult to implement within the sub-Saharan African context, due to lack of resources that can be invested in the establishment of an effective regulatory effort. At a policy level, some gains have been achieved through the established National Biosafety Frameworks [49], which provide basic regulatory guidance regimes, as a basis to move forward. To effectively move forward, countries in sub-Sahara need to develop a national biotechnology strategy that defines how biotechnology fits into the overall national agricultural research strategy, involving farmers and target sectors where biotechnology tools will be applied based on needs and priorities of stakeholders [31]. A key measure would be to regulate transgenic crops, food and feed products before they are imported, since once they are admitted, it is difficult to control their further spread and diffusion into conventional seed stocks and the environment. [31].

Most countries in SSA still lacks adequate trained man power and often face major barriers in utilizing biotechnology and biotechnology derived products. On the other hand, trained staff may exist but lack of consumables makes indulging in this technology a challenge. To address issues of trained man power, biotechnological/biosafety capacity training are recently being conducted for short-term and long term up to masters and PhD degree level [50]. Lately, various developmental organizations, notably the Food and Agricultural Organization (FAO), the Global Environment Facility (GEF) and the United Nations Environment Programme (UNEP), have been supporting the biosafety capacity building needs for developing/emerging countries. The range of activities include transgenic organism detection and monitoring; equipping of laboratories and harmonizing protocols among countries; and facilitating public awareness on biosafety [50]. In addition, efforts are being made to promote the standard operating procedures (SOPs) that test the suitability of introducing a transgenic crop in a specific country. The Cartagena protocol specifies the regulatory SOPs, aimed at guiding the step by step instructions in carrying out a complex routine to ensure efficiency, uniformity and quality procedures in evaluating adoption and promotion of transgenic crops [47,49].

5. FINAL REMARKS

There has been a lot of debate as far as the use of modern biotechnology technology is concerned. From what has been reviewed and discussed, it is clear that countries in sub-Saharan Africa are skeptical on the ethics of transferring a gene from one species to another and is evident from the low numbers of adoption and production. This is despite pro-transgenic crop advocates who have argued that this technique will promote production of more resilient crops for poor communities especially in SSA, as the improved transgenic crop species will result in higher yields and can withstand the adverse climatic conditions. Perhaps the efforts of pro-transgenic activists are equally counteracted by non-transgenic campaigners’ efforts which has led to a slow response to adoption of transgenic crops. In addition to the perceived adverse effect to consumers and environment, non-transgenic supporters further argue that conventional approach if well managed have the potential to feed the region. On the other hand, the Burkina Faso scenario where the once adored Bt-cotton was banned
entails that thorough investigation and research are required before commercialization of the transgenic product. This may help achieve sustained adoption. While the use of biosafety regulations have been introduced as a means of ensuring that developed transgenic products are safe, this should not be seen as a panacea as non-transgenic advocates continue to resent the technology. In my opinion, while some sections are skeptical with utilization of transgenic crops in SSA, use of modern biotechnology should not be demonized but rather embraced and used to what is easily adoptable and acceptable in specific countries for now. For instance, consideration can be on employing technologies such as developing cisgenic crops as that involves transferring genes within the same species.

6. CONCLUSION

Sub-Saharan African countries produce less than 2 % of transgenic crops of the total world hectarage. Improving such a low production output requires concerted effort of all stakeholders. Beside the current resentment of transgenic crop, the use of modern biotechnology should however be embraced by countries in the region and used productivity for non-controversial technologies.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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