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Review

Status of biotechnology in Eastern and Central Africa

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This work examines trends of both conventional and modern biotechnologies in selected Eastern and Central African countries namely Kenya, Uganda, Tanzania, Ethiopia, Rwanda, Burundi and Democratic Republic of Congo, with the aim of giving an up-to-date assessment of their national policies, institutional capacities, and the activities being carried out. Agricultural biotechnology seems to take the lead while biotechnologies related to health, industries and environment are lagging behind. Kenya leads the region with its biotechnology policy framework in place and more on-going biotechnology related activities, followed by Uganda. Tanzania has already developed its biotechnology policy but is slower to translate it into practice especially on matters related to modern biotechnology. The rest of the countries are yet to formulate their biotechnology policies but efforts are underway to achieve that goal. Plant tissue culture is done in all the countries and some projects have already been commercialised. Transgenic crops/animals projects are mainly at the field trial stage and none has been commercialised. The main constraints facing the biotechnology industry in the region are poorly skilled human resources, lack of modern facilities, poor public perception and weak political will by some governments. More vigorous practical actions are needed in order for biotechnology to benefit the people of this region in terms of food security, economic growth, improved health and environmental protection.

Key words: Biotechnology, genetically modified organisms, molecular assisted selection, tissue culture.

INTRODUCTION

Biotechnology is a branch of applied bioscience and technology which involves the practical application of biological organisms, or their sub-cellular components in agriculture, health, manufacturing and service industries, and in environmental management (Kasonta et al., 2002). It utilizes bacteria, yeasts, fungi, algae, plant cells or cultured mammalian cells as constituents of industrial processes (Persley, 1992). Successful application of biotechnology integrates multiplicity of scientific disciplines including microbiology, biochemistry, genetics, molecular biology, chemistry and chemical and process engineering. Some commercial products of biotechnology include beverages, vinegar, cheese, yogurt, biogas, compost and organic acids (citric acid, amino acids, acetic acid). Others are solvents (alcohols, acetone), gums, plastics, detergents, perfumes, hormones, peptide and steroids. Enzymes (hydrolases, proteases, amylases, peroxidases and oxilases) and vaccines, antibiotics, high fructose corn syrup, cellulose and single cell proteins are also products of biotechnology (Mtui, 2007).

In plant biotechnology, three applications of broad fields of study are plant tissue culture, plant molecular markers and genetic engineering, ranging from simple to sophisticated technologies (Brink et al., 1998). Tissue culture is the cultivation of plant cells or tissues on specifically formulated nutrient media. Under optimal conditions, a whole plant can be regenerated from a single cell. It is a rapid and essential tool in modern breeding for producing disease-free plants (Kumar and Naidu, 2006). Molecular markers are identifiable DNA sequences found at specific location of the genome. By determining location and likely actions of plant genes, scientists can quickly and accurately identify plants carrying desirable characteristics, hence breeding can be conducted with greater precision (Mneney et al., 2001). Molecular markers can be used in plant breeding in the following ways: increase the response and accuracy of selection by using marker assisted selection; increase the speed and efficiency of the introduction of new genes through marker assisted introgression; study of genetic diversity and taxonomic relationships between plant species; and studies of biological processes such as mating systems, pollen or disease dispersal (Johanson and Ives, 2001). Biotechnology enables the development of disease diagnostic kits for use both in the laboratory and in the field. Furthermore, diseases that are caused by microbes can be identified by a unique feature of the microbe, such as its DNA of a specific protein (Kumar and Naidu, 2006). Conventional biotechnology will do much better if blended with modern biotechnology.

On the other hand, modern biotechnology is a term which refers to biotechnological techniques for the manipulation of genetic material and the fusion of cells beyond normal breeding barriers. The most obvious example is genetic engineering to create genetically modified organisms through "transgenic technology" involving the insertion or deletion of genes. In genetic engineering or genetic transformation, the genetic material is modified by artificial means. It involves isolation of a gene and cutting it at a precise location by using restriction enzymes. Selected DNA fragments can then be transferred into the cells of the target organism, and that organism becomes 'genetically modified'. The commonly used method in genetic engineering is the use of a bacterium, *Agrobacterium tumafaciens*, as a vector (Johanson and Ives, 2001). Another method is ballistic impregnation method - attaching a DNA to be introduced onto a minute gold or tungsten particle, then 'firing' it into the plant tissue (Morris, 2011).

MODERN BIOTECHNOLOGY IN THE WORLD STAGE

Worldwide, modern biotechnology is centred in agriculture, with commercialised genetically modified maize, canola, soybean and cotton being the dominant crops in the developed countries (Johanson and Ives, 2001; Mugabe, 2003; Clive, 2010). In the developing countries, genetic and biotechnological improvements of 'neglected' food species are confined to specific crop centres in those countries and/or in specific collaborations with the agricultural research institutes in the industrialized countries. The goal of modern biotechnology is to produce genetically modified organisms with the following traits:

1) Increased resistance to pests and diseases – insects, viruses, fungi, bacteria and nematodes
2) Increased tolerance to environmental stresses – drought, flooding, soil acidity and alkalinity heavy metals and extreme temperatures
3) Increased yield
4) Reduced post-harvest losses
5) Improved nutritional contents of foods and feeds (Johanson and Ives, 2001).

Agricultural biotechnology presents many opportunities and challenges for the developing world. It promises to help meet food security needs, reverse declining per capita food production and improve the incomes and livelihoods of farmers. The international community acknowledges the potential of biotechnology to change lives. Overall, biotechnology promises to make a significant contribution in enabling the development of better health care, enhanced food security through sustainable agricultural practices, improved supplies of potable water, more efficient industrial development processes for transforming raw materials, and support for sustainable methods of reforestation and detoxification of hazardous wastes. Biotechnology also offers new opportunities for global partnerships. Biotechnology has grown into a global industry affecting many aspects of life. Globally, the biotechnology industry was estimated to have generated US$34.8 billion in revenues and employed about 190,000 persons in publicly traded firms worldwide in 2001, and an estimated 4,200 public and private biotechnology firms were in operation (Konde, 2006). In 2005, GM crops farm income alone was estimated at US$5.6 billion (Brookes and Barfoot, 2006), which jumped to US$10.1 billion in 2007 and US$ 44.1 billion for the period of 12 years of commercialised genetically modified organisms (GMO) crops (Brookes and Barfoot, 2009). In addition to high income generation, biotechnology offers comparative advantage compared to non-biotechnology processes: They are cheaper (that is less energy demanding); they offer longterm benefits as means of solving some major world problems such as those related to food security, novel medical and industrial products, pollution control and the development of new energy sources. They also hold a bright future in terms of market potential for new products (Johanson and Ives, 2001; Mtui, 2007).

