Agricultural Biotechnology in Uganda

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Introduction

Agriculture has, and is still playing a ctitical role in the economic development of Uganda, were it contributes over 40% of the Gross Domestic Product (GDP), contributes over 85% of the export earnings, supports a labour force of about 80%, and provides most of the raw materials to the agro-based industries including coffee hulling, cotton ginning, meat processing, dairy and leather products, tea processing, textile mills, sugar processing, cigarette manfucturing and soap industries (PMA, 2000). Therefore, investment in agricultural research with an objective of increasing and diversifying output is a rational strategy towards reduction of poverty and food security problems in Uganda. In parallel, it's also necessary to have a highly productive human capital base, which is a key ingredient for successful economic development. Clearly, investment in agricultural research and medical research (to ensure a highly productive labour force), will in a long-term be mutually reinforcing and hence spur economic progress in Uganda. Biotechnology, one of the youngest modern sciences, holds much promise towards addressing both agricultural and medical problems in Uganda.

The new and emerging tools of biotechnology offer significant opportunities to enhance agricultural productivity, food and nutritional security, and environmental quality worldwide. Some countries have already developed and commercialized genetically engineered crops. Many developing countries have initiated biotechnology research and developed programs to benefit from the new tools of biotechnology. Most notably, in Sub-Saharan Africa, it is recognized that the adoption and use of agricultural biotechnology would lead to improved food production and contribute towards the region's food security. In Uganda, biotechnology has been selected as one of the priority areas in the Government's Plan for the Modernization of Agriculture (PMA). Also, biotechnology is being used to address human threatening diseases, and to a very limited extent to address environmental concerns. Within agriculture, biotechnology tools involve use: of molecular markers in plant breeding, and characterization of plants and animals, diagnostics for plant and animal diseases, development of vaccines, and for *in vitro* conservation of plant and animal genetic resources. It is apparent from the foregoing that biotechnology is finding application in agriculture, animal health, and in the restoration of the degraded environment. Both public and private institutions are involved in biotechnology research. The public institutions involved in biotechnology application in Uganda include Departments and institutions within Makerere University, National Agricultural Research Organization (NARO). Two private laboratories are involved; Med Biotech Laboratories (MBL) and the Agro Genetic Laboratories Ltd. In addition to having reasonable physical infrastructural facilities, each of these laboratories has a critical mass of trained scientists and technicians in biotechnology and biosafety research and applications. That said however, there is need to further the intellectual

capital in biotechnology and biosafety, increase level of funding, provide a functional biosafety policy, increase awareness of the populace about biotechnology, and strengthen institutional collaboration and consultation on biotechnology. These are some of the key critical elements on the path to a successful harnessing of biotechnology and its products, which must be addressed.

Research capacity and capability in biotechnology and biosafety

The Government of Uganda established a National Agricultural Biotechnology Center (NABC) at the National Agricultural Research Laboratories, Kawanda. The NABC is the hub coordinating various institutional laboratory nodes located in major institutions namely Makerere University (i.e., Departments of Crop Science in the Faculty of Agriculture, Biochemistry in the Faculty of Science, Veterinary Parasitology and Microbiology), Institutes of Environment and Natural Resources (MUIENR)), National Agricultural Research Organisation (NARO; Biosciences laboratory at the National Crop Resources Research Institute, National Livestock Resources Research Institute and National Fisheries Resources Research Institute), and Agro Genetic Laboratories Ltd. Also, two CGIAR centres are actively engaged in agricultural biotechnology research in Uganda. The International Institute of Tropical Agriculture (IITA) with interest on cassava and banana biotechnology. And, the Centro Internacional de Agricultura Tropical (CIAT) that conducts biotechnology research on beans.

Biosafety is a major concern to the public regarding acceptance of products from biotechnology research. With the guidance of the Uganda National Council for Science and Technology (UNCST) and support from the Program for Biosafety Systems (PBS), staff at most of the above mentioned laboratories have been trained in various aspects of biosafety, risk/benefit analysis associated with biodiversity, the environment, and human health, and biopolicy to ensure compliance with inter/national regulations for handling and working with biotechnology and its derived products. It is worth to mention that issues pertaining to the environment and food safety risk-assessment and management become increasingly critical as we move along the development continuum from the laboratory research to research field trials and large scale commercial releases of biotechnology products. Hereafter, we examine the progress on biotechnology applications at these institutions.

Department of Crop Science: The department is involved in a number of collaborative biotechnology projects with International Agricultural Research Centres (IARC's), National Agricultural Research Systems (NARS), regional and international universities particularly in Europe and USA, and with the private sector. Initial research on banana primarily focused on assessing genetic diversity using molecular markers (Tugume *et. al.*, 2003). Recently banana genetic engineering approaches have been initiated through collaboration with International Network for Improvement of Banana and Plantain (INIBAP), NARO, and with the Catholic University in Leuven, Belgium (KUL). Connected with this, the department of CS is developing protocols for mass propagation of bananas. With support from the Swedish International Development Cooperation Agency (SIDA/SAREC), through the East African Regional Program and

