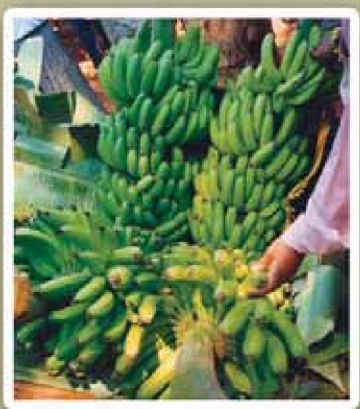
Feasibility Study on Technologies for Improving Banana for Resistance Against Bacterial Wilt in Sub-Saharan Africa



AFRICAN AGRICULTURAL TECHNOLOGY FOUNDATION
FONDATION AFRICAINE POUR LES TECHNOLOGIES AGRICOLES

Feasibility Study on Technologies for Improving Banana for Resistance Against Bacterial Wilt in Sub-Saharan Africa

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Fact file

Country	Burundi	Uganda	Kenya	Tanzania	DRC	Rwanda
Population (millions)	6.6	28	34	37.4	62.7	7.4
People living below the poverty line (%)	68	35	50	36	N/A	60
GDP/ Capita US$	600	1800	1100	700	700	1300
Percentage of arable land	44	21.6	7	4.23	2.9	35
Main food crops	b,c,sw,m,sor	b,c,p,m,sor	m,w,c,sor,p	m,c,b,w	c,b,m,	b,bn,sor,p
Importance of banana	Income, food	Food, income	Income, food	Food, income	Food	Income, food
Banana area ('000ha)*	300	1,805	80	373		363
Area in sq km (millions)	0.03	0.24	0.583	0.94	2.345	0.026
Arable land under banana (%)		38%	1.7% (ISAAA)			252.5 (000ha)

m=maize, b=banana, c=cassava, bn=beans, sor=sorghum, sw=sweet potato, p=potato, w=wheat
Source: World Fact Book
*FAOSTAT
Sergeant et al (2004)
ISAAA (1999)

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List of Abbreviations

AATF	African Agricultural Technology Foundation
ABSF	African Biotechnology Stakeholders Forum
AGTL	Agro-Genetic Technologies Limited
APEP	Agricultural Productivity Enhancement Programme
ASARECA	Association for Strengthening Agricultural Research in East and Central Africa
ASPS	Agricultural Sector Programme Support
BARNESA	Banana Research Network for Eastern and Southern Africa
BBTV	Banana Bunchy Top Virus
BBW	Banana Bacteria Wilt
BIO-EARN	East African Regional Progamme and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development (BIO-EARN)
Bt	*Bacillus thuringiensis*
BTA	Biotechnology Trust Africa (BTA)
C3P	Crop Crisis Control Project
CABI	Commonwealth Agricultural Bureaux International
CBOs	Community Based Organisations
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Centre for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Centre
CMD	Cassava Mosaic Disease
COMESA	Common Market for Eastern and Central Africa
COSTECH	Tanzania Commission for Science and Technology
CPB	Cartagena Protocol on Biosafety
CRS	Catholic Relief Services
DRC	Democratic Republic of Congo
ECABIO	Eastern and Central Africa Biotechnology and Biosafety
ECOTRUS	Provide full name
EU	European Union
FAO	Food and Agriculture Organisation
FFS	Farmer Field Schools
FHIA	Fundación Hondureña de Investigación Agrícola
FIBEC	Finance and Business Economic Consultants
GE	Genetic engineering
GM	Genetically Modified
GTL	Genetic Technologies International Ltd
HBFMA	Highridge Banana Farmers Marketing Association
IARCs	International agricultural research centres
IITA	International Institute of Tropical Agriculture
IFPRI	International Food Policy Research Institute

