Review

Biotechnology and the transformation of Africa’s agriculture: conceptualization, manifestation and policy framework

Samuel Igbatayo

College of Business and Management Studies Igbinedion University, Okada, Nigeria. E-mail: remisamuel2002@yahoo.com

Accepted 5 January, 2012

African countries lag behind other regions of the world in harnessing biotechnology for the transformation of agriculture. In recent times, however, leading African countries, including South Africa, Egypt, Kenya and Uganda have invested in robust agricultural biotechnology research programmes, resulting in field trials and a few varieties of transgenic crops produced in commercial quantity. The New Africa Rice is a success story driven by biotechnology, with a potential to transform African agriculture. The new rice is cultivated in several African countries, providing livelihood opportunities for farmers and saving many countries in the region annual rice import bills estimated at US$90 million. Therefore, the objective of this paper is to explore the attributes of agricultural biotechnology and its potential to transform Africa’s fragile and often failing agricultural sector. It provides policy initiatives aimed at fostering biotechnology as a framework to boost farm productivity and support farmers’ livelihoods.

Key words: Agriculture, Biotechnology, development, food security and Africa

INTRODUCTION

Biotechnology: A Conceptual Framework

The convention on biological diversity, in 1992, defined biotechnology as “any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use”. The Biotechnology Industry Organization (BIO, 2007. 1) also defines biotechnology as the use of biological processes; and technology – to solve problems or make useful products. It defines the concept of biotechnology in the new sense of the word as “the use of cellular and biomolecular processes to solve problems or make useful products”. In general, biotechnology is a collection of technologies that harness the attributes of cells, including their manufacturing capabilities, while using biological molecules, such as DNA (Deoxyribonucleic acid to produce useful products for agriculture, health and industry.

While initial concepts of biotechnology cover traditional techniques, such as in wine or cheese making; modern biotechnology generally refers to the modification of living organisms (plants, animals and fish) through the manipulation of genes (FAO, 2001.1). In general, there are two main types of biological processes. While the first uses genetic information to speed up and improve conventional plant or animal breeding; the second (and more advanced) modifies the genetic pattern of a plant or animal to create a new organism. Terms commonly associated with biotechnology include the following:

- DNA: The chemical molecule at the heart of life itself, made of four chemical elements called bases. These form a double helix, or spiral in which two strands twist around each other. Thousands or millions of these bases form a:
- Gene: the smallest complete unit of coded information in an organism. This constitutes the “source code” of the organism, just as sequences of 1 or 0 define a computer file or programme. Large numbers of these form a:
- Genome: The collection of genes contained in a cell and organized in a particular pattern that defines the
organism. These patterns can be identified by the use of:

- Molecular markers: DNA sequences that can be associated with a trait, such as cold tolerance or the ability to produce a certain toxin. It can also help researchers to characterize genetic diversity more quickly and speed up breeding programmes without modifying the genetic stock of the organism.

Another useful attribute of biotechnology involves reproducing a cell by placing it in an artificial environment that provides nutritional elements, in a process known as:

- Tissue culture: A technique used for micropropagation and breeding purposes.

- Genetically modified organism: An organism whose genetic stock has been modified by introducing a gene or genes or by deleting a gene of genes. “Imported” genes can come from different organisms or species.

Issues in Contemporary Biotechnology

Modern biotechnological discoveries are applied to address emergent global development issues, including demographic explosion, food insecurity, climate change, poverty and chronic under development. Novel genetic engineering technologies may consist of a number of DNA sequences assembled to form a different organism in what is often referred to as “transgenic organisms”. Public research organizations in both industrialized and developing countries, as well as the private sector routinely use biotechnology to manipulate genetic materials for improvement in crops and livestock. The most popular form of commercial application of biotechnology comes with the emergence of genetically modified (GM) crops (OECD, 2007.5; IAASTD, 2009.166). However, biotechnology is not without its critics. Some have expressed concern about the application of modern biotechnology outside containment, such as the use of GM crops. The controversy embraces technical, social, legal, cultural and economic issues. The three most contentious issues are as follows (IAASTD, 2009.40a):

- Lingering doubts about the adequacy or efficiency and safety testing, or regulatory frameworks for testing genetically modified organisms (GMOs).
- Suitability of GMOs for addressing the needs of most farmers while not harming others, particularly on issues surrounding intellectual property rights (IPR).
- Ability of modern biotechnology to make significant contributions to the resilience of small and subsistence agricultural systems.

Figure 1 illustrates the relationship between the original dimensions of biotechnology and its modern configuration.