Research Network for Biotechnology, Biosafety, and Biotechnology Policy Development (BIO-EARN), research was conducted to understand the population structure of *Cercospora zeae- maydis*, major constraint to maize production in East Africa; this study employed both Amplified Fragment Length Polymorphism (AFLP) and Restriction Fragment Length Polymorphism (RFLP) molecular markers to characterise East African *Cercospora zeae-maydis* populations (Okori, 2004). SIDA/SAREC also supported training on the molecular characterization of sweetpotato viral diseases (Mukasa, 2004). These are some of the most recently completed capacity building initiatives at PhD level, and have significantly boosted national capacity for biotechnology research. Also, with support from the Rockefeller Foundation, the Department has an on-going project on marker-assisted selection for maize streak virus (MSV) and quality protein maize (QPM); this project entails graduate training at PhD and MSc level. The department is also undertaking genotyping of causal agents for viral, bacterial and fungal, diseases of crops and diversity study of important crops, marker assisted selection for resistance to various diseases as well as nutritional enhancement in maize. The department has other on-going biotechnology projects on cassava (*Manihot esculenta*), cowpea (*Vigna unguiculata*), beans (*Phaseolus vulgaris*) sweetpotato (*Impomea batatus*), which essentially involve graduate training at either PhD or MSc level.

Department of Veterinary Parasitology and Microbiology: This department focuses on the use of molecular methods as a tool in epidemiology and diagnostics; the microbiology section of this department is involved in bacteriology, mycology, virology and immunology research **(**http://www.makerere.ac.ug/vetmed/departments/vet-para-micro.htm**).** The department uses diagnostic kits to assay for major livestock and wildlife infectious diseases including Brucellosis, Campylobacteriosis, Salmonellosis, Tuberculosis, and mastitis. Additionally, the department carries out diagnostic assays on key tropical parasites of livestock and wildlife including *Theileriosis*, *Anaplasmosis*, *Trypanosomosis*, Heartwater, *Onchocerchiasis*, and *Helminthiasis*. The department offers microbial quality analysis of foods, particularly, fish, dairy and meat products, and also has a molecular biology laboratory for routine molecular research and graduate training at MSc level. The department collaborates with Livestock Research Institute (LIRI) of the National Agricultural Research organisatiion, and with the Welcome Trust in the United Kingdom on the East Coast Fever disease. Biotechnological R4D activities include research on bovine hormone for growth and milk production, and DNA mapping in animal breeding.

Department of Biochemistry: The Department of Biochemistry is involved in identifying species possessing genes encoding enzymes, and thermophillic bacteria that might be of industrial value. Most of these research initiatives are being supported by World health Organization (WHO), SIDA/SAREC, International Foundations for Science (IFS), and the European Union.

The Institute of Environment and Natural Resources (MUIENR): The Institute takes an integrated approach to the problems of environmental pollution and conservation of natural resources. The laboratory depends entirely on donor funding, including funds from SIDA through the BIO-EARN program. One focus of research

involves the development of genetic markers to characterize various species including elephants (*Loxodonta africana*), hippopotamuses (*Hippopotamus amphibious*), buffalo (*Syncerus caffer*), wild plants species, and fish including Nile perch, wild and farmed tilapine species. These initiatives generate information on the evolutionary processes and therefore guide on conservation strategies. A second focus of interest is the identification and characterization of microorganisms that optimize nitrogen removal from contaminated areas. If identified, it's planned that genes useful in nitrogen removal will be isolated and used to transform bacteria in order to produce strains that remove nitrogen more efficiently.

Biotechnology research at National Agricultural Research Organisation (NARO)

Biotechnology research at NARO is done in collaboration with International Agricultural Research Centres (IARC's), National Agricultural Research Systems (NARS), regional and international universities particularly in Europe, and with the private sector. With support from SIDA/SAREC, studies were done to understand the mechanisms of starch synthesis and regulation in cassava (Baguma, 2004); this study involved human resource development at PhD level.

At the NABC, work is being conducted to improve the East African (Matoke) highland banana for resistance to pests and diseases mainly the BBW and BSD. Related to this gene discovery and acquisition for desired traits and development of molecular tools for pathogen and plant characterization. Some of the specific activities include; development of embryogenic cell suspensions of East African highland banana cultivars, development of highland banana genotypes with resistance to nematodes and weevils using Cystatins (OCI) and Bt (Cry6A) genes, earliness using cell cyclin genes (CycD2-1, D3-1 and D5-1), development of short and early flowering highland banana genotypes using early flowing AP1 gene, increased stem hardness using cellulose synthase genes (ces), development of markers for parthenocarpy in banana, and ploidy analysis of banana to quicken selection process and crossing schemes. Scientists at the NABC are collaborating with the International Atomic Agency in developing knowledge and tools of genomics of banana. In addition, work is being done to increase the nutritional of banana (enhanced vit E, zinc, and iron) through the bio-fortification project. These activities are done in collaboration with several partners including the Catholic University in Leuven, Belgium (KUL), Cornell University, INIBAP, University of Leeds, University of California, University of Ghent, University of Pretoria and Queensland University of Science and Technology in Australia. In addition to the above, using the tissue culture facility at the NABC, biotechnology applications have enabled banana shoot tip culture, embryo culture, somatic embryogenesis, short-term *in-vitro* conservation, and to a very limited extent cryopreservation. With support from the Global Trust Fund, this facility will also be used for cryopreservation of regional banana, cassava and sweetpotato germplasm.