INIBAP	International Network for Improvement of Banana and Plantain
IPGRI	International Plant Genetic Resources Institute
IPM	Integrated pest management
IPR	Intellectual Property Rights
ISAAA	International Services for the Acquisition of Agri-Biotech Applications
ISAR	Institut Scientific Agronomiques Recherche – Rwanda
ITSC	Institute for Tropical and Subtropical Crops (South Africa)
IRAZ	Institut de Recherche Agronomique et Zootechnique de la CEPGL
ISABU	Institut Des Sciences Agronomiques du Burundi
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KAPP	Kenya Agricultural Productivity Project
KARI	Kenya Agricultural Research Institute
KARI	Kawanda Agricultural Research Institute
KEPHIS	Kenya Plant Health Inspectorate
LMOs	Living Modified Organisms
MAAIF	Ministry of Agriculture, Animal Industries and Fisheries
MAR	Mikocheni Agricultural Research Institute
MINAGRI	Ministry of Agriculture – Rwanda
MTAs	Material Transfer Agreements
NAADS	National Agricultural Advisory Services
NARIs	National Agricultural Research Institutes
NARO	National Agricultural Research Organisation
NARS	National Agricultural Research Systems
NBF	National Biosafety Framework
NBFP	National Biosafety Focal Points
NCST	National Council of Science and Technology
NGOs	Non-Governmental Organisations
PBS	Program on Biosafety Systems
PCR	Polymerase chain reaction
PVP	Plant Variety Protection
RADA	Rwanda Agricultural Development Agency
SUA	Sokoine University of Agriculture
Tc	Tissue culture
TPRI	Tropical Pesticides Research Institute
TOSCA	Tanzania Official Seed Certification Agency
UDSM	University of Dar es Salaam
UNCST	Uganda National Council of Science and Technology
UNDP	United Nations Development Programme
UNEP-GEF	United Nations Environmental Programme – Global Environment Fund
UNFF	Uganda National Farmers Federation
USAID	United States Agency for International Development

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Executive Summary

Banana Bacteria Wilt (BBW), a bacterial disease with a potential to wipe out a thriving banana industry, was first reported in Uganda in 2001. It has since spread to almost all the main banana growing regions in the country and crossed into Kenya and Tanzania. In Rwanda, although some farmers claim to have noticed it as early as in 2002, the disease was officially reported first in July 2006. It is believed to have crossed from the Democratic Republic of Congo (DRC) to Rwanda through trade and importation of bananas. In Kenya the disease has been identified in Teso and Bungoma districts which border Uganda. In Tanzania, the disease is concentrated in the Kagera region and is said to have originated from Uganda. While the disease affects all types of bananas, in Uganda it has been reported to affect the sweet banana types, which are used for beer making, more than the other types.

Currently, there are no effective control methods for the disease. Attempts have been made to promote cultural control methods which include sanitary measures. While such measures have helped check the speed at which the disease is spreading, they have unfortunately not managed to stop the spread. Consequently, the disease has continued to spread in all banana growing areas.

The disease has had devastating effects on incomes and food security of the affected farmers. In Uganda, it has changed the cropping patterns of whole communities. There has also been significant increase in banana prices in Uganda, Kenya and Rwanda as a result of declining production of bananas due to the disease.

In Uganda it is estimated that in 2005, the country lost US$ 35 million worth of bananas to the disease. The estimated loss in Tanzania where it was reported in April 2006 is over US$ 350,000.

Conventional breeding for disease resistant material could take over 20 years due to the biological nature of bananas and since cultural control methods have had limited results. AATF in collaboration with other international, regional and national institutions are developing transgenic bananas resistant to BBW. AATF has brokered a gene from Academia Sinica in Taiwan that is currently undergoing proof of concept at Kawanda in Uganda by International Institute of Tropical Agriculture (IITA) scientists.

The assessment of capacities for transformation work with the national research systems indicates that laboratories in Kenya and Uganda are more advanced than those in the other countries. Tanzania is also establishing a laboratory capable of conducting transformation work at Mikocheni. In terms of human resources capacity, there is a significant critical mass of scientists within the region that has the necessary expertise to conduct transformation work. In terms of actual research work on genetic modified banana, Ugandan scientists have made considerable progress in this field and have already produced a banana product that is resistant to Sigatoka.

