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Chapter

Biotechnology in Agricultural Policies of Sub-Saharan Africa

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Abstract

The agricultural policy environment in sub-Saharan Africa in the last 15 years has been erratic, especially with regard to adoption of biotechnology. While many biotech products such as tissue culture (TC) banana, hybrid maize, and others are now frequent at farm level, the adoption of some of the technologies remains relatively low, partly due to political and regulatory bottlenecks that have hampered farm deployment and entry into market systems of genetically engineered crops and products. This chapter reviews the political landscape of biotech crops across sub-Saharan Africa; analyses the state of enabling policy environment in key countries; discusses the impact of push-pull factors on food security, research, and training; and identifies the opportunities for investment in biotechnology and agribusiness in sub-Saharan Africa.

Keywords: biotechnology, policy environment, Africa, agriculture, GMO, adoption, regulation

1. Introduction

Sub-Saharan Africa (SSA) is one of the regions that depend mainly on agriculture but have largely remained food insecure. In fact, food insecurity in SSA has progressively worsened since 1970 with the proportion of malnourished population reaching 30% in 2017 [1]. Farming in SSA relies on rudimentary methods, which, among others, are characterized by continuous tilling of land, which depletes soil nutrients, leading to poor soil quality. Many countries in the region are making efforts at rehabilitation and expansion of irrigable land, in addition to subsidy on fertilizer and seeds. However, intensive use of inputs depletes agriculture's natural resource base, jeopardizing current and future productivity. More than three-quarters of food is produced in this manner on smallholder farms despite serious production challenges including degradation and nutrient-deficient soils, soil-borne and plant pathogens and pests, unreliable rain-fed farming, high postharvest losses, especially of milk, grains, and tubers, resulting from poor processing and storage, poor farming skills, and limited access to and utilization of appropriate agricultural technologies. In SSA, studies have shown that majority of smallholder farmers lack awareness of improved agricultural practices and technical know-how, partly because of weak linkages between researchers, extension staff, and farmers [2]. The food production-consumption gap for SSA is projected to widen, allowing food insecurity to reach catastrophic levels in the coming years as majority of smallholder farmers continue aging, while the youth remain less attracted to farming. This will be exacerbated by the projected increase in population in the region, with a higher increase than rest of the world (**Figure 1**).

**Figure 1.**

World human population compared to Africa, across major timescales. Population in Africa has been and is projected to increase more rapidly than rest of the world.

The region's agricultural development is in a race against time to eliminate this deficit as climate change is expected to lead to significant reductions in crop yields, threatening the livelihoods of millions of poor subsistence farmers and agricultural workers [3]. On the other hand, closing the development deficit and providing farmers with access to the investment, technologies, and knowledge they need to adapt to climate change could transform their development prospects. Increasing farm productivity is therefore a priority as yields have stagnated at levels well below global averages. It is quite clear that scientific and technological advances could be used to mitigate the factors that have continued to keep African agricultural productivity at very low levels. Prospects do exist for significant productivity improvement through a combination of technological and policy measures. Improving farmers' access to technology is central to meeting the double challenge of closing the development deficit and adapting to climate change. The African Union (AU)'s comprehensive approach that envisions a 6% annual growth in agricultural productivity requires the deployment of advanced technologies coupled with strong policy support. It has been observed that realizing a 6% agricultural productivity growth rate will need unprecedented policy support from African governments and international development partners [4]. Such policy shifts should aim for sustained investment in the generation of agricultural technologies and most particularly for the deployment of advanced biotechnologies. "Biotechnology" as a term has evolved since it was coined in the early twentieth century and is today defined differently by different organizations, groups, and individuals. For example, the US National Science Foundation defines it as "The controlled use of biological agents, such as microorganisms or cellular components," while the Food and Agriculture Organization of the United Nations (FAO) and the Convention on Biological Diversity (CBD) define biotechnology as "any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use." Generally, therefore, biotechnology is *any use of organisms or its components in industrial, medical, agricultural and environmental engineering or processes*. The growing human population, coupled with climate change, has triggered the need to explore complementary biotechnological innovations for improving food production, better healthcare, and cleaner environment.

Many challenges faced in agriculture can be minimized through the application of various biotechnologies. Low production associated with degraded soils, drought episodes, emergent plant pathogens and pests, and postharvest losses can now be mitigated using suitable biotechnologies that enrich soils, target production traits for improved yields, selective breeding, and genetic engineering for insect resistance and drought tolerance. Further, biotechnologies now exist for overcoming accumulation of aflatoxin, usually produced by certain fungal species under moist and dump conditions. Generally, biotechnologies have revolutionized farming in industrialized economies, and have the potential to reduce food deficits, make farming more remunerative, and attract the youth to agriculture in

both middle- and low-income economies. In healthcare, various biotechnologies have been developed in the last few decades to manage both infectious and non-infectious diseases. Diabetes, for example, is now managed using insulin produced in bacteria through genetic engineering. To reduce malnutrition, biofortification for micronutrients and selective breeding for nutritional improvements have been used. In environmental conservation, biotechnologies are applied in removal of contaminants such as heavy metals, and waste decomposition. In industrial biotechnology, biological agents such as microorganisms, tissues, cells, or enzymes isolated from living systems have been used, either in the natural state or genetically engineered to reduce or remove waste materials from the environment. Others involve the use of genetically improved trees for phytoremediation (plant-based cleanup of contaminated soils), use of microorganisms to decompose effluent (sewage), and the use of biofertilizers and biopesticides instead of chemical sprays. Although biotechnology is applied in many fields beyond agriculture, this chapter focuses on its integration into agricultural policies of African countries.