At the Biosciences laboratory at Namulonge, the Rockefeller Foundation is currently supporting a project on marker-assisted selection for cassava mosaic disease (CMD),

which is a key constraint to cassava production. In collaboration with the Donald Danforth Plant Science Centre, USA, research work has been initiated on cassava transformation, more specially to generate resistance against CMD and cassava brown streak virus (CBSD) through pathogen mediated resistance techniques and deliver farmer-preferred varieties to Ugandan farmers. Work is also undergoing to explore the application of single nucleotide polymorphism (SNPs) in genotyping and search for rare root quality traits. In collaboration with the International Centre for Tropical Agriculture (CIAT), plans are under way for cassava biofortification. In collaboration with Makerere University, the Cereals Programme at NaCRRI is currently implementing a molecular breeding project on quality protein maize (QPM). The McKnight Foundation is also supporting research on diversity of sweetpotato landraces using molecular markers.

Biotechnology applications at NARO's Livestock Research Institute (LIRI) are done in collaboration with the Department of Veterinary Parasitology and Microbiology at Makerere University. These include: cloning and sequencing genes in trypanosomes that confer resistance to drugs; development of diagnostics for the detection of contagious Bovine Pleuropneumonia; development of vaccines against Bovine Pleuropneumonia; and optimization for Newcastle Disease vaccine. Research on East Coast Fever seeks to develop improvements to the currently used vaccine, which uses a cocktail of attenuated live strains of the virus. DNA mapping for animal breeding is also integral research activity as well as microbial quality analysis of foods (fish, diary, meat).

At the coffee research institute, studies on the molecular biology of coffee disease are being conducted in collaboration with CABI to understand the diversity of Coffee wilt disease caused by Fusarium xylariode. Arelated work focuses on establishing the potential of phlD fluorescent pseudomonas in the control of the wilt and bean root rot diseases. In order to accelerate the development of resistant varieties, information on molecular/genetic constitution of the coffee germplasm and its association with resistance to coffee wilt disease are planned for future studies. Plans are also underway to identify gene(s) for resistance to coffee wilt disease.

Biotechnology applications within the private sector

Agro Genetic Laboratories Ltd is exclusively involved in micro-propagation of banana. Research at MBL is aimed at developing molecular markers for determining cyanogenic glucoside content in cassava.

Biotechnology information and communication

It's apparent from the foregoing that Uganda is at various levels, involved in biotechnology applications within agriculture, livestock and animal health, and the environment. However, transfer of biotechnology and its products presents a complex challenge, which must be addressed through educating the populace on biotechnology.

To guarantee public awareness, institutions involved in biotechnology applications, have either individually or collectively devised ways of communicating to the public and or the

beneficiaries of the role of biotechnology and or biotechnology products towards improving the quality of life. Some key avenues used to promote biotechnology are high lightened below.

Agricultural shows: This is an initiative by the Government of Uganda to have a forum, where all institutions involved in the agricultural sector (and at times the medical sector), have an opportunity (1-2 weeks) to present to the general public their available products and or technologies. Through this initiative, NARO, Makerere University, Ministry of Health and the private sector that are involved in agricultural and or medical research, present an array of products, including biotechnology derived products to the general public, which comprises of students, donors, policy makers, researchers, and to the private sector. For example, during the shows, NARO presents technologies in form of improved varieties that have been developed through use of biotechnology tools particularly marker assisted selection (e.g., maize) or micropropagation, particularly with banana. Such shows are also used to promote the use of artificial insemination (AI) and vaccines available for on the livestock farmers. In principle, these shows are destined to increase public awareness and acceptance of the of biotechnology. Is also provides an opportunity for policy makers and or the donors to appreciate the use of biotechnology.

Laboratory visits: This normally involves organized visits by students, farmers groups, private sector, donors, and policy makers to the research institutions. These appointments mainly entail touring the biotechnology supporting laboratories established at KARI, NAARI, MUK, and at private institutions like MBL. The visitors are provided with an overview of current projects being implemented and or those that are in the pipeline. Through these strategies, visitors are provided with background information on how biotechnology can be used safely to enhance animal and crop productivity. Moreover, short-term training is also provided at these laboratories. For instance, since 1996, the banana tissue culture facilities at KARI have trained a total of 14 technicians from Rwanda, Tanzania, Zanzibar, Malawi, Ethiopia, Cameroon and Nigeria in banana tissue culture. Such visits at times provide an opportunity for donors to assess the potential of the laboratory before committing funds for biotechnology research.

Documentations: This is done in form of journal publications, proceedings, web-based reports, and book chapters. Documentation using these avenues aims at disseminating information to both the local and international scientific community about current biotechnology efforts being done in Uganda; this measure also prevents duplication of research efforts. Locally, NARO has the Uganda Journal of Agricultural Sciences (UJAS), as its publication outlet. Indeed, UJAS has published an inventory of agricultural biotechnology research capacity in Uganda (Braunschweig, and Sengooba, 2001). Makerere University, hosts the African Crop Science Journal, which is also the publication outlet of the African Crop Science Society; this too has considerably boosted the communication to the scientific community on biotechnology issues in Uganda. For instance, a Special issue on Biotechnology and Biosafety was published in 1995 (see African Crop Science Journal Vol 3 No. 3, 1995)

Others: Mass media involving use of televisions and radios are currently being used to target different public sections; these media outlets have considerably increased public awareness of the HIV/AIDS prevention in Uganda. It's therefore proposed that this approach will considerably increase public awareness on biotechnology. Topical issues on biotechnology are to a limited extent being discussed on both radio and television. The NewVision, a local newspaper, has devoted a section to agricultural every Thursday, as a means to educate the populace on the role of agriculture in economic development. Also, one-day workshops are also being organized; during these workshops, a panel of experts on biotechnology educates the participants on biotechnology highlighting its benefits and demerits. For instance in April 2004, a one-day workshop on the role of biotechnology in Uganda was held with parliamentarians, who were briefed on biotechnology, and their queries addressed.