In the area of biosafety policies for deployment of GM technologies, Kenya is the most advanced having conducted field trials for *Striga* resistant maize. Uganda is also completing the containment laboratory at Kawanda that can be used for contained trials of transgenic banana.

There were concerns expressed by a cross section of respondents concerning the acceptability of GM products. Farmers indicated that as long as their national scientists approved the technologies as safe and there was support from the government, they would have no problem in adopting the technology. However, they were wary of the possibility of a terminator technology and also feared that the cost of the technology could be beyond reach for the majority of banana farmers. In Burundi and Rwanda, farmers were not aware of GM technologies.

Some scientists were not convinced that GM technology was the only available option and wondered whether all other options for control of BBW had been exhausted. They also queried the efficacy and stability of the gene. However, there was general consensus that the GM option needed to be explored as a long term solution and that national programmes should be closely involved in the transformation process. Scientists from Kenya and Tanzania argued for a more decentralised transformation work while the rest were of the opinion that the bulk of the work be conducted at a centre of excellence (with facilities and necessary expertise), while national programmes are involved at the field testing and deployment stage of the technology.

The proposed project on transgenic banana, if successful, would provide a solution to a problem that is threatening to wipe out the banana crop in the region.

If the development of the technology is successful a possible deployment avenue will be through existing tissue culture (TC) laboratories. At the moment there is one private TC laboratory in Kenya, one in Uganda and two in Burundi. There are also public run TC laboratories in the region. The combined capacity of TC laboratories for TC banana is about 5 million suckers per year. There is significant experience for deployment of banana technologies through TC in the region and with some capacity building this can be an ideal avenue for deployment of GM banana planting material.

Interviews with donors and TC enterprise operators revealed several options for funding for technology development and deployment. Donors, for example, would be interested in funding technology development work that has a regional focus rather than a national one. They also indicated that there must be a demonstration that the technology development work is addressing a critical issue for the region. Additionally it was emphasised that banana must be an important crop for the countries involved. In the case of technology deployment, the options were donor funding, links with micro-credit schemes and direct purchases from farmers. These are the mechanisms currently in use for deployment of TC banana technologies in the region. Interviews with farmers in areas affected by BBW indicated that they would be willing to pay between US$ 1–1.2 per sucker of BBW resistant planting material.

Economic analysis shows that there is limited export risk in adopting GM banana since there is only insignificant export of bananas to GM sensitive markets in the European Union (EU). However, there is likely threat in intra-regional trade, but this can be addressed through a joint regional approach to biotechnology adoption which is currently being finalised under the auspices of the Common Market for Eastern and Southern Africa (COMESA).

Cost benefit analysis shows that a breakeven point will be achieved within the eleventh year of project implementation if the principal amount (US$ 6 million) invested is considered a social cost (not repayable) with an interest rate of 3% being repaid over the period. The breakeven point with both principal and interest rate at 3% being repayable is achieved in the twenty second year of project commencement.

Introduction

This feasibility study on Banana Bacteria Wilt (BBW) was commissioned by the African Agricultural Technology Foundation (AATF) and contracted to the Finance and Business Economic Consultants (FIBEC) in July 2006. The purpose of this assignment is to:

- assess the extent of the BBW problem in the region
- identify capacity for transformation and deployment of BBW resistant banana technology
- assess human and environmental concerns
- assess the capability of the technology
- assess the cost benefit analysis of adopting the technology

Detailed terms of the study are presented in Annex 1. The study was undertaken in five countries (Burundi, Kenya, Rwanda, Tanzania and Uganda) between 11 July and 23 August 2006.