THE PERFORMANCE OF AFRICAN AGRICULTURE AND IMPLICATIONS FOR FOOD SECURITY.

The Performance of Africa’s Agricultural Sector

Agriculture is the mainstay of the African economy, accounting for more than 30 percent of the region’s annual Gross Domestic Product (GDP) and 50 percent of
the value of its exports. The sector also accounts for up to 80 percent of employment in many countries and is the predominant source of livelihood for the region’s teeming population now placed at 970 million people.

Against the backdrop of low yield and poor investment in Africa’s agricultural sector, its contribution to GDP is inconsistent, measured at 29.2 percent in 1979-81 and 24.6 percent in 2002-2004, compared with the world averages of 7 percent and 3 percent, respectively (UNECA, 2009.118).

Table 1 shows the share of agriculture in GDP distributed across Africa’s Regional Economic Communities (RECs). The data show a disparity in the contributions of agriculture to GDP in Africa on the one hand; and the World on the other. The relatively high proportion of agriculture to GDP in Africa underscores the region’s reliance on agriculture for the people’s livelihoods.

Crops cultivated in Africa are informed by local climate conditions, tradition, taste, level of income, etc. Cereals cover a total area of 93 million hectares, with maize accounting for 29 percent, rice 8.4 percent and Sorghum 23.7 percent of the total cultivated area. Cassava accounts for 48.6 percent of total land under root crop farming. Table 2 shows that various commodities feature some variations across RECs, fueled by the use of irrigation and other yield-enhancing technologies and practices. Differences in weather conditions and the length of rainfall are also crucial as crop production in Africa is predominantly rain-fed.

Measured in metric tons per hectare (MT/ha), yields of cassava are highest in EAC (8.8) and IGAD (8.0) and lowest in ECOWAS (4.6), while yields of maize are highest in SADC (1.8), followed by COMESA (1.6) and AMU(1.6), and are lowest in ECOWAS. The high yields in EAC and IGAD are attributed to the widespread adoption of hybrid seeds and the use of inputs in these RECs. Except for SADC (0.5), yields for millet are almost similar across RECs (07 – 09MT/ha). Humid West African countries are the traditional oil palm producers, with old plantations and low yields. Sorghum yields, however, are relatively similar across the RECs, although AMU, COMESA and SADC have a slightly higher yield, according to the UNECA report. Yields of pulses are lowest in ECOWAS (0.5), possibly because of humid climate, while in other RECs they appear to be relatively similar. Rice yields are highest in AMU (3.7), attributed to the use of irrigation and are lowest in ECCAS (1.6), ECOWAS (1.9) and SADC (1.8), while its yields in other RECs are similar.

In general, low yields associated with crop production in Africa are blamed on low diffusion of agricultural technologies, including hybrid seeds and seedlings, irrigation systems, fertilizers, pesticides and herbicides, as well as agricultural mechanization for planting and maintenance. Consequently, the African Union (AU) and New partnership for Africa’s development (NEPAD), in 2004, established a road map for the implementation of the comprehensive African Agricultural Development Programme (CAADP), aimed at restoring food security on the continent and also identified four pillars for the transformation of the agricultural sector as follows: (AU – NEPAD, 2008.8):

- Improving agricultural research and technology dissemination and adoption;
- Increasing food supply chains, reducing hunger and improving response to emergencies;
- Extending areas under sustainable land management and reliable water control systems; and
- Improving rural infrastructure and trade related capacities for market access.

The state of Food Insecurity in Africa

While productivity of African agriculture has persisted for the past several decades, the demand for agricultural products has risen phenomenally, driven by fast population growth, urbanization, income growth and changes in diet patterns. In the light of these developments, food security in African countries has been threatened, turning many African countries from being net food exporters in the 1970s to often being food-aid-dependent, net food importers in recent times (UNCTAD, 2009.4). Of the 36 countries worldwide currently facing food crisis, 21 are African and it is estimated that more than 300 million Africans are facing chronic food hunger. This segment of the population remains particularly vulnerable by the changes in price levels of staple foods, which has trended upwards in the past few years, although the pace has waned since 2009.