Although numerous workshops with biotechnology themes have been done and some progress achieved, mixed reactions still prevail on the use of biotechnology to enhance crop and animal productivity in Uganda. Mechanisms to penetrate and sensitize a wider cross-section of interest groups including farmer's organizations (e.g. the Uganda National Farmers Association) and consumer's organization (Ugandan Consumers Protection Association), is currently being considered. Other options as described earlier also need to be stepped up, and should be more convincing to the populace, which is also receiving communication from the anti-biotechnology groups. An initiative to carry out a nationwide survey to capture the populace's perception on biotechnology is also underway. Realizing the human resource constraint in biotechnology in Uganda, concerted efforts are being made to build both human and infrastructure capacity. Human resource training involves graduate training at either PhD or M. Sc level, and depending on the funding organization, training can either be full time at a national or foreign university or can be a sandwich programme between a national and an international university.

Commercialization

Functional partnerships between the public and private sectors are necessary for the transformation industrial sector. Realising the importance of this partnership, NARO has recently engaged in collaborative activities with a number of private sectors including: Mukwano Group of Companies (on soybean); Maganjo Grain Millers (on Vitamin A sweetpotato); and private seed companies (Farm Input Care Centre Ltd; East African Seeds U Ltd); and Victoria Seeds Ltd); possibilities of using cassava in the industrial sector are also under way through the Pan African Cassava Initiative. Through these partnerships, NARO is specifically developing varieties being demanded by the private sector. Moreover, it's also creating a huge local market base for farmers adopting her technologies. This continuum from production to utilisation is by far one of NARO biggest achievement, which has considerably stimulated the research-industrial link These are some of the linkages NARO has established with the private sector, that are not necessarily using biotechnology derived products.

However, a joint venture by Ugandan and Swedish investors, Agro Genetic Laboratories Ltd, was approved by Uganda's National Council of Science and Technology to produce coffee and banana plantlets using tissue culture; ideally, this formed that the first commercial agricultural biotechnology laboratory (http://www.isaaa.org/kc/).

Legislation

Previously, national laws including The Food and Drug Act, 1964, The Animal Disease Act, 1964, The Pharmacy and Poison Act, 1964, The Dangerous Drug Act, 1964, The Plant Protection Act, 1964, The Public Health Act, 1964, The National Drug Policy and Authority Statute, 1993, and The National Medical Stores Authority Statute, 1993, did not have provisions for biotechnology (ref Annex 2). Since biotechnology has been emphasized under the Uganda's Plan for the Modernization of Agriculture, that aims to transform the largely subsistence farming into commercial farming (PMA, 2000), the need to have biotechnology laws was seriously considered. In practice, legislation on the use of biotechnology should principally aims to ensure that safe products are produced for consumers and for the environment. Indeed, Uganda has ratified the international convention of the World Trade Organisation (WTO), which impact on biosafety. This are additions to the already binding bilateral and multi-lateral trade agreements with the United Nations Conference on Trade and Development (UNCTAD), the International Trade Centre (ITC), the LOME Convention, the Common Market for East and Southern Africa (COMESA), and the East Africa Co-operation (EAC), which are currently under review to find their appropriateness.

The Ugandan Government with support from United Nations Environment Programme (UNEP) commissioned the Ugandan National Council of Science and Technology (UNCST) to draft national guidelines on biosafety consistent with international standards. These guidelines are meant to protect individuals and the environment by minimizing potential hazards resulting from application of biotechnology in Uganda. Specific areas on interest include: 1) genetically engineered plants and animals, 2) large scale production and or accidental release of GMO's, 3) provision of a risk assessment mechanism of GMO's in the environment and 4) vaccines and pharmaceutical products resulting from biotechnology. To ensure compliance, two committees have been setout, the National Biosafety Committee (NBC), which comprises of members of the UNCST, universities, private industry, and ministry institutions involved in biotechnology research, and the Institutional Biosafety Committee (IBC), which comprises mainly of members of the institution. Although these biosafety guidelines are yet to be approved by Parliament, they strongly demonstrate the commitment of the Ugandan Government towards application of biotechnology.

Constraints, opportunities and incentives for use of biotechnology

The ever-increasing population of Uganda needs to be met with increased food production and productivity of agricultural land, with better use of available land and water resources and minimum environmental degradation. The increase in agricultural production in Uganda can be attributed to increased use of improved breeds resulting

from conventional breeding, and also due to expansion of area under cultivation that has seen the degradation of many forests and wetlands. Moreover, Uganda's economy largely depends on the agricultural sector, which comprises of crop, livestock, fisheries, and the forestry sectors. Most of these sectors are currently constrained by an array of biotic and abiotic factors, which have elsewhere been addressed through use of biotechnology. Furthermore, there is great potential for biotechnology to translate discoveries and knowledge about organisms, processes and the environment into practical applications in agriculture. For example in the crop sector, application of biotechnology can 1) broaden the crop usage through value addition, 2) reduce cost of pesticide application as evidenced with *Bt*-crops, 3) reduce research costs by use of molecular markers in breeding programmes, 4) permits long-term conservation of genetic resources, and 5) ensure sustainable use of natural resources and yet maintaining optimal yields. Somewhat similar benefits can be achieved through application of biotechnology in the livestock, and forestry sectors. It's for these reasons, that Uganda is fully committed to engage in application of agricultural biotechnology in its key economy-driving sectors, as a way to reduce hunger and poverty.