Methodology

The consultants used a number of methods while executing this assignment. Firstly, a literature/document review was done, during which a number of documents that included published articles, unpublished reports and documents posted in different websites were reviewed. This was followed by a briefing meeting with AATF technical and administration staff. The first meeting was for introducing the research team, discussion on the approach and the geographical coverage of the study and the expected outcomes. The consultants then prepared various data collection tools and embarked on the research. On completion of the field work, the team held a debriefing meeting with the AATF technical staff.

The field work included collection of primary data through interviews with farmers and traders. Data collection tools used included structured questionnaires targeting banana producers, banana programme leaders, tissue culture laboratories, biotechnology research laboratories and biosafety policy institutions and traders. Other tools included survey checklists targeting banana researchers, farmer groups/associations in banana growing areas, extension personnel, heads of research institutions and researchers working with banana research networks. Photographs of affected banana fields and control measures used were also taken and are used for illustrations in the report.

Interviews were conducted among National Research Institute directors in Uganda, Rwanda, Burundi and Tanzania and among banana programme leaders in Uganda, Tanzania, Kenya and Rwanda. In Burundi interviews were conducted with the director of Institut de Recherche Agronomique et Zootechnique de la CEPGL (IRAZ). The research team also visited and conducted interviews among national agriculture ministries and university laboratories in Kenya, Uganda, Tanzania, Burundi and Rwanda. Interviews were also conducted among national biosafety policy committees and national councils of science and technology in Kenya, Uganda and Tanzania. Other institutions interviewed included; Eastern and Central Africa Biotechnology and Biosafety (ECABIO)/Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) in Uganda, International Food Policy Research Institute (IFPRI) in Uganda, East African Regional Progamme and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development (BIO-EARN) in Uganda and International Services for the Acquisition of Agri-Biotech Applications (ISAAA) in Kenya.

The research team also conducted interviews among private and public banana tissue culture enterprises in Kenya, Uganda and Burundi. Field visits were made to the banana wilt affected areas in Uganda, Tanzania, Rwanda and Kenya and interviews conducted among public extension staff, farmers, farmer organisations and other local leaders. Structured interviews were conducted among banana farmers and traders (wholesale and retail) in Uganda, Kenya, Tanzania and Rwanda. The data collected using structured questionnaires was analysed using SPSS computer package.

Background

Banana belongs to the family *Musaceae* and genus *Musa* and is therefore closely related to plantains. Together with plantains they constitute a major staple food crop for millions of people in developing countries. Banana is the most cultivated fruit crop globally being grown in 140 countries. Although the origin and centre of diversity for banana is believed to be southeast Asia, the east African highlands is recognised as a secondary centre of diversity. Original bananas contained large seeds but the varieties selected for human consumption are triploid, meaning that they possess three sets of chromosomes and thus sterile or parthenocarpic and seedless. Therefore their mode of propagation is very different from crops that produce seed. They are propagated asexually from offshoots of the plant called suckers.

The vast majority of producers are small scale farmers growing the crop either for home consumption or for local markets. Because bananas and plantains produce fruit year-round, they provide a valuable source of food during the hunger season and it is for these reasons that bananas and plantains are of major importance to food security.

In terms of volumes of food consumed by human, bananas are ranked fourth in the world after rice, wheat and maize.

Banana genome levels

Modern day banana is a cross between two wild species, *Musa acuminata* and *Musa balbisiana* which contributed the AA and BB genomes, respectively.

The east African highland bananas are derived from the *acuminata* bananas of southeast Asia and, like the dessert bananas, they are triploids. In genetic terms, crops that possess three sets of chromosomes (triploid) rather than two or four are sterile and produce no pollen. Through mutations, several new cultivars with different characteristics arose and were given different names. Cooking bananas (*matooke*) that constitute the majority of the east African highland bananas have the AAA-EA genome type, whereas beer bananas are mostly AAA, AB and ABB genome types. Roasting bananas belong to the AAB group while dessert or sweet bananas such as *ndizi* have the AB genomes but Gros Michel and Cavendish have AAA genomes.