TRENDS OF BIOTECHNOLOGY IN AFRICA

Substantial biotechnology related research is being carried out in most African countries, but few of these countries have reached the take-off stage on development of local and regional market products. Development of biotechnology, mostly plant biotechnology, in African countries relies on established biotechnological centres, either of a regional or international character, that specialize in *in vitro* cultivation of cash crops such as banana, coffee, cocoa, palm-oil, vanilla; and food crops such as maize, millet, cassava and cowpea (Massola, 1992). Plant-based biotechnology have so far achieved the following: Production of high quality biofertilizers; bioprospection of new nitrogen fixing species of bacteria and mycorrhizae; creation of novel genetic and hybrid variability; *in vitro* cloning of plants of ornamental and economic significance; and diversification of bio-industrial production of plant metabolites of medical significance like reserpine (*Rauwolfia serpentina*), glycyrrhetic acid (*Abrus precatorius*) and rotenone (*Tephrosia vogelii*). South Africa is the leader of biotechnology in Africa, as it has already developed and commercialised transgenic products such as maize and cotton. Other South African countries (Zimbabwe, Malawi and Madagascar) are doing micro-propagation of disease-free banana, rice, maize, groundnuts and tropical woody trees. North African countries (Morocco and Tunisia) are doing biological research and preliminary trials on palms, potatoes, tomatoes, maize and forest trees (Morris, 2011). West African countries (Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Nigeria, Gabon and Senegal) are doing various projects related to biological nitrogen fixation; production of legume inoculants; fermented foods; medicinal plants; plant tissue culture of cocoa trees, rubber trees, coffee trees, yams, oil-palm, pineapple, cotton, tea, banana, cassava, ginger, eucalyptus and acacia; and production of mycorrhizal-based bio-fertilizers for rural markets (Brink et al., 1998). Out of 53 countries of the African Union, only 16 have laws, regulations, guidelines or policies related to modern biotechnology. Of these, only South Africa, Egypt and Burkina Faso have experiences in commercialisation of GMO crops (Makinde et al., 2009). The main problems facing biotechnology experts in Africa is the scarcity of resources and slow passage of GM crops from experimental to commercial stages and difficulties in meeting regulatory requirements (Michaelis, 1993; Lynam, 1995; Nyira, 1995; Thomson, 2004). Africa’s under-development in terms of insufficient good quality food, poor health care, unreliable sources of energy and degraded environments would be greatly reversed if the continent embraces biotechnology.

BIOTECHNOLOGY IN EASTERN AND CENTRAL AFRICAN COUNTRIES

This work attempted to carry out a facts-and-figures review on biotechnology activities in the Eastern and Central African countries namely Kenya, Uganda, Tanzania, Ethiopia, Rwanda, Burundi and Democratic Republic of Congo (DRC). While Kenya, Uganda and Tanzania have already developed and operationalized their biotechnology policies and guidelines, the rest are yet to do so (Table 1). Burundi is in a process of formulating its policy while the rest have only managed to put up biosafety frameworks, and efforts are underway to develop their biotechnology policies. Currently, biotechnology projects that have already been commercialised are mainly on conventional tissue culture and plant/animal breeding, while GMO related projects are still undergoing contained research in laboratories or screen houses, and confined experiments are being carried out in the trial fields (Olembo et al., 2010).

Table 1. Status of biotechnology policy frameworks in some Eastern and Central African countries (Republic of Kenya, RoK, 1998; Republic of Uganda, RoU, 2004); United Republic of Tanzania, URT, 2005; Republic of Rwanda, RoR, 2005, Republic of Burundi, RoB; 2006, Democratic Republic of Congo, DRC, 2007; Kassa 2011).

Country	Policy framework
Kenya	Biotechnology policy (2007)
Uganda	Biotechnology policy (2008)
Tanzania	Biotechnology policy (2009
Ethiopia	None
Rwanda	None
Burundi	In preparation
DRC	None

Status of biotechnology in Kenya

Kenya is the leading economy in East Africa. Apart from tourism, Kenya’s economy is dependent on agriculture where tea, coffee, sisal and pyrethrum are the leading export crops, while the staple food crops are maize and wheat. Coconuts, pineapples, cashew nuts, cotton, sugarcane, sisal and corn are grown in the low-lying areas. Biotechnology is taking roots in Kenya. After the government had passed the national biotechnology policy in 2007 that was developed by the Kenya National Council for Science and Technology (NCST; www.ncst.go.ke, cited on 13th August 2011), many biotechnology projects got a big boost. Conventional biotechnology procedures such as tissue culture (TC) are widely used for production of planting materials for pyrethrum, banana, sugarcane, potato, strawberry, cassava, vanilla, oil palm and flowers. Marker assisted selection (MAS) is used for characterization and mapping of maize streak virus and grey leaf spot resistance genes in maize; development of drought tolerant wheat and aphid resistant maize and wheat; smut resistant sugarcane, breeding for desirable traits in cassava, rice and sorghum; and characterization of indigenous species of cattle, forages and tsetse flies. In case of livestock, biotechnology is directed at development of recombinant DNA vaccines for Newcastle disease, Rift valley fever and rind pest fever (Karembu, 2007; Olembo et al., 2010).