Opportunities

• *Institutional framework*

The creation of a public research organization, the National Agricultural Research Organization (NARO), provided the opportunity for a key player in agricultural biotechnology research in Uganda. Three NARO institutes, Namulonge, Kawanda and the Livestock Research Institute in Tororo undertake different aspects of modern agricultural biotechnology research. In 2004, the lab at Kawanda was commissioned the president of the country as the National agricultural biotechnology research laboratory. Makerere University is the other public institution that is active in agricultural biotechnology research. The three faculties of Agriculture, Science and Veterinary medicine undertake different aspects of modern agricultural biotechnology research. These institutional arrangements provide an important base on which to build.

• *Human resource*

Although the number is still very low, there are scientists actively engaged in agricultural biotechnology research in Uganda. Most of these have returned over the last few years from overseas training in modern agricultural biotechnology to positions mainly within NARO and Makerere University. This has helped to expand the portfolio of agricultural research in Uganda and training at graduate level.

• *Supportive political environment*

The government of Uganda is clearly committed to the use of modern biotech in agriculture specifically, and the use of science as one of the key engines to drive national economic development. A Biotechnology and Biofasety bill is under consideration in parliament, which, when passed will set favourable environment for agricultural biotechnology research and provide the general regulatory framework. Institutional and national biotechnology and Biosafety arrangements are already operating in Uganda.

• *On-going and potential projects*

Although on very limited scales, agricultural biotechnology research is already being carried out in the areas of genomics, molecular breeding, diagnostics, livestock vaccine technology, characterization and conservation of genetic resources and there are initial efforts at developing platforms for crop genetic transformation. There are on-going activities on cassava, bananas, sweetpotato, maize, beans, chicken and cattle to address diverse interests including increased yields, enhanced pest and disease resistance, germplasm conservation, livestock vaccines. Other traits with great opportunity and potential benefit for the country include drought tolerance, enhanced nutritional quality and safety of foods (biofortification with essential vitamins and micronutrients and development of acyanogenic cassava), reduced post-harvest losses (due to pests, pathogens and post-harvest physiological deterioration). There are also projects that are planned to develop novel products for the market, such as cassava starch for different end uses including bioplastics, biofuel, and pharmaceuticals. Another very promising area is that of bioremediation to address the issues of environmental degradation.

• *Bioprospecting*

Uganda is very rich in biodiversity that has only been sparsely utilized for food and industrial applications. Agricultural biotechnology provides the opportunity to search the country's biodiversity for beneficial genes, gene products and compounds and devise ways for the best use for applications such as crop improvement, pharmaceuticals and energy. Using modern biotechnology tools, it is possible to transfer genes regulating the expression of such valuable bioresources from wild plants into cultivated crops.

• *Partnerships and collaboration*

Different research groups vary in competencies and comparative advantage. Realising this, a lot of agricultural biotechnology research projects can be best implemented in collaboration at institutional, national, regional and international levels. Ugandan researchers are already engaged in several partnerships and new opportunities continue to emerge, such as NEPAD's Biosciences East and Central Africa facility in Nairobi.

Constraints

• *Unreliable support services*

Carrying out modern biotechnology research necessitates services that are taken for granted in the developed world. Some of the institutes carrying agricultural biotechnology research in Uganda often experience erratic electricity and water supplies, internet connectivity and bad roads. Modern biotechnology research heavily uses bioinformatics databases (data from genomic analyses), which most Ugandan scientists have no access to. The supply of laboratory consumables is most times unreliable.

• *Low level of investment*

The current level of investment by both government and private sector in infrastructure and human resource for agricultural biotechnology research is low and does not approximate the critical mass of the necessary competent national scientific capacity for agricultural biotechnology research. There is need for increased investment, especially from the public sector into human resource development in critical areas such as genomics, bioinformatics and biosafety. There is also need to improve existing physical

infrastructure. Only a few of the institutes currently undertaking agricultural biotechnology research are well equipped with modern facilities. Moreover, the additional public institutes and the private companies need to be supported to conduct agricultural biotechnology research.

• *Insufficient funding*

Biotechnology application requires modern equipment, supplies and highly trained personnel. Apparently, this is a major challenge, which often makes funding for biotechnology research in Uganda terribly insufficient. Far greater financial resources are needed than is currently being allocated and success should not be expected without long term and dedicated availability of the required funds. Currently, most of the on-going biotechnology projects in Uganda are of a collaborative nature, which is so often dictated by the donors. Moreover, a lot of the on-going research is supported by small grants won by the researchers from international donors and can only do very limited work. In some cases, the donors funding thrust is in discrepancy with the national priorities; this too, may limit availability of research funds. There is need to prioritise and identify for substantial public funding, key commodities for agricultural biotechnology research that have very good potential to result in increased agricultural productivity to address future problems of food insecurity and poverty. Considering this dilemma, the Government of Uganda, with leading support from His Excellency the President, is making concerted efforts to source and or allocate funds to biotechnology research. NARO its self, is committed to supporting biotechnology research at its institutes at KARI and NAARI, by engaging in collaborative work with advanced laboratories and IARC's.