The banana therefore possesses multiple ploidy levels which makes it difficult to be improved through the conventional cross breeding methods. Instead, it is vegetatively propagated.

Wild relatives and gene flow

In eastern Africa, the most commonly reported wild relative of the banana is *enset*. *Enset* is an important food crop in the highland areas of south western Ethiopia. Though *enset* is present in Uganda, Rwanda and perhaps in Burundi in few numbers, it does not cross naturally with banana cultivars. There are other wild relatives of banana reported in Uganda such as *zebrina* and *canana lily*; undocumented pockets exist in central Kenya, Rwanda and Burundi. However, in all these cases there are no known natural hybrids between cultivated and wild banana relatives. Chances of gene flow in banana are non-existent.

BBW was first noticed in Uganda in 2001 and its spread has now been confirmed in four other countries in the Great Lakes region (Kenya, Rwanda, Tanzania and DRC). It is only in Burundi where the problem has not been reported.

Efforts to control the spread of the disease using cultural methods have not been successful. AATF has identified BBW as a one of the most important problems in the Great Lakes region and has negotiated for a gene to transform local bananas for resistance to the disease. AATF's objective is to provide smallholder farmers with access to suitably adapted high yielding banana and plantain varieties with resistance to abiotic and biotic constraints. Its role will be to resolve Intellectual Property Rights (IPR) issues associated with obtaining access to and using advanced transgenic crop improvement research methodologies, ensuring regulatory compliance and project stewardship.

Importance of Banana in the Region

East Africa (most notably the Great Lakes region covering portions of Rwanda, Burundi, Tanzania, Kenya and DRC) is the largest banana producing and consuming region in Africa (Smale M and De Groote H, 2003). Banana is largely grown as a food crop and is the most important food crop in Uganda, Rwanda and Burundi. Other important food crops in the region include cassava, maize, sweet potato, potatoes and beans. Banana is also an important cash crop within the region. It is said to be the most traded food crop in Uganda (Aliguma and Karamura, 2006).

Uganda is the second largest producer of bananas in the world after India, with an estimated production of 10.6 million metric tonnes per year. It is the world's largest consumer of bananas (Sergeant A et al, 2004). Banana yields in the region have however been on the decline due to a number of diseases and pests. In eastern Africa in general, production fell by over 40% in the 1990s. During the 1970s, for instance, Uganda produced 15 to 20 tonnes of bananas per hectare and by 2000 banana yields had declined to 6 tonnes per hectare. However new varieties such as FHIA-17 (also known as the Kabana 3), which are resistant to the disease have been introduced. These new varieties taste different from the traditionally grown banana which has slowed their acceptance by the local farmers.

The main banana growing areas in the region include south western and central Uganda, most parts of Rwanda and Burundi. In Tanzania it is a major crop in western, northern highlands, southern highlands and eastern highlands. In Kenya it is an important cash crop in central region and an important food crop in the Kisii region of Nyanza province (Figure 1).

There are four main types of bananas grown in the region. These include cooking bananas, popularly known as *matooke* in Uganda; beer bananas, important in Rwanda and Burundi; and dessert and juice bananas. Roasting bananas are also grown, although on a limited scale.

In countries such as Uganda, Burundi and Rwanda per capita consumption has been estimated at between 250 and 450kg per year, the highest in the world (Wikipedia encyclopaedia, online; Aliguma and Karamura, 2006; ISAR/IITA, 2001; and Sergeant A et al, 2004).

Both cooking and brewing bananas are of economic importance to farming communities in the banana growing areas in Rwanda. The brewing bananas have a high income generation dimension with about 80% of the production being market targeted[1], while over 50% of the cooking type are consumed at home in Rwanda.

[1] 60–80% of income among households surveyed during the ISAR/IITA/INIBAP PRA survey was derived from bananas.

Farmers in Rwanda prefer production of bananas because they guarantee continuous income under conditions of acute land shortage. The Rwanda Ministry of Agriculture has advocated for replacement of brewing bananas with cooking bananas without success.