Research and development (R and D) institutions are engaged in the GMO research projects, with the Kenya Agricultural Research Institute (KARI) taking the leading role. The GMO projects on virus-resistant sweet potatoes and cassava; insect resistant maize, cotton, cowpea and sweet potatoes; drought resistant maize; and bio-fortified rice are among the projects which are at different stages of permit applications, laboratory and screen house containments, or fields trials (Thompson, 2004; Macharia, 2010; Olembo et al., 2010; Mugo et al., 2011). At the

Kenyatta University, research on striga-resistant sorghum is on-going and it has reached a confined field trial stage (Sithole-Niang, 2004; Kingiri and Ayele, 2009). Furthermore, the plant transformation laboratory at Kenyatta University is currently exploiting the availability of genes and technologies to improve drought tolerance, nutritional value and adaptability of major food crops (Muoma, 2010).

The International Livestock Research Institute (ILRI; http://www.ilri.org, cited on 13th August 2011) in Nairobi conducts research in systems analysis and impact assessment; people, livestock and environments; livestock policy analysis; livestock health; livestock feeds and nutrition; livestock genetics and genomics; strengthening partnerships for livestock research; smallholder dairy; and smallholder livestock systems. Being part of the consultative group on international agricultural research (CGIAR), ILRI works with partners worldwide to help poor people keeping their farm animals alive and productive. It also helps farmers to find profitable markets for their animal products. In the area of biotechnology, ILRI focuses on development of appropriate diagnostics to help identify disease threats and develop specific vaccines; identifying and using genetic adaptations such as disease resistance and developing appropriate marker technologies to facilitate delivery of genetic improvement into farmers' herds/flocks; and genetic adaptations to increase the quality of feeds (Olembo et al., 2010). Other R and D institutions involved in biotechnology research in Kenya include the University of Nairobi (Department of Biochemistry), Jomo Kenyatta University of Agriculture and Technology (JKUAT) and the National Potato Research Centre (NPRC). The private sector, including the genetic technologies international limited (GTIL) and MIMEA are involved in tissue culture and mass propagation activities. The on-going biotechnology-related research projects in Kenya are summarized in Table 2.

In Kenya, at least six genetically modified organisms (GMO) projects have been approved and they are under contained laboratory and screen house trials while others are in various stages of application (Table 3).

Kenya is moving fast up the biotechnology ladder. Concerted efforts by the government and other stakeholders in addressing insufficient financial, human resources and infrastructure challenges would sustain it as a leader of biotechnology in the Eastern and Central Africa region.

Status of biotechnology in Uganda

Uganda is endowed with significant natural resources, including ample fertile land, regular rainfall, and mineral deposits. Biotechnology in Uganda is set to contribute to the national goals of poverty eradication, improved healthcare, food security, industrialization and the protection of the environment. The Uganda National Biotechnology and Biosafety (BAB) policy was approved by the Ugandan Cabinet in 2008 after a thorough review and deliberation of various stakeholders. The policy, which was formulated by the Uganda National Council for Science and Technology (UNCST) in 2002, aims to build and strengthen national capacity in biotechnology through research and development, promote the utilization of biotechnology products and processes as tools for national development and provide a regulatory and institutional framework for safe and sustainable biotechnology development and application (www.absfafrica.org, cited on 25th August 2011). The objective of the BAB Policy is to provide regulatory and institutional framework for sustainable and safe application of biotechnology for national development (www.uncst.go.ug, cited on 25th August 2011).

Uganda has made an impressive start in biotechnology related activities which are mainly being carried out by R and D institutions. There are growing applications of biotechnologies related to agriculture, health, environment and industry such as tissue culture, production of transgenic crops, diagnostic tools, medicines, vaccines and hormones. Biotechnology is used in bioremediation, biofuels and production of enzymes (Olembo et al., 2010). The main public research and development institution in Uganda is the Makerere University with the following biotechnology-related departments: Department of Crop Science, Biochemistry, Animal Science, Parasitology and Microbiology, Food Science and Technology, Institute of Environment and Natural resources and the Medical School. Other R and D public institutions are the Natural Agricultural Research Organisation (NARO), which has the following research centres: Kawanda Agricultural Institute (KARI), Namulonge Agricultural and Animal Producing Research Institute (NAARI), Livestock Research institute (LIRI), Coffee Research Institute (CRI), Forest Research Institute (FRI) and Food Science and Research Institute (FSRI). Other public Institutes are the Uganda Virus Research Centre (UVRC) and the Joint Clinical Research Centre (JCRC). Private sector institutions are the Med-Biotech Laboratories (MBL) and Agro-Genetic Laboratories (AGL), while international institutions involved in biotechnology R&D in Uganda are the International Institute of Tropical Agriculture (IITA) and the International Network for Improvement of Banana and Plantain (INIBAP) (Olembo et al., 2010). The activities of these institutions are summarized in Table 4.

Several international and regional bodies have been supporting biotechnology projects in Uganda. They include the Rockefeller Foundation which has been supporting a project on disease-free banana and cassava and striga-resistant maize; the Mexico-based international maize and wheat improvement centre (CIMMYT) that supports insect and striga-resistant maize

Table 2. Institutions involved in biotechnology activities in Kenya (modified from Brink et al., 1998; Johanson and Ives, 2001; Glover, 2007, Onsongo, 2009; Olembo et al., 2010).

Institution and collaborators	**Activity**
KARI, Bill and Melinda Gates	Bio-fortified sorghum
KARI, CIMMYT	Insect resistant maize (leaves and seeds)
KARI, Monsanto	Insect resistant cotton
KARI, Monsanto	Virus resistant sweet potato
KARI, USAID	Virus- resistant cassava
KARI, and various collaborators	1) Production of disease free plants and micro-propagation of pyrethrum, bananas, potatoes, strawberries, sweet potato, citrus, sugar cane. 2) Micropropagation of ornamentals (Carnation, Alstromeria, Gerbera, Anthurium, leopard orchids) and forest trees. *3) In vitro* selection for salt tolerance in finger millet. 4) Transformation of tobacco, tomato and beans. 5) Transformation of sweet potato with proteinase inhibitor gene. 6) Tissue culture regeneration of papaya. *7) In vitro* long-term storage of potato and sweet potato. 8) Marker-assisted selection in maize for drought tolerance and insect resistance. 9) Well-established MIRCEN providing microbial biofertilizers in the East African region.
ILRI	1) Development of recombinant vaccines against East Cost fever. 2) Development of improved control interventions for *Peste des Petits* Ruminants virus. 3) Breeding for improved chicken production. 4) Development of molecular diagnostic and control tools and strategies for pork tapeworm cysticercosis. 5) Identifying appropriate germplasm for dairy development and delivery mechanisms. 6) Strain restricted immunity to parasitic protozoa that cause East Coast fever. 7) Developing second-generation vaccines for critical bovine diseases.
Nairobi University Biochem Department	Research on GM capripox virus, rinderpest recombinant vaccine production and production of transgenic sweet potato, MAS sorghum.
JKUAT	Tissue culture of various food crops and ornamentals.
Kenyatta University	Transgenic sorghum for resistance to Striga parasitic weed. Transgenic maize for drought tolerance.
NPRC	Tissue culture of Irish and sweet potatoes.