• *Uncertainty of policy environment*

The overall policies, strategies and regulatory framework for biotechnology research in Uganda are not yet clearly in place. The process of developing the Biotechnology and Biosafety bill has taken very long and it is yet to be passed into law.

• *Difficult access to existing technologies and IP issues*

Traits of interest in agriculture for which technologies already exist may be subject to proprietary concerns. On the other hand, the legislation in the country need to be revised to take into account intellectual property issues that cover products of agricultural biotechnology research.

• *Communication of biotechnology*

Much of the Uganda population is not aware about the promise of modern biotechnology, its associated benefits and risks. The lack of knowledge often leads to the mistake referring to hybrid crops developed through conventional breeding as GMOs. Improving public awareness is therefore a major challenge. There is a dearth of qualified and knowledgeable science writers. As a result, journalists without the necessary background and experience try to fill the gap and often produce articles that do not effectively communicate the intended messages. The media needs to be more involved in communication of agricultural biotechnology research and play its rightful role as a platform for dialogue on modern biotechnology between scientists and the civil society.

• *Emerging and re-emerging biological challenges*

Agricultural research has to search for solutions to problems that impair agricultural productivity, some of which are not easy to address. The history of agriculture in Uganda in marked by frequent outbreaks of new diseases and pests. These include the epidemics of cassava mosaic disease, coffee wilt disease, banana bacterial wilt, bean root rots, maize streak virus and livestock diseases. Recently, there were reports of new outbreaks of cassava brown streak virus disease and a new strain of wheat stem rust, Ug99, that threaten cassava and wheat production not only in Uganda but the whole East African region and the World. Other constraints include the difficult nature of some traits of interest and loss of biodiversity. Emphasis could be put on improvement of locally adapted crops and livestock.

• *Development, field testing, monitoring GMOs*

The improvement of crops through genetic transformation is new in Uganda and skills are still very limited not only for the development process, but also in risk assessment and management. Significant resources in terms of numbers of scientists and funds are required for this in order to meet biosafety concerns, regulation and development of technologies that are easily acceptable and attract funding for dissemination.

• *Public-Private partnerships*

Agricultural biotechnology researchers in Uganda have established or can easily get into scientific collaboration with other researchers. However, as in the developed World, commercialization of products of research will greatly rely on partnerships with the private sector. At the moment, private sector participation and interest in agricultural biotechnology research in Uganda, is at best, very limited.

Areas of interest for development of biotechnology in Uganda

Genetically modified organisms: Uganda has not yet produced and or introduced GMOs of crops, fish, and ornamentals due to lack of a functional regulatory guide particularly for crops. We however, hope to introduce and or produce GM crops after approving the Biosafey Act in parliament.

Micro-propagation of endangered and commercially important species: Micro-propagation of banana is currently under way in Uganda, and its being done by both NARO and private company Agro Genetic Laboratories Ltd. Besides propagation, in vitro conservation is also being done for banana at NARO, and for bull semen at the Artificial Breeding Centre (ABC), Entebbe. It's envisaged that capacity will be needed for micro-propagation of other commercial crops, and their long-term in vitro conservation.

Development of genetic markers: Capacity for using genetic makers is slowly being built. Currently, genetic makers are being used to select for disease resistance in maize (maize streak virus), beans (angular leaf spot), cassava (cassava mosaic disease), and for quality traits (quality protein maize). Microsatellites and mitochondrial DNA sequences are being used to study the population genetics of elephants (Loxodonta africana), hippopotamuses (Hippopotamus amphibious), buffalo (Syncerus caffer), and various fish species. This are by far limited applications of genetic markers considering the variety of use to which they can be applied. Thus, at a national level, various efforts are

underway to broaden on the application base and development of genetic makers in Uganda.

Industrial biotechnology: Realizing the potential use of biotechnology to produce industrial products including enzymes, paper, bioplastics, feedstocks and biofuels, NARO with support from SIDA/SAREC initiated research to understand the underlying mechanisms involved in cassava starch synthesis. It was envisaged that baseline information gathered from this study would through, application of biotechnology tools guide in cassava starch modification to meet various uses including use of cassava as a source of fuel. Clearly, this initiative is still at an infant stage, however, as capacity in biotechnology increases, significant progress in terms of product diversification will be made.

Public awareness and education: This is critical for the successful application of biotechnology in Uganda. Although biotechnology utilization aims at improving the quality of life of individuals, care should be taken while promoting these initiatives, taking into account the communication from the anti-biotechnology sections. For instance, when the European cotton buyers learnt that Monsanto was applying to the UNCST to conduct field trials on Bt- cotton, they threatened not to buy any more cotton from the Ugandan Cotton Growers Association. Such examples call for more aggressive campaigns aimed at educating students, farmer groups, scientists, policy makers about the benefits and risks involved in the use of biotechnology.

Sustainability and ethical considerations

Since biotechnology application is perceived as a tool that can enhance economic progress and to improve human health, its necessary that initiative be established that ensure its sustainability. Commitment by the Government of Uganda in form of establishing regulatory framework, and funding, are key indicators of sustainable support. To further sustain the initiative institutions involved in biotechnology research are forming mutually reinforcing partnerships with the donor community and regional networks including the New Partnership for African Development (NEPAD), Association for strengthening Agricultural Research in Eastern and Central Africa (ASARECA), and Bioscience Eastern and Central Africa (BECA). Sustainability of biotechnology application also requires ethical considerations, which have largely been addressed by the biosafety guidelines provided by the UNCST.