2. Regulation and management of biotechnology

Application of biotechnology requires, among others, at least the following to be in place: systems that ensure there is adequate capacity to develop and apply the technologies; systems that promote research, extension, and wider adoption; and systems that regulate the sector to assure sustainable use of resources, environmental and human safety. With growing urbanization and the supply crisis from food production deficits, and as more and more people gain interest in agribusiness, there is urgent need to develop guidelines and policies that create a conducive climate for agricultural investment while providing safeguards against environmental and social risks. Although biosafety relates to all biotechnology applications, and genetic engineering is just one of the many biotechnologies in use today, most discussions about biosafety in many countries worldwide revolve around whether a country has projects involving genetic modification (GMO), and hence some internationally agreed way of treating safety and associated assessments. The GMO-centered handling of biosafety emanates from the erroneous interpretation among non-experts that biotechnology = GMO. Biotechnologies (whether low- or high-tech) may introduce certain risks. Both modern biotechnology such as genetic engineering and traditional techniques commonly used such as crossbreeding (with wild counterparts) may confer the same kind of risks but which many people generally do not know about. From a scientific perspective, therefore, the controls should be the same if the risks (real or perceived) are the same, or nearly same. Practically across the world, however, this is not the practice. The level of protection required for a product should necessarily relate to its intrinsic characteristics rather than to the method of obtaining it, a position taken both by world toxicologists in their valuable position paper on genetically modified foods [5].

As a country determines an appropriate level of protection for any product, social and political considerations have to be built-in within the scientific decision framework in order to calibrate the balance between controls and safety, against accessibility/benefits. Agricultural wisdom dictates striking a balance between economic development and human as well as environmental health. Thus, an enabling policy environment comprises deliberate actions intended to promote technology development (such as trained personnel, research and development (R&D) infrastructure and R&D funding, efficient extension or advisory services that link labs to farms, policies, laws, and regulations for development and application of biotechnologies in the sector, among others). Consequently, all products

of biotechnology are regulated and undergo risk assessment. For example, seeds developed through selective breeding are managed through phytosanitary regulations as well as seed varieties legislations. Risk assessment is a process used every day when choices and decisions have to be made, and is the most critical component of biosafety implementation. Although risk assessment is necessary for all biotechnologies applied in agriculture, health, and environmental work, the attention appears concentrated on genetic engineering and its products (GMO). The risk assessment process used for GMOs closely resembles the assessments made for environmental impact. Before a GM crop is released to the market, regulators worldwide require these products to undergo rigorous risk assessments to ensure an adequate level of safety to humans, animals, and environment. As such, all GMO products available in the market today have undergone a risk assessment. Products of genetic engineering (GMO) are managed through a more stringent regulatory system, often referred to as National Biosafety Frameworks (NBFs). As such, biotechnology policies for most countries are all about GMO and similar products developed through “modern biotechnology”—a term used to refer to more advanced biotechnologies that include tissue culture, molecular marker technology, and genetic engineering, which generally require laboratories and significant level of skills to perform.

2.1 Global management of biotechnology

One of the decisions of the United Nations Conference on Environment and Development (UNCED) in 1992 was the adoption of the Convention on Biological Diversity (CBD), to regulate biotechnology (Articles 8 (g) and 19). In response to Article 19 (3), a decision was made during the Conference of Parties (COP5) in 1995 to develop a protocol on biosafety. The Cartagena Protocol on Biosafety (CPB) was a direct international legal response to the CBD contributing toward the conservation and sustainable use of biological resources. The entry into force of the protocol (2003) obligated signatories to the protocol to localize it within their national laws. Current intergovernmental mechanisms governing the application of modern biotechnology in which African countries actively participate include: (1) The *Codex Alimentarius* Commission, (2) Cartagena Protocol on Biosafety (CPB) to the Convention on Biological Diversity (CBD), and (3) Plant Protection Convention (IPPC). Signatories to the CPB obligated themselves to localize the protocol within their national laws. So far, nearly all SSA countries have ratified or complied with accession requirements of the CBD, except for Equatorial Guinea, Liberia, Sierra Leone, and South Sudan.

Within regional trading blocks of SSA, frameworks of action for biotechnology require a collective understanding among member states, and a regional framework on biosafety. Many regions have made attempts to foster a united framework, but none of these have progressed beyond mere intentions. For example, the East African Cooperation (EAC) Protocol on Environment and Natural Resources (2006) urges partner states to “develop and adopt common policies, laws and take measures to ensure that the development, handling, transport, use, transfer and release of any living modified organisms are undertaken in a manner that prevents or reduces the risks to environment, natural resources and human health” (C 3, A 27(1)). However, implementing such a recommendation would first require a regional discussion to enable member states to understand current issues, trends, challenges, and opportunities for agricultural biotechnology, and to have a collective understanding that will catalyze common policies and biosafety regulations, in line with the goals of regional integration, and to eliminate some of the non-tariff trade barriers associated with transboundary movements of GMOs. At the national level, the National Biosafety Frameworks (NBFs) provide the overall policy, legal and institutional mechanisms for development, deployment and use of biotechnology.