Table 2. Contd.

Moi University	Marker assisted selection in sorghum, maize
GTIL	Tissue culture of various plants including banana, potatoes, and sweet potatoes, coffee, pyrethrum, sugarcane, vanilla, fruits, trees and medicinal plants.
MIMEA	Mass propagation of cassava, sweet potatoes, banana and ornamentals.

project; and the Bill and Melinda gates which supports the WEMA Project (Olembo et al., 2010). Efforts towards commercialisation of GMOs in Uganda are underway. Already, 5 projects have been approved and are currently undergoing field trials while and 5 others are under review (Table 5).

The progress of biotechnology activities in Uganda is encouraging. With the Biotechnology and Biosafety Policy in place, the current research-based contained and confined trials will soon move a step further to realise commercial release of GMOs. Uganda is, however, faced with financial constraints, insufficient skilled manpower and inadequate facilities to fully engage in modern biotechnology operations. The government should, therefore, invest more in those lines in order to address the country's food security, improved people's health and overall socio-economic development challenges.

Status of biotechnology in Tanzania

Tanzania is faced with mass poverty and remains to be among the poorest countries of Sub-Saharan Africa and the 22nd poorest in the world with over 30% of its population living below the international poverty line, earning less than 1 USD per day (URT, 2005). The burden and incidence of poverty is more widespread in rural than urban areas, where over 60 percent of the people live and agriculture forms the main stay. Realizing that, it considers biotechnology to be one of the means to rid itself out poverty, ensure food security and public health (www.mst.go.tz, cited on 25th August 2011). The Tanzania Biotechnology Policy (TBP) was approved in 2009. Its mission and vision are "to achieve significant investment in harnessing biotechnology tools for generation of products, processes and technologies in food, agriculture and health for socioeconomic development". The general objective of the policy is to ensure that Tanzania has the capacity to capture the proven benefits arising from agriculture, health, industry and environmental applications of biotechnology while protecting and sustaining the safety of the community and the environment (Mneney, 2010). Biotechnology in Tanzania is mainly agricultural based. Activities involved include tissue culture and micro-propagation, marker-assisted breeding, disease diagnostics, livestock vaccines, and genetic engineering to produce GMOs (Mneney, 2001; Rutabanzibwa, 2004). In Tanzania, banana, cassava, sweet potato, pyrethrum, coconut and sisal have been tissue-cultured (Table 6). Regional projects are supporting marker assisted selection (MAS) research and contained field trials in the following crops: cassava, sweet potato, rice and maize, maize, sorghum, coconut and cashew nuts (Tairo et al., 2005, 2008). In health sciences, biotechnology is still at a research stage where molecular diagnostic tools for malaria, tuberculosis and HIV/AIDS are being investigated. The leading institutions in health related biotechnology are the national institute for medical research (NIMR; http://nimr.or.tz, cited on 5th October 2011) and the Ifakara Health Institute (IHI); www.ihi.org, cited on 5th October 2011). In veterinary sciences, projects on development of diagnostics and vaccines for east coast fever (ECF), New castle disease (NCD), Rift valley fever (RVF), contagious bovine pleuropneumonia (CBPP) and breeding for improved milk and meat production are underway at the animal diseases research institute (ADRI; www.mifugo.go.tz, cited on 5th October 2011). Various international projects have been supporting research in agricultural biotechnology and facilities at the University of Dar es Salaam (UDSM), Sokoine University of Agriculture (SUA), Mikocheni Agricultural Research Institute (MARI),other Agricultural Research Institutes (ARI) at Tengeru, Ukiriguru and Uyole; Tanzania Coffee Research Institute (TaCRI), Tanzania Pesticide Research Institute (TPRI), National Plant Genetic Resources Centre (NPGRC) and other R&D institutions. Contained research activities are carried out at MARI and UDSM. Confined field trial on

Table 3. Progress of GMO development in Kenya (modified from Thompson, 2004; Kingiri and Ayele, 2009; Macharia, 2010).

Genetically modified organisms (GMO) activity	Stage of development
Genetic engineering in sweet potato for disease resistance (feathery mottle virus).	Contained laboratory and confined field trials.
Genetic engineering in maize for resistance to African maize stem borer.	Contained laboratory and greenhouse; field trial.
Genetic engineering in cassava for cassava mosaic disease (CMD) resistance.	Contained greenhouse and confined field trials.
Genetic engineering in cotton for bollworm resistance (Bt cotton).	Contained greenhouse and confined field trials.
Genetic modification of sorghum for Striga (weed) resistance.	Contained laboratory and screen house.
Genetically modified water efficient maize (WEMA).	Contained and confined field trials.
Genetically modified sorghum for improved protein quality, digestibility and enhanced Iron and Zinc.	Application for contained greenhouse trials.
Genetically modified Maruca pod borer resistant cowpea.	Application for controlled trials.
Genetic engineering for bio-fortified (pro-vitamin A) cassava.	Application for confined trials.
Genetically modified vaccine for rinderpest marker vaccine.	Application for confined trials.
Genetically modified weevil resistant sweet potato.	Application for contained greenhouse trials.

Table 4. A summary of biotechnology activities in Uganda (modified from Ntawuruhunga et al., 2007; Mugoya, 1999; Olembo et al., 2010; Wamboga-Mugirya, 2010; Opuda-Asigo, (2010).