The share of sub-Saharan Africa in world hunger is very disproportionate compared to the rest of the world. With only 11 percent of the world’s population, the sub-continent is home to 25 percent of the total number of hungry people around the world in 2003-05. Also, the

Table 1: Share of Agriculture in GDP and its Distribution across RECs in Africa.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>AMU</td>
<td>13.7</td>
<td>17.7</td>
<td>13.9</td>
<td>13.8</td>
</tr>
<tr>
<td>CEN-SAD</td>
<td>31.7</td>
<td>32.3</td>
<td>31.4</td>
<td>29.8</td>
</tr>
<tr>
<td>COMESA</td>
<td>29.9</td>
<td>27.2</td>
<td>27.8</td>
<td>25.6</td>
</tr>
<tr>
<td>EAC</td>
<td>47.2</td>
<td>41.1</td>
<td>36.5</td>
<td>34.6</td>
</tr>
<tr>
<td>ECCAS</td>
<td>25.7</td>
<td>28.7</td>
<td>25.6</td>
<td>24.5</td>
</tr>
<tr>
<td>ECOWAS</td>
<td>34.8</td>
<td>34.2</td>
<td>33.1</td>
<td>31.6</td>
</tr>
<tr>
<td>IGAD</td>
<td>48.4</td>
<td>39.2</td>
<td>33.1</td>
<td>28.7</td>
</tr>
<tr>
<td>SADC</td>
<td>22.4</td>
<td>21.1</td>
<td>19.5</td>
<td>18.7</td>
</tr>
<tr>
<td>Africa</td>
<td>29.2</td>
<td>28.5</td>
<td>25.8</td>
<td>24.6</td>
</tr>
<tr>
<td>World</td>
<td>7.0</td>
<td>5.0</td>
<td>4.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Source: UNECA, 2009.118
proportion of undernourished people on the continent is well above world average (13 percent) and 2 points higher than the average of the developing world. In a trend that is marginal in North Africa, at less than 5 percent; the prevalence of hunger in sub-Saharan Africa (30 percent), is almost twice the average of the developing world (UNECA, 2009.1a).

Between December 2005 and April 2009, only sixteen countries out of a sample of forty-six African countries can be classified as food secure, i.e. they did not face any food crisis that required emergency assistance, according to the UNECA report. The countries concerned harbour 25 percent of the total number of hungry people around the world in 2003-05.

THE STATE OF AGRICULTURAL BIOTECHNOLOGY AND TRANSFORMATION OF AFRICA’S AGRICULTURAL SECTOR.

The Profile of Agricultural Biotechnology Initiatives in Africa

At the dawn of the 21st century, Africa faced challenging development issues, ranging from endemic poverty, widespread hunger, unsustainable urbanization, environmental degradation, low life expectancy (at birth) and chronic underdevelopment. One of the most serious issues however relates to the complex nexus of Africa’s unsustainable population growth rates and food insecurity dimensions. The vulnerability of many African countries to perennial food insecurity has been exacerbated by such emergent challenges as the global climate change, bad governance, regional instability, including armed conflicts.

In the light of emergent food insecurity challenges undermining development efforts in Africa, agricultural biotechnology has become a relevant instrument to addressing the following issues (Machuka, 2001.2)

- Food and nutrition security
- Crop and animal productivity
- Environmental degradation
- Food processing
- Sustainable livelihoods.
- Diseases and pest control.

Although there is considerable reservation about the consumption of GM crops in Africa, the technology associated with the crop is not new to the region. The continent has at its disposal a rich number of National Agricultural Research Institutes, as well as International agricultural centres, with a profile of robust research initiatives, including the harnessing of biotechnology for agricultural productivity. Some African countries have taken bold initiatives in promoting agricultural biotechnology. These include South Africa, Egypt, Kenya and Uganda. The profile of agricultural biotechnology initiatives in these countries are examined as follows:

South Africa

South Africa has an advanced research agenda under its agricultural biotechnology programme. The nation’s research on GM crops, particularly with grains is well documented in literature. For example, about 20-30 percent of yellow maize and 80 percent of cotton in South Africa are derived from GM crops. Estimates for the 2003/04 production season showed that about 27 percent of total yellow maize area (used in animal feed) were derived from GM crops, while white maize (for human consumption) is planted on less than 8 percent of the total maize area.

An insect-resistant potato variety was developed in South Africa in 2001, with the aim of assisting small-scale farmers to become commercial farmers. While field trials were successful, commercialization was, however, delayed. Also, the University of Cape Town, in collaboration with the Agricultural Research council (ARC) developed and released for field testing the first transgenic potato in the country, with the traits for resistance to potato virus Y and leaf roll virus. Further, the University also developed tobacco resistant to

Table 2: Comparison of Crop Yields and Production across African RECs, 1990, 2006.