2.2 National biosafety framework

A National Biosafety Framework (NBF) is a combination of legal, administrative, and technical instruments put in place to build a country's competence to handle biotechnology research, development, and commercialization. Specific components of these instruments are the national biosafety policies, statutes passed by parliament and specific regulations linked to the statutes, administrative and technical systems for risk assessment, public awareness and participation, decision-making, enforcement and monitoring. An NBF is also a tool to be used in the implementation of the CBP. These frameworks often focus on GMOs, and have been generally driven by the crop sector, although they are meant to cover broad biotechnology research and applications. Although varying from country to country, NBFs usually contain a number of common elements, such as policy on biosafety, regulatory regime for biosafety, a system to handle notifications or requests for authorizations for certain activities, field releases of GMOs into the environment, among others. All these involve public participation and risk assessment, a mechanism for monitoring and inspections, and a system for public awareness and public information.

The next section appraises the state of enabling policy environment within the SSA in the broad sense, examining specific indicators such as: evidence that a country has an agency that promotes the application of biotechnologies, support for biotechnology development through research funding, support to adoption through extension services, existence of policies, laws and regulations, and specific agency that regulates the use of biotechnology—how efficiently these systems function.

3. State of biotechnology policy environment in SSA

As stated earlier, application of biotechnology requires systems that ensure there is adequate capacity to develop and apply the technologies safely; promote research, extension, and wider adoption; and regulate the sector to assure sustainable use of resources, environmental and human safety. These components together include the national biosafety policies, statutes passed by parliament and specific regulations linked to the statutes, administrative and technical systems for risk assessment, public awareness and participation, decision-making, enforcement and monitoring. This section audits the policy environment by assessing indicators and evidence for promotion and support for biotechnology development through research funds, support to adoption through extension services, existence of policies, laws and regulations, and specific agency that regulates the use of biotechnology within each sector (crops, forestry, livestock, and aquaculture) and overall across sectors. Scores—ranging from very low or very weak to very high or very strong—are assigned to each country based on information (qualitative and quantitative) gathered from various sources, which then forms the basis of the classification.

3.1 Policy and biosafety frameworks

Countries in SSA are at different levels of development and implementation of NBFs. The levels and extents of development of the frameworks largely depend on their adherence to, and domestication of, key international agreements, the political good will as well as human and financial capacities. SSA countries started putting in place biosafety legislation in the 1990s; today, only 18 countries have biosafety

| Country | Biosafety framework (<i>policy, law, regulations, guidelines, and institutions</i>) | GE crops |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| Burkina Faso | Has NBF; Act 2006 (revised 2013); Biosafety Decree 2004; Biosafety Law 2011; Policy on Biotech; National Biosafety Authority | Cowpea; CR of cotton suspended in 2016—discussions underway to restore with new variety |
| Cameroon | Has NBF; Biosafety Act 2003 (revised 2007); Biosafety guidelines 1995 | Cotton; no ER of any product |
| Egypt | Legislation under review; robust R&D; past commercial release | Wheat, potato; CR of maize suspended due to regulatory changes in 2012, with all GM |
| Ethiopia | Has framework and R&D; product approved for commercial release | Enset, maize, cotton; CR of cotton approved in June 2018; maize, enset in CFTs |
| Ghana | Act 2011 (Enacted into law 2012); Regulatory Communication Strategy 2014; Regulatory framework yet to be finalized; Policy on Biotech; NBC | Cotton, cowpea, rice; but no ER |
| Kenya | Has NBF; National Biotechnology Policy 2006; Biosafety Act 2009; 4 biosafety Regulation 2011, 2012; National Biosafety Authority | Cotton, maize, cassava, banana, sweet potato, gypsophila flower, sorghum; NPT for cotton underway, for maize pending; Import ban on GM since 2012 |
| Lesotho | Has some elements of NBF; National Biosafety bill 2005; amended 2014; National biosafety policy; National biosafety awareness strategy 2013; National Biosafety Council; no research | — |
| Malawi | Has NBF; Act 2002; Biosafety guidelines 1995; Biosafety regulatory framework 2007; National Biotech policy 2008; draft legislation | Banana, cowpea, cotton; NPT for cotton advanced; no ER |
| Mali | Has NBF; Biosafety law 2008; Biosafety decree 2010; National Biosafety Committee; GMO research prohibited | — |
| Mauritius | Has elements of NBF; GMO Act 2004; Plant Protection Bill 2006; Ministry of Agro Industry and Food Security | Sugarcane |
| Mozambique | Has NBF; Biosafety law 2007 (revised 2012); draft biosafety regulations; GIIBS; NBC | Maize, cotton; no ER; <i>Bt</i> maize ready for ER; <i>Bt/DT</i> stack in CFT |
| Namibia | Has elements of NBF; Biotechnology and biosafety policy 1999; Biosafety Act 2006; Draft legislation; Biosafety Council of the NCRST; no research | — |
| Nigeria | Has NBF; Biosafety bill 2011 (bill still in Senate); Biosafety guidelines 2001; National Biosafety Management Agency (NBMA) | Cotton, cassava, cowpea, sorghum, soybean; CR of cotton approved in July 2018 |
| Republic of South Africa | Has robust NBF; GMO Act 1997; Biosafety guidelines; National Biotechnology Policy and Strategy 2001; Directorate of Biosafety | Maize, soybean, cotton, wheat, potato, sugarcane; CR for cotton in 1997, maize in 1998, and soybean in 2001 |
| Sudan | Has NBF; Law of Biosafety 2010; National Biosafety framework 2008; Sudan National Biosafety Council | Cotton; CR of cotton approved in 2012 |
| Swaziland | Has elements of NBF; Biosafety Act 2012; legislation under review | Cotton; CR of cotton approved in May 2018 |