Institution	Biotechnology related activities
Makerere University	
Department of Animal Science	Marker assisted selection for local cattle breeds.
Department of Crop Science	MAS Research on disease/pest resistance; tolerance to abiotic stresses in maize; genetic engineering in banana and cassava; DNA fingerprinting in sweet potato; bean mosaic viruses and maize parasitic fungi.
Department of Veterinary Parasitology and Microbiology	Molecular diseases diagnosis; vaccine development and MAS for East Coast Fever virus.
Department of Food Science and Technology	Characterization of banana juice and starch, and characterization of lactic acid bacteria for yogurt production.
Medical School	Recombinant HIV vaccine, DNA sequencing.
Institute of Environment and Natural Resources	Genetic markers for wildlife; genetic characterization of microorganisms in wastewater treatment systems.
NARO	
KARI and NAARI	Protocols on somatic embryogenesis, molecular characterization of bean common mosaic; GM cassava varieties to resist the virulent cassava mosaic virus (CMV) and cassava brown streak virus (CBSV).
LIRI	Cloning and sequencing of trypanosome genes; diagnostic tools for bovine pleuropneumonia; East Coast fever vaccine improvement.

Table 4. Contd.

UVRI	Development of viral and bacterial diagnostic tools.
JCRC	Aids virus research/molecular diagnosis.
MBL	Molecular diagnostic tools and markers for malaria and cassava research; novel restriction enzymes.
AGT	Tissue culture production in coffee and banana.
IITA	Virus resistant sweet potatoes and cassava.
INIBAP	Banana transformation.
Coffee Research Centre (COREC)	Coffee wilt disease (CWD) resistant/tolerant coffee variety, with genes from wild relatives.
National Semi-Arid Resources Research Institute (NaSARRI)	BT and HT resistance to the African cotton bollworm and with genes from Bollgard II™ for herbicide-tolerance.
African Agricultural Technology Foundation (AATF)	CFT for drought -resistant maize (water efficient maize for Africa (WEMA).
National Agricultural Research Laboratories (NARL)	Bio-fortified banana with vitamin A, and Iron; the apple banana; Nakyitembe bananas modified with two genes; Sigatoga (fungal disease) resistant banana.

genetically modified water-efficient maize (WEMA) is planned at Makutopora, Dodoma. Research on industrial and environmental biotechnology (biogas, bioremediation, biofertilizers and biopesticides, are conducted at the Department of Molecular Biology and Biotechnology, UDSM (Parawira, 2009; Mneney, 2010).

Constrains facing biotechnology R and D in Tanzania include inadequate funding, limited capacity for biotechnology, lack of critical mass of highly trained scientists, technicians and entrepreneurs, lack of capacity to supply, service and repair scientific equipments and lack of inter-institutional networks (Mneney, 2010; Bull et al., 2011). Tanzania needs to invest more in biotechnology to take advantage of its richness in natural resources. It also needs to exploit new biotechnology innovations avenues such as novel DNA technologies, bioinformatics and genomics. The government should provide adequate funding by increasing budget for S and T; create enabling environments; and improve awareness and education in biotechnology.

Status of biotechnology in Ethiopia

Ethiopia is a country whose 41% of the economic activities depend on agriculture, including marketing, processing, and export of agricultural products. Principal crops include coffee, beans, oilseeds, cereals, potatoes, sugarcane, and vegetables (Kassa, 2011). Ethiopia does not have a national biosafety policy yet. It needs one in order to develop its capacity and apply the technology in Agriculture, environment, health and energy sectors. Ethiopia is one of the major genetic centers of origin with huge biodiversity of flora and fauna. A few examples of the legacy of Ethiopia to the rest of the world as a source of important genes include the yellow dwarf virus (BYDV) resistance gene found in barley (Niks et

Table 5. Progress on GM development in Uganda (Wamboga-Mugirya, 2010. cited on 27th August 2011).

Project	Status
Black sigatoga disease resistance in East African Highland Bananas (EAHBs	Confined field trial (CFT) data analysis
Herbicide tolerant cotton - RR Flex™	CFT
Bt cotton - Bollgard™	CFT
Biofortified banana (Iron, Pro-Vit A, Vit E)	CFT
Virus (CMV) resistant cassava	CFT
BXW resistant banana	CFT application under review
Drought tolerant maize	CFT application under review
Virus (CBSV) resistant cassava	CFT application under review
Virus resistant sweet potato	CFT application under review

Table 6. Institutions involved in biotechnology activities in Tanzania (modified from Mneney, 2010).

Name of institution	Type of biotechnology	Products
Kizimbani, Zanzibar	Tissue culture	Banana
SUA	Tissue culture	Banana and horticultural crops
	Disease diagnostics of ECF, NCD, RVF and CBPP	Disease resistant animals
	Training	Molecular biology, disease diagnostic tools.
NPGRC	Tissue culture	Banana
Central veterinary laboratory (CVL)	Disease (RVF, ECF) diagnostics	Disease resistant animals
TaCRI	Tissue culture	Coffee
Tengeru ARI	Tissue culture	Banana and horticulture crops.
Uyole ARI	Tissue culture	Pyrethrum and aeroponics.
MARI	Tissue culture	Cassava, banana, sweet potatoes cashew
	MAS	Cassava, sorghum, cashew.
	Disease diagnostics	Disease-free coconuts, cassava, rice, sweet potato and banana.
	GMO	Virus resistant cassava
NIMR, IHI	Disease diagnostics	Malarial, tuberculosis, HIV/AIDS diagnostic tools.
UDSM	Bioremediation	Biogas
	Biofertilizers	Nitrogen fixation, mycorrhizal inoculation
TPRI	Biotechnology regulation	Agricultural inspectors

al., 2004); mlo-11 and related genes for powdery mildew resistance (Piffanelli et al., 2004); the “stay-green” gene for drought tolerance (Haussmann et al., 2000; Mahalakshmi and Bidinger, 2002; Borrell et al., 2003, 2004); genes for cold tolerance, high lysine content, disease resistant sorghum (IBC, 2008) and drought tolerance in grass pea (Kassa, 2011). Currently, a total of 65 projects are underway in the country and most of them are in areas of agricultural, industrial, health and environmental biotechnology. These projects are on tissue culture, bio-fertilizers, molecular marker, embryo transfer, immunology, vaccine and diagnostic kit development and epidemiology, mainly for crops such as coffee, grass pea, teff and forest trees (Brink et al., 1998, Kassa, 2011). The institutes involved in biotechnology in Ethiopia include the Addis Ababa University (AAU), Ethiopia Institute of Agricultural Research (EIAR), Federal Research Centers (FRCs), Institute of Biodiversity Conservation and Research (IBCRI), National Veterinary Institute (NVI) and National Health and Nutrition Institute (EHNRI) (Table 7).