Other than food security and income generation, bananas have a wide range of cultural values detailed later in this report.

Although Uganda is among the leading banana producers in the world, it is among the least exporters of bananas in the world, occupying number 70 among the leading banana exporters. This is because the bulk of its bananas are the east African highlands cooking bananas, which are consumed locally and regionally but represent a negligible share of internationally traded bananas that are dominated by sweet or apple bananas.

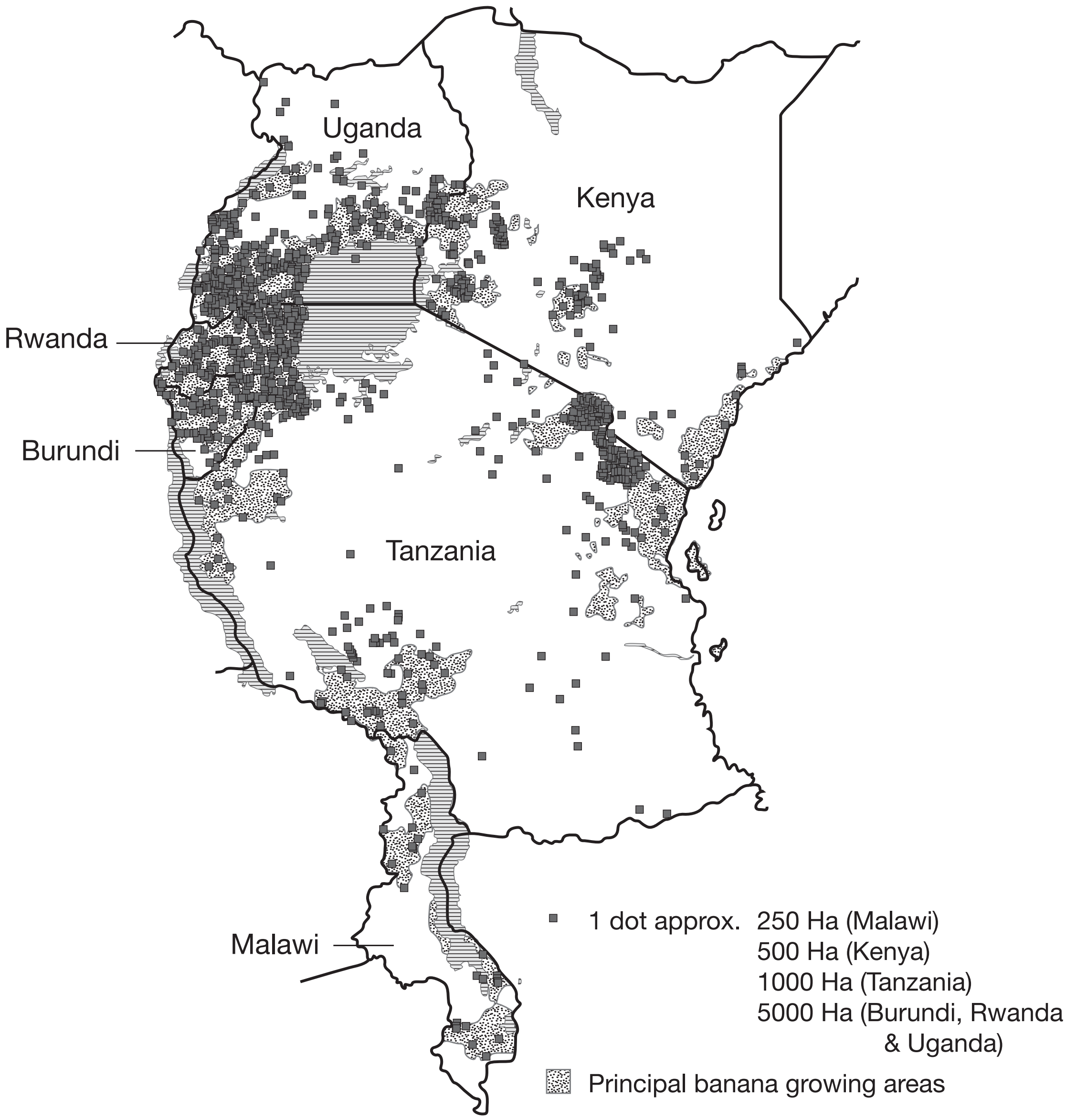

Figure 1. *Principal banana growing areas in eastern Africa*

Banana production systems

Scientists as well as farmers expressed the fear that introduction of GM banana could contaminate other crops grown within its environment. While such fears appear unfounded, given banana is a sterile crop which does not cross pollinate, the research team found it necessary to investigate crops that are intercropped with bananas.

In all the five countries visited, the banana production system includes mono-cropping as well as intercropping. In Uganda, banana is intercropped with cassava, coffee, sweet potato and more recently vanilla. In Kenya it is intercropped with maize, beans, sweet potato and in some areas it has also been intercropped with vanilla. In Tanzania, it is intercropped with beans, coffee, maize, cassava or vanilla. In Rwanda and Burundi bananas are intercropped with coffee, cassava, maize and vegetables.

The presence of wild relatives of bananas was not reported in the study areas.

Production practices

Banana production practices in eastern, central and southern Africa are diverse and complex. The complexity derives from the diversity in agro-ecological conditions as well as the socio-economic variability across the regions. Consequently, it is not possible to define concurrently any one production practice except for commercial plantation systems. Other systems are merely an assortment or a blend of several sub-systems even in one eco-region.

For our purpose, the production systems will be divided into three broad categories: backyard garden systems; subsistence systems and commercial plantation systems. Although the systems are variable, each has distinct characteristics that broadly distinguish it from the others. The characteristics define the intensity and/or level of management associated with a given system and range from crop management practices, planting materials used, irrigation, pest control practices, cropping systems employed (mixed or inter-cropped), levels of yield attained and associated end users and incomes to socio-economic factors around the farmer including their perceptions, opinions, priorities, availability of inputs and markets (INIBAP, 1998).