<table>
<thead>
<tr>
<th>COMMODITY (unit)</th>
<th>COMESA</th>
<th>EAC</th>
<th>SADC</th>
<th>IGAD</th>
<th>ECOWAS</th>
<th>ECCAS</th>
<th>AMU</th>
<th>CENSAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava (MT/ha)</td>
<td>7.4</td>
<td>8.8</td>
<td>7.5</td>
<td>8.0</td>
<td>4.6</td>
<td>7.0</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>Maize (MT/ha)</td>
<td>1.6</td>
<td>1.3</td>
<td>1.8</td>
<td>1.2</td>
<td>1.1</td>
<td>1.3</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Palm oil fruits (MT/ha)</td>
<td>9.4</td>
<td>12.2</td>
<td>10.6</td>
<td>-</td>
<td>7.9</td>
<td>10.8</td>
<td>-</td>
<td>8.2</td>
</tr>
<tr>
<td>Pulses (MT/ha)</td>
<td>0.83</td>
<td>0.7</td>
<td>0.6</td>
<td>0.7</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Sorghum (MT/ha)</td>
<td>1.1</td>
<td>1.1</td>
<td>0.98</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Rice (MT/ha)</td>
<td>2.7</td>
<td>2.7</td>
<td>1.8</td>
<td>2.8</td>
<td>1.9</td>
<td>1.6</td>
<td>3.7</td>
<td>2.6</td>
</tr>
<tr>
<td>Milk (000MT)</td>
<td>802.5</td>
<td>847</td>
<td>5321.4</td>
<td>1901</td>
<td>163.3</td>
<td>85.5</td>
<td>259</td>
<td>217</td>
</tr>
<tr>
<td>Meat (000MT)</td>
<td>211.1</td>
<td>214.1</td>
<td>242</td>
<td>274.7</td>
<td>152.2</td>
<td>66.8</td>
<td>627</td>
<td>670</td>
</tr>
<tr>
<td>Millet (MT/ha)</td>
<td>0.7</td>
<td>0.9</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>0.8</td>
<td>0.9</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Source: UNECA, 2009.120
Table 3: Current Agricultural Modern Biotechnology Projects in Kenya.

<table>
<thead>
<tr>
<th>Product</th>
<th>Year of approval(s)</th>
<th>Partners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recombinant Livestock vaccines (for diseases, including Reinderpest and capripox)</td>
<td>1995 (ad-hoc)</td>
<td>KARI, Fulbright (UK), University of California, Davis</td>
</tr>
<tr>
<td>Virus-resistant sweet potato</td>
<td>1998</td>
<td>KARI, Monsanto, USAID, ISAAA, ARC-VOPI, Dan forth Centre, USA.</td>
</tr>
<tr>
<td>Insect-resistant (Bt) cotton</td>
<td>2003</td>
<td>KRIA, Monsanto</td>
</tr>
<tr>
<td>Virus-resistant Cassava</td>
<td>2003</td>
<td>KARI, Dan forth centre (USA), USAID/ABSPII</td>
</tr>
</tbody>
</table>


cucumber mosaic and tobacco necrosis viruses.

South Africa’s legislative instruments for regulating biotechnology research and development include the Genetically Modified Organisms Act (GMO Act) of 1997 and the Regulations for its implementation adopted in 1999. The legislative framework establishes norms and rules for importing and exporting from the country GM organisms. The process requires permission of the national regulatory authority, which may be issued after a scientific assessment and risk analysis have been conducted and approved by the executive council.

Kenya

Kenya has a relatively long history engaged in genetic engineering, working with non-GM biotechnologies, particularly the production of bio-fertilizers and tissue culture in the past several decades. The first transgenic crop to be produced in Kenya was a GM virus and weevil-resistant potato crop. The project started in 1991 under a public–private partnership framework between the United States Agency for International Development (USAID) the Kenyan Agricultural Research Institution (KARI) and the Monsanto Company. The institutional service for the Acquisition and Application of Agricultural Biotechnology (ISAAAAB) joined the alliance in 1999. However, the field trials met some setbacks, blamed on a defective construct for the virus resistance, which was not well tested and did not perform well. On the other hand, KARI had been collaborating with CYMMIT, in Mexico in a partnership that developed insect resistant transgenic maize crop, which was tested in 2005. The crop is being developed for resistance to stiga and tolerance to drought. It is important to note that Kenya’s agricultural biotechnology research agenda remains mainly at field trials, as commercial cultivation of GM crops is yet to commence. Table 3 shows current biotechnology projects and partner organizations in Kenya.