| Country | Biosafety framework (<i>policy, law, regulations, guidelines, and institutions</i>) | GE crops |
|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| Tanzania | Has NBF; Biotech policy 2010; Environment Management Act 2004; Biosafety regulation 2009; National Biosafety Committee; strict liability regulations revised in 2015 to allow CFTs; strict liability remains if product is commercialized | Maize; no ER |
| Uganda | Has NBF; National biosafety bill 2012, (Passed 2017; referred back to Parliament); Biosafety guidelines 1995; Draft Biotech and Biosafety Policy 2013; National Biotechnology Policy 2008; Uganda NCST; National Biosafety Committee | Banana, maize, cassava, rice, cotton, potato, soybean; no ER |
| Zambia | Has elements of NBF; Biosafety Act 2007 (revised 2013); National Biosafety Policy 2013; National Biosafety Authority 2013; no research allowed | — |
| Zimbabwe | Has elements of NBF; National Biotech Authority Act 2000; Biosafety guidelines 1998; National Biotechnology Authority; no research allowed; cultivation and imports of GMO banned | — |

GE, genetically engineered; ER, environmental release; CR, commercial release; NPT, national performance trial; CFT, confined field trial

Table 1.
Status of policy environment for biotechnology in some notable SSA countries.

legislation in place (**Table 1**). The majority of these (9) were passed in the period 2006–2010. The extent to which biotechnology has contributed to agricultural productivity in various countries is closely linked with, and has been dictated by, the policy/political landscape and the nature of legislation enacted to govern the technology. The lack of biosafety legislation, biotechnology policies, and absence of biosafety procedures in several countries continues to be a major gap and a significant impediment and discouragement to research institutions that are willing to undertake high-end biotech R&D. This is because the institutions are not able to obtain approvals from regulatory authorities, or because processes for application are opaque and tedious, and generally the institutional landscape does not encourage R&D with significant biotech content.

In terms of ranking for policy environment for development, application, and adoption of biotechnology across sectors, Republic of South Africa is comparatively very strong in all sectors except fisheries and aquaculture. Five (5) other countries (Ethiopia, Ghana, Kenya, Nigeria, and Sudan) are “strong” across sectors in enabling environment for application of agricultural biotechnologies. Eight (8) are medium, while the rest are either weak (8) or very weak (22), as summarized in **Table 2**. In comparison, more than half of the countries in SSA have a weak enabling environment in all the sectors. When looked at in terms of two categories, as either weak or strong, three-quarters (75%) of the countries cluster in the weak category, with only 10 countries appearing as above average or strong. This category comprises Botswana, Ghana, Kenya, Malawi, Namibia, Nigeria, South Africa, Tanzania, Uganda, and Zimbabwe. Three countries (Ethiopia, Sudan, and Zambia) cannot confidently be assigned to either of these two groupings because they classify with a wide variation across sectors.

| Enabling environment | Countries |
|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Very weak | Angola, Benin, Burundi, Chad, CAR, Congo, Djibouti, DRC, Eritrea, Gambia, Equatorial Guinea, Gabon, Guinea, Guinea Bissau, Lesotho, Liberia, Niger, Togo, Sierra Leone, Somalia, South Sudan, Swaziland |
| Weak | Burkina Faso, Cameroon, Cote d'Ivoire, Madagascar, Mauritius, Mozambique, Rwanda, Senegal |
| Medium | Botswana, Malawi, Mali, Namibia, Tanzania, Uganda, Zambia, Zimbabwe |
| Strong | Ethiopia, Ghana, Kenya, Nigeria, Sudan |
| Very strong | Republic of South Africa |

Table 2.
Classification of countries on basis of enabling policy environment for biotechnology.

3.2 Public and private investments

While the formulation of policy and establishment of biosafety frameworks are principally a function of the political will of the country, and not necessarily resource-endowment, a major aspect of the enabling environment that seems to challenge the majority of SSA countries is “resourcing” of biotechnology programs. This includes investments in capital items (labs, equipment, etc.), human resources, and operations. Although precise value of agricultural biotechnology spending is difficult to obtain, estimates (focusing only on crops and livestock) obtained from IFPRI’s Agricultural Science and Technology Indicators (ASTI) database (www.asti.cgiar.org) show that SSA countries invest very limited amounts on agricultural R&D generally, and agricultural biotechnology in particular. Staffing levels (FTEs) from ASTI data indicate low levels of staffing in the majority of countries. Although FTEs (which is only one of the aspects of investment) cannot be used to fairly interpret the level of public or private sector investment (because a section of the experts may have been trained outside their countries, either through incoming scholarships or self-sponsored programs), the low numbers point to a low level of public investment. The total agricultural research for development (ARD) spending takes a similar pattern to policy frameworks, that is, South Africa, Kenya, and Nigeria are consistently among the top in terms of ARD spending. As expected, private investments in ARD in SSA are mainly directed toward high-value crops and non-traditional products such as cut flowers. A recent development is the proliferation of private agribusiness investment funds targeting African agriculture. In addition, although progress is slow since Maputo Declaration (in 2003), the position as at 2015 (lead up to Malabo Declaration) indicated that some countries have taken steps to honor their commitments to increasing investments in agriculture and a number of countries have taken a proactive role in attracting private sector agribusiness investments by offering various incentives such as tax holidays within the first few years of an agribusiness establishment (e.g., Nigeria) and zero duty on agricultural machinery (e.g., Ghana, Nigeria).