Biotechnology research and development in Ethiopia is at its infant stage compared to the neighboring countries like Kenya and Uganda where modern biotechnology projects are taking roots (Thomson, 2008). The lack of biosafety policy and guidelines; lack of proper assessment of the level of biotechnological capacity available in the country; poor coordination of the limited biotechnological capacity available in some institutions and research centers; lack of public’s appreciation of opportunities provided by agro-biotechnology and financial constraints suggest that the government need to move steadfastly to address the situation (Abraham, 2009).

Table 7. Biotechnology activities in Ethiopia (modified from Otim-Nape, 2007; Kassa, 2011).

Institution	Activity
Addis Ababa University (AAU)	1) Research on Ethiopian flora including description of at least 60,000 Ethiopian plants. 2) Screening, isolation and characterization of key cereal crops using protoplasm fusion and somaclonal variations. 3) DNA sequencing for genetic characterization and micro-propagation of indigenous plants and tree species. 4) Localization on the chromosome quantitative trait loci (QTL) in Teff using RFLP techniques. 5) Genetic and biological approach towards producing clean and disease free Enset. 6) Micro-propagation of African redwood (Cusso) with reference to rooting. 7) Diagnosis and detection of viral pathogens in crops. 8) Biological nitrogen removal from tannery wastewater in Ethiopia. Development of various biological water treatment systems
EIAR	Tissue culture of banana, cardamom, grapevine, citrus fruits, garlic, potato, geranium, Enset, Teff, nigger, cabbage, coffee, sweet potato, ginger and cassava.
Jimma	Tissue culture – coffee, pineapple, spices and cassava
Holleta	Tissue culture – potato and enset
Melkassa	Tissue culture - Banana, sweet potato and garlic
Ebre Zeit	Tissue culture - grapevine, endod and Teff
IBCRI	Applying cytogenetic, biochemical and tissue culture techniques in the identification and characterization of collected germplasm.
EARO	Tissue culture and MAS to improve Teff, coffee, fruit cultivars and forest trees for commercial purposes.
NVI	Molecular and biochemical characterization of parasites
EHNRI	1) Screening of pathogenic bacteria such as Escherichia and Shigella, using DNA probes. 2) Development of animal vaccines against rinderpest, sheep pox, Newcastle, African horse sickness, foot and mouth disease and bovine pleuropneumonia.

Status of biotechnology in Rwanda

Rwanda, one of the least developed and densely populated countries in Sub-Saharan Africa, faces severe land shortage and land degradation due to the fragile ecosystem and poor land management. Yet, more than 90% of the population depends on agriculture (RoR, 2005; Rwanda ETOA, 2008). Therefore, adoption of biotechnology seems to be an inevitable strategy for achieving sustainable food security and poverty reduction. However, there is no clear biotechnology policy framework and guidelines to guide biotechnology R and D in Rwanda. In addition, there is no national strategy for biotechnology, reflecting limited appreciation of the importance of biotechnology in the socio-economic development of the country (RoR, 2005).

There is limited but steadily growing range of applications of conventional biotechnology in Rwanda covering various sectors including agriculture, health, environment and industry. Conventional biotechnology embraces tissue culture and tissue multiplication, production of various multipurpose plants, medicinal plant exploration and exploitation, brewing of beer, and production of juice and yogurt. Biotechnology is also used in diagnostics, production of bio-energy, and waste treatment. Rwanda has made modest progress in biotechnology applications mainly in the area of agriculture, animal husbandry (plant tissue culture, embryo transplants) and medicine (HIV/AIDS diagnostics, vaccine trials using recombinant DNA technology) as shown in Table 8. The R and D institutions involved in biotechnology in Rwanda include Institut des Scienses Agrinomiques du Rwanda (ISAR)-Rubona, ISAR-Musanze, the National University of Rwanda’s (NUR; www.nur.ac.rw, cited on 25th August 2011), Kigali Institute of Science and Technology (KIST; www.kist.ac.rw,

Table 8. Summary of biotechnology activities in Rwanda (RoR, 2005).

Institution	Activity
National University of Rwanda (NUR) Research Commission	Biotechnology research related to plants, animals and human being in areas of tissue culture and disease diagnostics.
Kigali Institute of Science and Technology (KIST)	Research of food science and technology; applied microbiology; molecular biology and applied biotechnology; production of varnish and glue from locally available materials.
Ministry of Education, Science and Research Institutions	Production of Azolla and Rhizobia-based biofertilizers for rice cultivation; Tissue culture of medical plants and micropropagation of disease-free potato, banana and cassava.
Institut des Scienses Agrinomiques du Rwanda (ISAR)-Rubona, ISAR-Musanze.	Tissue culture of Irish potato, sweet potatoes, cassava, potatoes, banana and coffee. Disease diagnostics for cassava and sweet potato.

cited on 25th August 2011) and the Ministry of Education Science and Research Institutions (RoR, 2005).

The development and application of modern biotechnology in Rwanda is just emerging, and faces enormous challenges. There is very low human resource and infrastructure capacity coupled with lack of biotechnology facilities. To build the required capacities, the government of Rwanda needs to invest in biotechnology policy formulation, human resource training and infrastructure development. These efforts will require political will at the highest level to ensure that biotechnology is given the priority it deserves within sectoral and national development strategies and budgets. The development of the national biosafety framework for Rwanda (RoR, 2005) signifies a good start towards facilitation of safe development and application of modern biotechnology.