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Annex 1: **Reflections on global biotechnology breakthroughs**

Year	Development	Reference
1877	Louis Pasteur and Joules F. Joubert first describe inhibition of bacterial growth	Persidis, 1999
1922	Insulin[1] is first isolated	Banting and Best, 1922
1929	Alexander Fleming[2] develops the first effective antibiotic (penicillin) from the fungus *Penicillium* sp.	McFarlane, 1984; Persidis, 1999
1944	DNA is first identified as the hereditary material in cells; this discovery was later confirmed in 1952	Avery et al., 1944; Hershey and Chase, 1952
1953	F. H. C. Crick and J. D. Watson[3] discover DNA's double-helix structure	Watson and Crick, 1953a, b
1960	Genetic code is deciphered[4]	Crick et al., 1961
1970	Discovery of DNA ligase as catalyst for the ligation of DNA fragments	Sgaramella et al., 1970
1970	Specific restriction endonucleases are discovered[5]	Smith and Wilcox, 1970
1973	The first event of genetic engineering occurs: development of molecular cloning	Cohen et al., 1973
1976	First biotechnology firm is established (Genentech, USA)	Genentech, Inc.
1977	Methods of DNA sequencing are described[6]	Maxam and Gilbert, 1977; Sanger et al., 1977
1977	Rat insulin genes are cloned	Ullrich et al., 1977
1979	cDNA, containing the entire coding of human growth hormone mRNA, is cloned	Martial et al., 1979
1980	USA Supreme Court rules that micro-organisms can be patented	Chakrabarty, 1980
1980	*Agrobacterium tumefaciens* is successfully used to introduce foreign DNA into plants	Hernalsteens et al., 1980
1982	First pharmaceutical substance (insulin; Eli Lilly's Humulin®) produced by a genetically engineered bacterium approved for sale in USA and UK	Eli Lilly and Company, 2003
1982	First transgenic animal is produced (growth hormone gene transferred from a rat to a mouse)	Palmiter et al., 1982
1984	First transgenic plant is produced, using an *Agrobacterium* transformation system	De Block et al., 1984
1985	K. B. Mullis[7], working for Cetus Corporation, California, invents the polymerase chain reaction (PCR)	Saiki et al., 1985
1985	U.S. Patent Office extends patent protection to genetically engineered plants	Hibberd, 1985
1985	First transgenic farm animals are produced (pig, rabbit and sheep)	Hammer et al., 1985

1988	U.S. Patent Office extends patent protection to genetically engineered animals	Leder and Stewart, 1988
1988	Thermal stable DNA polymerases are isolated from thermophylic bacteria, making PCR a very useful procedure	Innis et al., 1988
1988	Human genome mapping project starts	NRC, 1988
1990-1992	First transgenic wheat and maize plants are produced, extending genetic engineering to cereals	Gordon-Kamm et al., 1990; Vasil, 1999; Vasil et al., 1992
1993	First gene for plant disease resistance (Pto) is cloned	Martin et al., 1993
1994	Genetically modified tomato is marketed in USA	Kramer and Redenbaugh, 1994
1996/97	A cloned sheep named Dolly is born at the Roslin Institute, Scotland	Campbell et al., 1996; Wilmut et al., 1997
2002	Draft sequences of the rice genome are published	Goff et al., 2002; Yu et al., 2002
2001	National Center for Food and Agricultural Policy quantifies, for U.S. farmers, the benefits of crop biotechnology in 30 crops	Gianessi and Silvers, 2001
2002	About 59 million hectares of land are planted to genetically modified crops	James, 2002
2003	The famous cloned sheep Dolly is put to sleep in February 2003, after being diagnosed with a progressive lung disease	Giles and Knight, 2003

Annex 2: Overview of the historical time line of the policy, legal and institutional framework for biotechnology Research & Development in Uganda.

1964; The Food and Drugs Act 1964: This law handles standards for foods and drugs. Accordingly, any research or products of biotechnology regarding genetically modified foods and drugs have to meet the strict requirements of this Act.

1964; The Plant Protection Act 1964: This law regulates the introduction into the country of exotic plants and microorganisms. The statute however does not directly support biotechnology R& D for the production of GM crops nor does it provide mechanisms for minimising the risks of involuntary gene transfers and for managing the risks involved in biotechnology R & D. Accordingly, this statute would require amendment in order to bring it up to date to counter wrongful introductions and transfers of alien GM species of crop plants resulting from Biotechnology R & D.

1990; The Uganda National Council for Science and Technology Statute 1990: The law, which established the Council, empowers it to formulate policies and strategies for science and technology in all fields of science and technology including biotechnology and biosafety. The Uganda National Council for Science and Technology has drafted policy and regulatory instruments to handle biotechnology R&D and biosafety issues in Uganda.

1990; The Uganda National Council for Science and Technology: The Uganda National Council for Science and Technology (UNCST) is the local agency for the implementation of the Biotechnology and biosafety policy and legislation in Uganda. The Uganda National Council for Science and Technology is the national focal point for biotechnology and biosafety coordination and management. The Uganda National Council for Science and Technology was created by the Government of Uganda in 1990 to oversee the integration of science and technology in the National development process. The law empowers the Uganda National Council for Science and Technology to formulate policies and strategies in all fields of science and technology including biotechnology and biosafety.