Other than Republic of South Africa, the other top countries in total ARD and biotech spending are Nigeria (96.4 million USD total ARD spending), Kenya (50.8 m), Ghana (42.9 m), and Uganda (25.2 m). The figures show that even these leading countries spend only modest amounts on biotech (**Figure 2**). Among the other countries spending more than 10 million USD on crop and livestock biotech are Burkina Faso, Cote d'Ivoire, Ethiopia, and Zimbabwe, with the rest of the countries spending less than 10 million USD (**Figure 1**). Although many countries signed the Maputo Declaration, committing at least 10% of agricultural

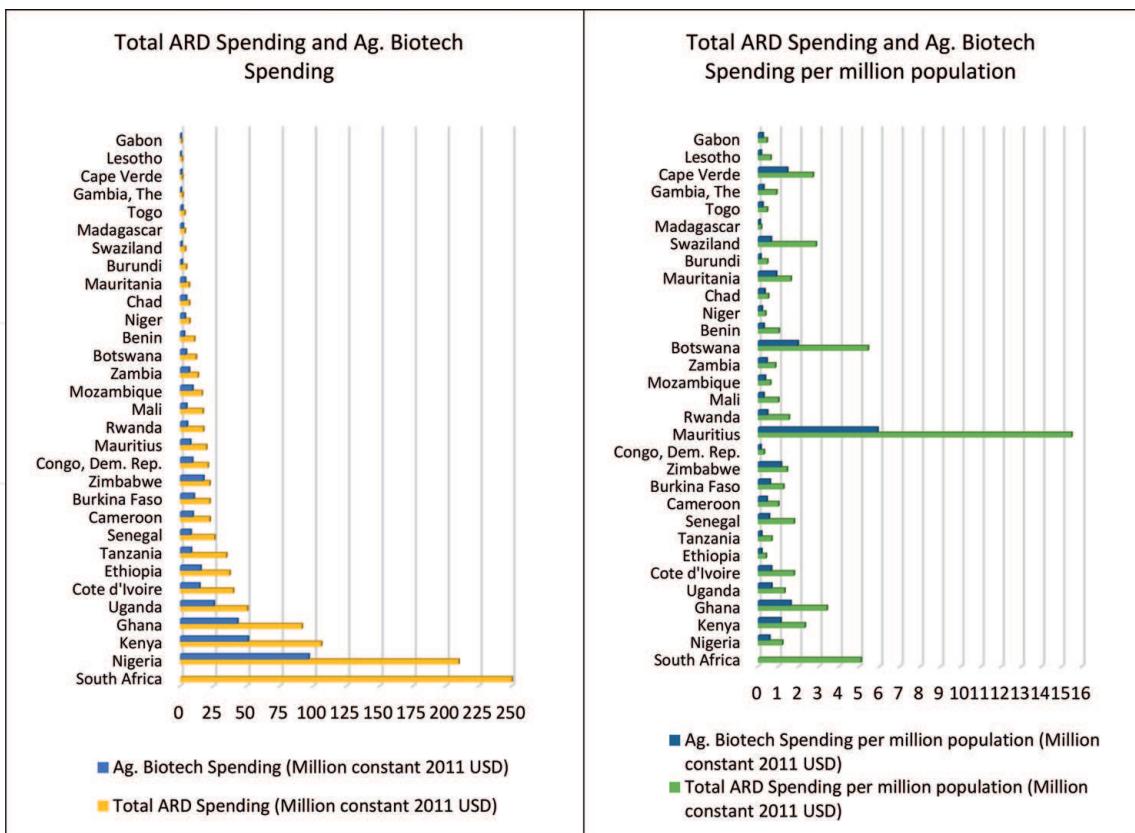


Figure 2.

Total ARD versus biotech spending (in USD) in SSA—absolute, and per million inhabitants (Data obtained from ASTI, 2014) *Comparable biotech spending data for Republic of South Africa was unavailable.*

GDP to R&D, rough estimates suggest that the gross expenditure on R&D for SSA is less than 0.3%. In most of the countries, government contribution to National Agricultural Research Institutes (NARIs) is inadequate, irregular, and often late [6] whereas international donors provide 75% of NARI's budgets. Overall, an estimated 40% of SSA countries spend less than 5 million USD on crop and livestock biotech a year. It appears that the level of spending on agricultural biotechnology largely corresponds to country classifications (**Figure 2**; **Table 2**)—where top 10 spenders are also the countries predominantly classified in the “Strong” and vice versa even though other indices for enabling environment were also used in the classification.