Status of biotechnology in Burundi

Burundi is a poverty stricken country, ranking 169th out 177 countries in terms of human development index (RoB, 2006). Around 90% of its population depends of agricultural sector. Having recognized the importance of using biotechnology as an important tool for development, it initiated a process of formulating biotechnology and biosafety policies for the purpose of improving agricultural productivity, health delivery and environmental conservation. In Burundi, there is only limited application of biotechnology, mainly at research stage in the R and D institutions (RoB, 2006). The University of Burundi's Faculty of Agromomic Sciences (FACAGRO), Faculty of Science (FoS) and the Higher Institute of Agriculture (ISA) are the main players. Other institutions include the Institute of Agronomic Science of Burundi (ISABU), the Agronomic and Zoootechnical Research Institute (IRAZ), and the National Centre for Food and Technology (CNTA). The types of research which is done there include *in vitro* tissue culture for mass propagation of cereals, roots and tuberous plants; ornamental plants, medicinal plants and microorganisms. Other plant biotechnology researches are onphytopathology, plant breeding, biofertilizers, single cell protein, mycoculture, conservation of germplasm and transformation of food products. Animal biotechnology at ISABU deals with bovine genetic improvement, embryo rescue and animal disease diagnostics. Biotechnology research related to human health is quite limited; only diagnostic techniques such as ELISA and Western blot techniques are being carried out. A summary showing biotechnology activities in Burundi and the institutions involved is shown in Table 9.

Biotechnology in Burundi is at its embryonic stage. The efforts that are being made by the government in formulating the biotechnology policy and guidelines are commendable. The joining of Burundi to the East African Community in 2007 puts it in a good position to advance technologically by forging close collaborations with other member countries such as Kenya and Uganda where biotechnology has already made more progress.

Status of biotechnology in Democratic Republic of Congo

The Democratic Republic of Congo (DRC) is a country endowed with vast natural resources. A country of 60 million people, it has 100 million h of arable land that supports a wide range of flora and fauna. The DRC does not have a stand-alone biotechnology policy but it has related policies such as agriculture policy, health policy and industrial development policy. The policies, however, do not address the issue of modern biotechnology. Even the scientific and technology policy fails to set any guidelines regarding biotechnology R and D. The DRC is under pressure from the southern African development community (SADC)'s agricultural research and development committee to set up harmonized legislation on biotechnology and biosafety (DRC, 2007). Biotechnology in the DRC is limited to conventional technologies such as production of beers and soft drinks,

Table 9. Summary of biotechnology activities in Burundi (RoB, 2006).

Name of institution	Type of biotechnology	Products
FoS, Burundi University	Tissue culture	Various crop and medicinal plants
FACAGRO	Phytopathology, Plant breeding, Bio-innoculation Mycoculture	Various *in vitro* crop plants Various crop and ornamental plants Biofertilizers Mushrooms
ISABU	Tissue culture Animal improvement Disease diagnostics	Cassava, sweet potatoes, Irish potatoes, yams, soya beans Cows – Ankole/Sahiwal crossing with exotic breed Cassava and sweet potato.
CNTA	Technology innovation	Transferred technologies
IRAZ	*In vitro* culture	Banana, potato, cassava, taro
Ministry of Agriculture and Livestock	Tissue culture and Animal diseases diagnostics	Various *in vitro* plants; Vaccines, medicines.
Ministry of Health Agro and Biotechnologies (AGROBIOTECH)	Disease diagnosis Tissue culture	Vaccines, molecular diagnostic tools Banana, Taro and potato.
Phytolab	Tissue culture	Sweet potatoes, cassava, Irish potato, taro, pineapple and tree species.

transformation and conditioning of dairy products, and traditional production of fermented foods. Its application is limited to a few experimental trials carried out by some research and teaching institutions such as universities and colleges. The agricultural sector dominates the DRC economy, with food crops such as cereals, roots, tubers,oilseeds, vegetables, and legumes; commercial crops such as coffee, cotton, tea, rubber, palm oil, cocoa, hevea, quinquina, onion, sugar cane, fruits and vegetables; forest products; and breeding of cattle, sheep, pigs, goats and poultry. In agricultural biotechnology, only a few trials have been carried out to date, such as transgenic banana and transformation of cassava to reduce the level of cyanide (Glover, 2007). In a total of 8 (all non-GMO) projects, 6 are related to crops, 1 on livestock and 1 on forestry (www.absfafrica.org, cited on 5th October 2011). These research activities are mainly carried out at the University of Kisangani and other R&D institutions as summarized in Table 10.

The constrains facing the biotechnology industry in DRC include the lack of a biotechnology policy, poor public awareness and participation in matters related to modern biotechnology and over dependence on donor-driven biotechnological projects. These shortfalls call for the DRC government to invest more on modern biotechnology.

CHALLENGES FACING MODERN BIOTECHNOLOGY IN THE EASTERN AND CENTRAL AFRICAN REGION

The development and application of biotechnology in the studied Eastern and Central African countries face the following challenges:

1) There is lack critical mass of skilled personnel, basic infrastructure and facilities, unreliable access to modern communication systems, unreliable power supply and poor availability of chemicals and consumables for research.
2) Indigenous ‘neglected’ crops attract funding only for exploitation outside Africa; and there is lack of basic research on ‘neglected’ or underutilized crops (Brink et al., 1998).
3) Linkages and networks (both internally and externally) are either weak or lacking.
4) Exotic crops are not well adapted to Africa, since imported lines or cultivars are not adapted to local conditions; these crops may be susceptible to local diseases and insects.
5) Lack of (national/regional) policies, strategies or legislation in biotechnology is evident in some countries in the Eastern and Central Africa Region. Some countries are yet to enact biosafety laws; such limitation constitutes

Table 10. Summary of biotechnology activities in the Democratic Republic of Congo (DRC, 2007).