1992; The National Agricultural Research Organisation Statute 1992: The NARO statute mandates the National Agricultural Research Organisation to conduct research in all fields of agriculture, including biotechnology. The law covers broad areas for handling agricultural research including biotechnology research. The National Agricultural Research Organisation has a seed certification unit, appointed under the Agricultural Seeds and Plant Statute, which is responsible for approving the standards of any seeds developed through biotechnological applications and for certifying private sector entities that are appointed in the production and commercialisation of seed varieties. Main strides have been in tissue culture in bananas and to develop molecular markers to study various traits in cassava and bananas.

1993: Uganda ratified the Convention of biological diversity, which *inter alia* promotes biotechnology transfer and conservation of biodiversity, sustainable use of its components and fair and equitable sharing of benefits arising from such use.

1994; The Uganda Agricultural Seeds and Plant Statute 1994: The statute was enacted to provide for the promotion, regulation and control of plant breeding and variety releases, multiplication, conditioning, marketing, importing and quality assurance of seeds and other planting materials and for other matters connected therewith. Biotechnology techniques and R & D is implicit in the `multiplication and testing of seed and plant varieties before their release as governed by the Statute. The Statute provides for a National Seed Testing Laboratory designated to carry out official seed tests.

1996; The National Biosafety Committee: The National Biosafety committee is the national administrative arm of the Uganda National Council for Science and Technology on matters concerning biotechnology and biosafety. The National Biosafety Committee (NBC) was set up by the Uganda National Council for Science and Technology in 1996 and represents the legal, research and practicing sector (Biotechnology research and Development). The National Biosafety committee comprises representatives from the Uganda National Council for Science and Technology, institutions in Ministries involved in biotechnological and environmental issues, universities and institutions in the private sector involved in biotechnology research. The main function of the National Biosafety Committee is to provide technical advice on biosafety issues to government especially with regard to the continued assessment of risks and benefits associated with the production and/or application of biological materials produced in laboratories and those occurring in nature, and maintain links with biotechnology institutions through institutional biosafety committees.

1999; The Draft Biosafety Regulations, 1999: This is so far the only comprehensive legislation governing biotechnology issues and specifically biosafety in Uganda. The Regulations contain provisions on Risk Assessment, Risk Management, Unintentional release and emergency measures, Identification and labelling, exports of GMOs or products of GMOs, among others. While the regulations make provision for biotechnology products, this is made within the context of liability and redress regimes.

2000; The Poverty Eradication Action Plan 2000: The Government of Uganda's Poverty Eradication Action Plan (PEAP), 2000 is intended to provide a framework for government planning and policy development in all sectors in order to combat poverty.

2001: Uganda signed the cartegena protocol in 2000 and ratified it in 2001.This was the first legally binding instrument to emerge from the convention on biodiversity (CBD).

2001: The Plan for Modernisation of Agriculture (PMA). The Plan for the Modernization of Agriculture (PMA) is a poverty-focused framework of principles whose main objectives are to Increase incomes and improve the quality of life of the poor subsistence farmer through increased productivity and increased share of market production.

2001: The National Science and Technology Policy 2001. The National Science and Technology Policy of 2001 provides for the formulation of a biotechnology policy to guide the judicious use of biotechnology for sustainable development and envisages the development of a national institutional framework for regulatory administration and Research and Development activities in biotechnology including the promotion of an enabling environment for the creation of partnerships between the Private Sector and the Public Sector for the development of products of biotechnological applications.

2001*:* The Animal Breeding Act 2001. The Act sets up the national Animal Genetic Resources Centre and data bank to promote the regulation and control, marketing and generally dealing in animal and fish genetic materials. The Act regulates the implementation of the national breeding policy and promotes the development and use of animal genetic resources that are relatively more tolerant to disease and environmental stress. This implies that the national breeding policy envisages the use of biotechnology R & D and practices in the development of animal genetic resources for the realisation of the objectives of the Animal Breeding Act.

Legislation governing Intellectual Property - The Patents Statute 1991 and the Patents Amendment Act 2002. These govern the protection of intellectual property in the form of patenting of new creations/ designs. These laws give minimal protection if any, to

biotechnological applications and products of biotech R & D since they will not technically fall within the definition of patentable applications in order to be protected by this regime of laws. Uganda is currently developing a legal regime that seeks to adopt the obligation under article 27.3(b) of the Agreement on TRIPs to protect plant varieties by patents or "*effective*" *sui generis systems* or a combination of both. However, what "sui generis system" satisfies the obligation for IP protection is unclear and is still a subject of differing views.

2001*:* The National Agricultural Advisory Services (NAADS) Act. The Act establishes the National Agricultural Advisory Services for the promotion of market-oriented agriculture. The objectives of the organisation are to promote food security, nutrition and household incomes through increased productivity among others. The organisation is enjoined to support technology development and linkages with markets and support private sector and farmer institutional development. This implies that the NAADS Act, which is an off shoot of the Plan for the Modernisation of Agriculture, would support the use and dissemination of biotechnology R & D to meet its objectives, particularly of food security and increased productivity.

2003: National biotechnologies laboratory established at Kawanda Agricultural Research Institute.

2004: Draft policy on National Biotechnology and Biosafety Policy has been developed by the Uganda National Council for science and Technology (UNCST) currently the undergoing legislative process.