3.3 Collaboration and networking

African countries' entry into biotechnology has been stimulated by many interrelated factors, particularly the cumulative nature of the advancement in biotechnology. In addition, the pace at which SSA biotechnological advancement has benefited from regional and subregional organizations and networks credited with the development of ARD capacity in SSA have also contributed in significant ways to many aspects of *enabling environment*. These include the biotechnology support programs and initiatives driven by the Consultative Group on International Agricultural Research (CGIAR) whose centers have, for over three decades, worked collaboratively with many SSA countries on biotechnology research and application in different sectors [7]—with the countries hosting the centers accounting for a relatively larger share of this. In the livestock sector, the International Livestock Research Institute (ILRI) working in partnership with national and other international partners has made strides in developing genetically engineered vaccines while in forestry, the World Agroforestry Centre (ICRAF) has provided support in capacity development as

well as research and application of low to medium level forestry biotechnology. It is perhaps in the crops sector that the CGIAR centers have made the greatest contribution, with several centers including ICRISAT, CIMMYT, the International Potato Centre (CIP), and IITA contributing substantially in the research and application of medium- to high-level biotechnology for maize, potato, cassava, and sorghum, among other crops. Further, African regional research organizations such as AGRA and AATF, among others, have played a part in research and development as well as application of biotechnology especially in the crop sector [7].

There is a close relationship among existing capacities, level of application, and enabling policy environment for biotechnology. Higher capacities correspond with higher levels of application and enabling policy environment. A relationship cycle can explain this observation—a stronger enabling policy environment promotes higher capacity and hence enables technology development and application. On the other hand, a country cannot regulate “nothing”—a robust biotechnology research and application would require and hence catalyze the development of regulation, policy, and laws, for example. Policies and legislations on biotechnology in a country with no research on, or application of, biotechnology is meaningless unless it is part of a plan. However, overall, having a critical mass of requisite human capacity is the critical starting point.

3.4 Public awareness and political support

Political support for anything, including biotechnology application, is difficult to gauge, and has to be inferred, for example, from specific deliberate actions. Based on such inferences, therefore, political support for biotechnology application in SSA is varied across countries. The presence of a policy and law on biotechnology and biosafety can be interpreted as evidence of political support, except cases where these laws are enacted to prohibit the use of biotechnology. Due to controversy surrounding GMO in agriculture across SSA, there is more public scrutiny of the application of this technology. This can explain why the media is awash with articles and stories demonstrating, on the one hand, the usefulness of biotechnology to farmers, and on the other, skepticisms and outright opposition, specifically to GMO [3]. Unfortunately, the perceptions and misrepresentations on GMO are often extended to any conversation about agricultural biotechnology as a whole. With the exception of South Africa, there are no calibrated national surveys assessing the public understanding, perception, and acceptance of biotechnology in Africa. The Agricultural Biotechnology Programme of the University of Nairobi has data from an opinion survey on awareness and willingness to use genetically engineered products, and another on actual use of these products in the manufacturing sector. The survey showed more than 90% of raw materials for millers and manufacturers in Kenya to be sourced both from East Africa and countries such as Southern Africa, USA, Europe, and others known to predominantly grow genetically engineered crops such as corn. The South African study [8] reveals a very high level of ignorance about biotechnology among the general population, and favorable support for biotechnology among the informed respondents. Thus, public awareness remains a gap even in countries that rank high in the policy environment for agricultural biotechnology. Thus, despite the perception that the public is aware about biotechnology and what it can do or not do, much of the paranoia can be attributed to lack of understanding, political and business contests.

As explained earlier, development and adoption of agricultural biotechnology require both regulatory and promotional systems. Political will and support can drive agricultural biotechnology even in the absence of NBFs. One of the latest examples where strong political support has been demonstrated is Uganda. In Uganda, a Biotechnology and Biosafety Bill, which has been awaiting enactment

since 2012, was passed in Parliament in October 2017 but referred back by the President for some amendments. It was passed again in 2018, but this time with strict liability clauses that will definitely retard biotechnology development in the country. However, the country has a presidential order allowing GMO R&D, awaiting enactment of a biosafety law. Somalia (which has had frequent civil strife since 1991) has also shown a strong political will—as seen in many laws in draft stage but is operational (such as the Veterinary Code—Law No. 34/2006 & 2008 implemented in draft form since 1997). Perhaps the presence of fewer experts (many have fled the country) and a less secure environment for foreign experts to operate have contributed to the slower pace of policy development to support agricultural biotechnology. It is obvious that if a technology is not being applied, then enactment of laws is never urgent. In the neighboring Djibouti, there are some laws and regulations, including those aimed at positioning her for adoption of modern biotechnologies including genetic engineering. However, there lacks specific roadmaps for achieving some of the goals envisioned in the legislation.

The Water Efficient Maize for Africa (WEMA) *Bt* maize adoption in Kenya provides a context to understand the complex political environments that can impede biotech adoption. Kenya is one of the countries with many genetically engineered products at various stages of development: Insect-protected *Bt* maize and *Bt* cotton have both undergone confined field trials (CFTs), and are awaiting the last stages before commercialization—National Performance Trials (NPTs). To prepare the ground for agricultural technology uptake, the government of Kenya put in place legal, structural, and other regulatory frameworks including human capacity to manage GMOs by 2009. This heavy investment in legal, human, and infrastructural capacity for GM research was expected to improve capacity to develop and manage processes for detecting, testing, and assessing the safety of GM foods and products. Four regulations that implement the Biosafety Act have been gazetted (2011–2013) to ensure compliance with all activities undertaken within a field, introduction into the environment, labeling, and import, export, and transit of GMOs. Despite this preparedness, the adoption of GM crops and products has been hampered by political and regulatory bottlenecks that have delayed farm deployment and entry into market systems. In disregard of the provisions of the act and implementing regulations, together with existing infrastructure to manage GMO, the country imposed a ban on GMO in 2012. This ban has undermined efforts to even conduct NPT, a pathway to commercialization of *Bt* maize.