Institution	Activity
University of Kisangani	Research on transgenic banana; Research on transformation of cassava with the application of bacteria and fungi to reduce the level of cyanide; *In vitro* propagation of potato, soybean, maize, rice and multipurpose trees, for example, *Acacia* and *Leucaena*. Production of rhizobial-based biofertilizers in experimental stage; Tissue culture of medical plants, for example, *Nuclea* sp *and Phyllanthus* sp.
National Institute for Agronomic Studies and Research (INERA)	Stability of geneotypes of cotton, cassava, maize, rice, plam coffee, oil seeds in various environments; Research on conservation of phlogenetic resources; Tissue culture of leguminous plants, root and tuber plants.
Agri-Food Research Centre (CRAA)	Industrial research in the agri-food science and technology (enzymology, bacteriology, quality control, spectroscopy)
National Seed Service (SENASEM)	Plant genetics and breeding centre including production multiplication and certification of seeds.
Maize Research Centre (CRM)	Maize breeding and general agronomic studies
National Livestock Development Authority (ONDE)	Zoo-sanitary protection, artificial insemination and animal disease diagnostics.
National institute of Biomedical Research Institute (INRB)	Human and veterinary biological and biochemical analyses. Research on malaria, trypanosomiasis, HIV/AIDS and medicinal plants.
National Natural Science Research Centre (CRSN-Lwiro)	Molecular biology and biotechnology research in agricultural, veterinary, entomology, limnology and marine biology.

a serious constraint that impairs the use, evaluation and release of genetically modified organisms.

6) Lack of protection of intellectual property rights hampers the development of new technologies, profitable inventions and investments, and initiatives by entrepreneurial biotechnologists.

7) Governments are not taking enough proactive political roles in promoting biotechnology (Sengooba et al., 2009).

8) Public acceptance is being frustrated by anti-modern biotechnology activism fuelled by internal and external pressure groups (Brink et al., 1998, Makinde et al., 2009).

Way forward

Investments in, and development of biotechnological research capacity in Africa would best be accomplished in phases. The first phase is conventional biotechnologies such as plant tissue culture and breeding, which is appropriate for Africa as many of the important food crops such as cassava, sweet potato, yam and banana are vegetatively propagated and could be crossbred to improve quality. The second phase would be the application of biotechnological tools, which can improve the efficiency of selection of varieties/cultivars, the techniques that include anther culture and embryo rescue, as well as molecular marker applications (diagnostics, fingerprinting and marker-assisted breeding). The third phase is the development of capacity to produce transgenic plants/animals, which would include gene isolation and cloning; gene insertion/transformation; regeneration of transgenic plants/animals followed by commercial release of GMO products (Lynam, 1995).

As a prerequisite, national biotechnology and biosafety policy frameworks are crucial so as to give directions on which way the technology should proceed (Keizire, 2000; Muraguri et al., 2003). In spite of the lack of support of national biosafety laws, all the Eastern and Central African countries covered in this study have formulated biosafety frameworks. Among the seven studied countries, only Kenya, Tanzania and Uganda have comprehensive biotechnology polices. It is suggested that the remaining countries should move fast in preparing their draft biotechnology policies so as to catch up with the rest. Burundi is moving faster in that direction, while Ethiopia, Rwanda and DRC are in the preparatory stages (RoK, 1998; RoU, 2004; RoR, 2005; URT, 2005, RoB; 2006; EPA, 2007; DRC 2007).

The successful application of biotechnology requires an adequate infrastructure, well trained technical expertise, and a critical mass of researchers with sufficient supporting sustainable funding to cover the high cost of modern biotechnology research. None of the studied countries have commercialised any GMO product yet, but Kenya and Uganda are far ahead of Tanzania, Ethiopia, Rwanda, Burundi and DRC towards that end. A South-South partnership with government agencies, universities, research institutions and private companies within the countries, and with other African countries like South Africa, Egypt and Burkina Faso (which have already commercialised genetically modified organisms) would be desirable. Whereas funding from the United States of America is generally supportive of GM technology, the opposite is true of funding from European sources. African countries are thus pulled in two different directions. The way out of this dilemma is for countries in the Sub-Saharan African region to develop strong South-South collaborations, whereby developing countries such as Argentina, Brazil and South Africa would partner with least developed countries to exploit biotechnological resources and develop new products (DaSilva et al., 2002, Morris, 2011). Where possible, in adopting modern technology, indigenous organisms should be utilized because they are adapted to local conditions. Moreover, countries' intellectual property rights (IPR) policies and regulations should be adhered to.

Strong leadership, effective priority-setting and adequate working opportunities for scientists are, however, required to provide incentives for the establishment of biotechnology-based economies. Participatory extension approach programs could be an ideal channel for the implementation of biotechnology products, as well as endowing resource-poor farmers with the confidence to develop and apply solutions to some of their problems. The Eastern and Central African region should take full advantage of its soil fertility, valuable biodiversity and favourable climatic conditions (Woodward et al., 1999; Makinde et al., 2009). It is emphasized that biotechnology alone will not solve the multitude of problems that Eastern and Central African countries face, but it has potential to contribute to transforming the livelihoods of its people from abject poverty to prosperity.

Conclusion

This study reviewed the current status of biotechnology-related policies and activities in Kenya, Uganda, Tanzania, Ethiopia, Rwanda, Burundi and Democratic Republic of Congo. Only Kenya, Uganda and Tanzania have biotechnology policy frameworks. Most of the biotechnology-related activities are being done by government agencies and public/private R and D institutions, with financial support from regional and international bodies. Conventional biotechnology activities such tissue culture and breeding are being practiced in all the countries, while modern biotechnology activities are mainly being field-tested in Kenya and Uganda. None of the countries studied has already commercialised any genetically modified product, but Kenya and Uganda will soon arrive to that goal. Biotechnology holds great potential in promoting socio-economic development in the Eastern and Central African region through increased productivity, improved resistance to biotic and abiotic stresses, reduction in pesticide usage, and enhancing nutritional quality, thereby contributing to food security and poverty alleviation. The Eastern and Central African region can benefit from previous experiences and results achieved in other developing regions in obtaining benefits from the applications of biotechnology. This can be done through proper planning, interactive cooperation among countries and network participants. The main challenges facing the region on matters pertaining to research and development in biotechnology are insufficient trained human resources, poor infrastructure and facilities and poor political will by some governments. The region stands to benefit from biotechnology if the governments invest more in terms of policies and budgets in order to speed up development and commercialisation of biotechnology products. It is envisaged that soon biotechnology will play an important role in food security, improved health and environmental management in the region. While it is not a panacea to all the socio-economic problems facing the Eastern and Central African countries, biotechnology will largely complement other approaches aimed at driving the region out of its poverty woes.

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