Egypt

Egypt has a long history in agricultural biotechnology research dating back several decades and is reputed with the largest production of transgenic crops in Africa. The performance of the Genetic Engineering services Unit (GESU) of the Agricultural Genetic Engineering Research Institute has an enviable record in technology research and is involved in micro propagation of satavia rabaudiana and mulberry, as well as the production of diagnostic kits for detecting viruses in banana, potato, tomato and beans. Plant biotechnology research at AGERI has grown to include transferring of genes that confer virus resistance on many crops, including potato, cotton, maize, beans, cucurbits, wheat, banana and date palm.

Uganda

Uganda is a country with an active research agenda in agricultural biotechnology. The National Agricultural Research Organization (NARO) opened a new research laboratory in 2003 to conduct work on the genetic modification of banana, with the aim to insert genes that will confer resistance to Black Sigatoka and banana weevils. A partnership framework involving African and other international institutions was forged with international Institute of Tropical Agriculture (IITA) the University of Pretoria, South Africa, and Leeds University in the U.K. The collaborative efforts have spawned field trials on Bt cotton in several countries, including Kenya, Zambia and Zimbabwe. Biotechnology and safety issues are regulated in Uganda under international conventions. The country signed and ratified the Cartagena protocol on Biosafety on May 24, 2000 and November 30, 2001, respectively.

Agricultural Biotechnology and the Transformation of Africa’s Agriculture.

Critics in both industrialized and developing economies have expressed considerable reservation to the adoption of transgenic products by developing countries. Apart
from safety issues associated with GM crops, many claim that the crops are unlikely to help poor farmers, as production is driven by commercial farmers and large multi-national companies. However, results from field trials and a few transgenic crops available in commercial quantity in Africa point to a different dimension. Results from the production of several transgenic crops, particularly grains, cotton vegetables, potato and beans on the continent reveal that they are not only safe for human consumption but also feature high yields, disease, pest and drought resistance, with the potential to increase the income and improve livelihoods of poor farmers in Africa (Bayer and Wanyama, 2005.4).

The potential of agricultural biotechnology is demonstrated by the success story associated with the New Rice for Africa or NERICA, a new variety of rice produced by scientists at the Africa Rice Centre (WARDA) in Benin by crossing a variety of Asian rice (Oryza sativa) and an African variety (Oryza glaberrina). The new varieties of rice created out of the germplasm, feature such qualities as higher yields, shorter growing seasons, resistance to local stresses, as well as higher protein content. The new rice has been released to farmers in Cote D'ivoire, Nigeria, and Uganda, while they are being evaluated in Benin, Burkina Faso, Ethiopia, the Gambia, Mali, Malawi, Mozambique, Sierra Leone, Tanzania and Togo. WARDA researchers revealed that more than 200,000 hectares of the new rice varieties were to be under NERICA cultivation, producing about 750,000 tonnes per year and creating a saving on annual rice imports estimated at US$90 million (Juma and Serageldin, 2007.26).

Widespread adoption of agricultural biotechnology holds the key to the transformation of Africa’s agriculture from its fragile, often failing state, to a highly productive and technologically driven sector that can become the solid foundation for a dynamic African economy in the 21st century. Indications are that there is a momentum driven by National and international research institutions in and beyond Africa putting agricultural biotechnology research at the top of the development agenda (Woodward et al, 1999.8).

RECOMMENDATIONS AND CONCLUSION

Recommendations

In order to realize the full promise of agricultural biotechnology in Africa there is need for a policy framework aimed at addressing technological, economic and environmental challenges that task the ingenuity of policy makers. This section presents the following pertinent recommendations:

- Prepare a policy framework that links the potential economic impacts of biotechnological innovations to the wider economy.
- Simplify regulation to encourage use of biotechnology to improve the nutritional content of staple crops in Africa.
- Create a Public-Private Partnership Agenda to fast track research and development of transgenic crops and animals critical for food security and livelihood improvement of resource-poor African farmers.
- Increase budgetary allocation to fund research and development of promising agricultural biotechnology projects
- Forge enduring collaboration between African National Agricultural Research institutes and international agricultural research bodies to mobilize finance, technology and enhance human capital development in Africa.

Conclusion

Although biotechnology is hardly new to Africa, the continent has lagged behind in harnessing the attributes associated with the innovation. Some have expressed reservations about the efficacy of GM crops in addressing the needs of poor African farmers. However, several African countries have embraced agricultural biotechnology and embarked on research, as well as field trials for the production of GM crops, particularly grains and other staple foods. Success stories are being recorded in some African countries, where transgenic crops have been produced in commercial quantity. NERICA rice is a prime example, which has transformed the livelihoods of farmers and fostered food security in a few African countries.

REFERENCES