Apart from its effect on high-tech biotechnologies (genetic engineering—GMO), lack of political support can hamper even low-end biotechnologies such as biopesticides. For example, synthetic chemical pesticide (lindane) was first introduced in Nigeria in the early 1950s. Adverse effects resulting from excessive utilization of synthetic chemicals have become widely reported (e.g. [9]). Several studies have identified plant-based sources of pesticide in Nigeria, including *Cannabis sativa*, *Eucalyptus globulus*, *Balanites aegyptiaca*, *Khaya senegalensis*, *Nicotiana tabacum* [10] and neem leaf water extract, and aqueous tobacco extract [11], and demonstrated that tissues from these plants contain bioactive pesticide agents. The broad anthology of living and non-living entities present in biopesticides vary considerably in their properties, mode of action, fate, composition, and behavior within their surroundings. As a result, the government needs to set strict health, safety, and environmental monitoring regulations before granting approval for the production and handling of biopesticides. However, the lack of governmental interest, support, and advocacy, and clear policies on biopesticide development, regulation, and implementation in Nigeria has hampered progress, investments, development, and accessibility to biopesticides, and has deterred farmers from patronizing biopesticides [12].

4. Gaps and opportunities for biotechnology advancement

This section examines areas or issues constituting either challenges which if addressed, or opportunities which if harnessed, will enhance research and commercial applications of agricultural biotechnologies in SSA. Besides selective breeding as well as germplasm characterization based on phenotypes, tissue culture in crops, clonal propagation in trees, sex reversal in aquaculture, and artificial insemination (AI) in livestock, use of modern advanced technologies remains limited in SSA, mostly confined to research projects. However, use of molecular and genomic technologies, while still low, is increasing rapidly especially in research. A major constraint to the application of most of these technologies in SSA relates to capacities (human resources and facilities) and several dimensions of enabling environment—especially political will, low public awareness, and associated effect on acceptance, lack of financial investments, and limited organizational capacities. Five key gaps can be identified for SSA, corresponding to opportunity areas for action: (1) policies and biosafety frameworks, (2) awareness and public participation, (3) utilization of research products and public-private partnerships (PPPs), (4) human capacity and research infrastructure, and (5) financial resources for R&D.

4.1 Biotechnology policies and biosafety frameworks

There is a close relationship between the extents to which biotechnology is being deployed in countries and the policy and political environment for biotechnology. As stated earlier, the relationship among application, capacity, and enabling environment is complex, each somehow acting as driver for the others—with mutually re-enforcing effects. Specifically, countries that are consistently ranked high in applications of biotechnology have also made progress in developing biotech-specific biosafety policies. For high-tech technologies such as genetic modification, the lack of biosafety legislation, policies, and biosafety procedures in several countries continues to be a significant impediment and discouragement to institutions, including private sector institutions that are willing to undertake high-end biotech R&D because processes for application are opaque and tedious, and generally the institutional landscape does not encourage R&D with significant biotech content. Tanzania, for example, has shown a strong political will to promote agricultural biotechnology, as evidenced by the National Biotechnology Development Policy, Biosafety Regulations 2009, Environmental Management Act, and other policies and laws. However, the country's legal framework is prohibitive. Strict liability and redress provisions in the law and regulations are currently a hindrance to advancing biotechnology research and development in the country. Djibouti has some laws and regulations, including those aimed at positioning her for adoption of modern biotechnologies including genetic engineering. However, there lacks specific roadmaps for achieving some of the goals envisioned in the legislation. Djibouti should focus on creating a favorable policy environment to attract private sector working on agricultural biotechnology. Mozambique, on the other hand, has enacted several laws, a large majority of which are focused on protecting natural resources. A few plans have been prepared, such as the National Agriculture Investment Plan 2014–2018. However, these lack clear roadmaps and time-bound actions. While Madagascar has clearly paid attention to policy and legislation side, other enablers that can enhance research and applications are still relatively absent.

4.2 Public awareness and participation

There are major gaps in public awareness and understanding of the science, and the potential promise and usefulness of biotechnology in African agriculture. There

are also knowledge gaps, with misinformation on risks and perceptions of risks remaining one of the key factors that have hindered the adoption of biotechnology in Africa. Consequently, there are misconceptions and lack of knowledge about biotechnology in general, and about GMOs in agriculture in particular. Although there have been successes in public awareness creation, there are still gaps in policy support, political commitment, and acceptance of genetic engineering technologies, and this continues to hinder the adoption of certain biotechnologies in agriculture.

4.3 Utilization of research products and public-private partnerships

The process by which biotech research translates to (commercial) applications in the field requires early engagement of industry (private sector players). On the other hand, agricultural biotech research in almost all SSA countries is still primarily driven by NARI and university scientists who either have limited knowledge on or drive to commercialize research products. Indeed, the incentive of the majority scientists seems to be more about the science and the academic products of science (in form of publications and patents). There is limited or no incentive to invest efforts in commercialization, and the research funding mechanisms do not normally include the commercialization phase and modalities for it. At the same time public extension services are generally weak. Although public-private partnerships (PPPs) have been recognized as one of the ways to drive the conversion of biotech research into practical use, and despite the fact that there are a number of PPPs operating in some countries, there remain major gaps in operationalizing the concept and developing functional partnerships at scale. Simple PPP models have been used in delivery of animal health and AI services in some countries—for example, where semen and vaccine production is done by public sector and field delivery done by private sector, including farmers' organizations and cooperatives. Where new technologies and innovations are involved, a major gap in PPPs is the issue of proprietary rights, especially patents, intellectual property rights, and sharing of benefits accruing from joint biotechnology research and development activities.