Banana backyard garden systems

This is a low input system found throughout the region but the intensity of which decreases as one approaches the sub-tropical regions. It is usually found in the peri-urban areas of Uganda, Rwanda, Burundi, Kenya and Tanzania and where other crops have higher commercial or subsistence importance than bananas/plantains. In peri-urban areas banana production is constrained by land size and availability, while in rural areas where other crops have higher commercial value the banana crop is planted at the points where household waste water and garbage is dumped.

In this system, farmers usually pay minimum attention to crop management practices as the purpose of the crop is to supplement other food sources. In Uganda, backyard gardens provide green leaves for wrapping and cooking *matooke*. Therefore, cultivars which produce many leaves such as Kayinja are preferred. Because of minimal attention, these gardens tend to be foci for pest/disease from which other banana stands in the vicinity may be infested or infected.

Banana subsistence systems

Most banana and plantains of the banana tropical world are grown within the subsistence systems. This system is responsible for over 87% of global banana/plantain production (INIBAP, 1998). Bananas are perennial and are grown using low inputs and on small acreages (0.25–5ha) in rural areas (Table 1). The overriding purpose of the system is food security. But commercial interests as shown by expanding local banana markets have become important. The system has attracted considerable technical attention particularly with regard to pest management. In spite of these efforts, not much success has been recorded. Pests and diseases have increased in some areas and in some extreme cases the yields have fallen below 10tonnes/ha (INIBAP, 1998). This in turn has resulted into massive cultural displacement and associated socio-economic upheavals. Moreover, other changes such as population pressure and attendant effects on land use have resulted in the degradation of the natural resource base which in turn aggravates the pest and disease impact in subsistence systems.