4.4 Human capacity and research infrastructure

In most SSA countries, there is a clear lack of a critical mass of scientists in areas relevant for agricultural biotechnology. Even countries that rank as relatively "high" in capacities do not necessarily have critical mass in the more "advanced" areas of modern biotechnology such as genomics, and genetic engineering, for example. The majority of SSA national agricultural research systems (NARS) have research programs that are often limited in scope and dependent on a handful of scientists. Due also to the financial and infrastructural constraints, many such programs often have limited national capacities to implement initiatives beyond pilot scales. This calls for innovative ways of forming critical mass of research teams across sectors—working around issues that allow sharing of staff (and facilities). The acquisition and maintenance of the expensive infrastructure needed for high-tech applications remain a challenge for most countries. Facilities in several countries (the low-capacity countries) are too basic to support modern biotech research. In other cases, equipment acquired through projects only function during the life of these projects and thereafter cannot be maintained—due to budget constraints. The lack of engineers and technicians trained to service these fast-evolving and sophisticated equipments presents another challenge, as do inadequate power supplies and frequent power outages, which also affect reliable cold chains—such as for AI and vaccine field delivery. These challenges have informed the establishment of regional shared biotechnology platforms such as the BecA-ILRI Hub; the concept of shared

facilities is, in the short- to medium term, seen as a means of gradually supporting the strengthening of capacities in the biotechnology fields in SSA. In SSA, the four agricultural sectors—crops, forestry, livestock, and fisheries/aquaculture—are not necessarily under the same ministry. Indeed, in some countries all of these sectors are in different government ministries—although finding livestock and crops under the same ministry is increasingly more common. The administrative separation of these sectors, combined with poor cross-sectoral coordination is inimical to efficiency in the development of technologies. It limits consolidation and exploitation of synergies across sectors owing to bureaucratic procedure required to share physical and human resources—such as labs and personnel. For most countries, sharing of these resources across ministries is just not practiced at all. Even mobilization of resources is done separately by sector, and the amounts allocated to the “hosting ministry” do not always reflect the needs. The countries also need to establish and/or strengthen biotechnology R&D multisectoral networks at national levels and explore mechanisms for linking these to subregional and continental initiatives in order to leverage resources, create synergies, and avoid duplication (hence, enhance efficiency), facilitate learning, horizontal and transboundary transfer of technologies, and upscale best practices and technologies.

4.5 Financial resources for R&D

The main challenge for public agricultural biotechnology R&D in SSA remains how to mobilize investment capital (beyond what is needed for personnel and infrastructure) to initiate or sustain research (and facilitate the process of taking findings to commercial use). Although there has been some growth in the level of funding to ARD in some countries, the level of financing is still extremely low, especially for biotechnology, and not allowing countries to engage effectively in cutting-edge biotech research. Most of the current biotechnology R&D programs are donor funded—with very limited domestic investments; in most countries the allocation is only for salaries (for the limited number of biotech personnel). Although precise value of agricultural biotechnology spending is difficult to obtain, estimates made on the basis of 2014 sector figures (focusing only on crops and livestock) obtained from ASTI database show that most countries invest very limited amounts on agricultural biotechnology. Mobilization of resources (from domestic and other sources) for agricultural biotech is clearly a major area that governments need to look at. In the meantime, given the high cost of biotech R&D, available investments need to be used in a much more coordinated manner to achieve efficiencies from scale and complementarity—and hence the need for cross-sector coordination in biotech R&D. Despite the clear dominance of the public sector both in the financing and implementation of agricultural research, the unstable funding of ARD to date suggests that other avenues should be explored. Universities in SSA, for example, are an underutilized resource that could greatly increase research output with just slight increases in targeted funding to them.

5. Conclusions

Application of biotechnology in agriculture has increased in recent years due to unrelenting effect of climate change exacerbated by a rapidly growing population. Countries that have adopted biotechnology in their agricultural systems, for example, have significantly improved yields and other farm-level benefits. Safety of biotechnology and particularly products of genetic engineering is assured through rigorous safety assessments conducted within national and international biosafety

frameworks. However, lack of awareness on these processes has slowed the adoption of GMO in some countries, especially those with a weak policy environment for biotechnology. It appeared that the enabling policy and regulatory environment is, in early phases, principally driven and shaped by the demand (applications)—and not just the existence of capacity. That is, it starts and evolves at a pace that reflects the level of vibrancy on the “applications.” In other words, governments could develop the required frameworks but they will serve very little purpose and will not “evolve” if they are not being subjected to real tests through active applications. Although it is envisaged that existence of biosafety framework would catalyze biotech adoption, the Kenya *Bt* maize situation and similar examples have shown that legal frameworks alone are insufficient to guarantee an enabling policy environment for investment in remunerative agriculture through biotech crops. Countries in SSA adopting biotechnology may require a comprehensive approach that includes anchoring biosafety laws in their constitutions and a strong political will to drive the agenda. Other focus areas are summarized under Section 4. It is emphasized that countries have to deliberately promote public understanding and awareness on modern biotechnology, vigorously improve resourcing for biotechnology development and adoption, including greater private sector engagement, and improve the available research infrastructure and human resources.

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