Table 1. Cropped area under banana

Country	Average area under banana (acres)	Cropped area under banana (%)	No.
Rwanda	1	46.2	60
Kenya	0.4	8.7	50
Uganda	0.725	24	50
Tanzania Lake Zone	1.173	56.3	50
Tanzania Arusha	0.655	7	30

Source: Survey results

The system is complex in terms of cultivars grown, soils, terrain, pests, diseases, communities, management skills as well as crop uses even in the same eco-region. It is common to get up to 12 cultivars in one farm plus a mixture of intercrops. This means that any meaningful technology must take into account the ecological as well as socio-economic aspects of the crop, pest and disease problems encountered as well as the complexity of the system.

Farmers grow several cultivars on the same piece of land for fear of an epidemic, which could wipe out one cultivar. They also grow different cultivars for different uses; some are for beer or dessert and others for cooking. Therefore the number of cultivars grown can be determined by the different uses/types and as a risk insurance against pests and diseases.

Banana plantation systems

The plantation system can be described as intensively managed from selection and treatment of planting materials, seedbed preparation, crop establishment and stand management through to marketing/processing. Yields are high in the range of 40–60 tonnes/ha and profit is the ultimate objective (INIBAP, 1998) compared to the average of 6.5 tonnes/ha for the great lakes region (FAOSTAT, 2005). This system is by far the least complex. Often it has a single cultivar and uniform management. It is however the least important since it accounts for only 12% of global production (INIBAP, 1998).

Within the Great Lakes region, it is almost non-existent. In the areas where interviews were carried out, there were no banana plantation systems. Hence the dominant system was subsistence with backyard gardens.

Agronomic practices

The agronomy of bananas is ably presented in many textbooks and summarised in booklets. Mbwana (1998) has provided such guidelines on requirements for moisture/rainfall, altitude, optimal temperatures, protection from damage by wind, spacing, dimensions of holes, how to source planting material, plant protection and proper harvesting techniques. These standards were used by the study team to rate the standards of management and the quality of planting materials.

Following the visits made to various farms in the target countries, it was observed that there was poor management of banana fields. Most fields were not cleaned up, and the stems were generally not healthy meaning there was little or no manure added on yearly basis. No mulch was observed in most farms visited but the fields in Kagera region were clean. There were many suckers per stool and that means that there is no pruning as per the agronomic practices recommended. This coupled with increased pests and diseases has led to a general decline in productivity in all countries visited.

Most of the farmers did not observe the recommended spacing of bananas, with some unaware of the recommended spacing. Majority of the farmers sourced their planting material from older stools. There was no general observance of the renewing of banana stools to maintain good yields even among farmers that had adopted TC materials. In central Kenya, farmers who had adopted TC material claimed they were not aware that they should replant their fields with new material after every five years to maintain good yield. This indicates a poor extension service, lack of technical information and back-up from the TC material providers.

Poor management standards for banana orchards among the subsistence systems were attributed to limited resources.

Farmer-preferred banana types and varieties

In order to make decisions as to what varieties or group of varieties to transform in each country, the team collected data through literature review and interviews with farmers, traders and key informants on main varieties produced in each country. Through interviews with farmers and traders (traders were assumed to provide information on consumer preference and choice) information was gathered on variety traits that make them popular with producers and consumers. Information on consumer and producer preference is important in the transformation process because it provides guidelines on what traits must be preserved to ensure that the transformed varieties maintain their constituency of consumers and producers.

Banana types grown in the region vary from country to country. Based on previous studies carried out in Uganda, Tanzania, Rwanda and discussions with the various stakeholders in the five study countries, the preferred banana types in percentage are shown in Table 2.

Table 2. Preferred banana types in the Great Lakes region

Country/types	Cooking (%)	Brewing (%)	Dessert (%)	Roasting (%)	Total (%)
Uganda	76	8	14	2	100
Rwanda	20	70	10	0	100
Burundi	14	85	1	<1	100
Tanzania	52	7	20	21	100
Kenya	60	NONE	40	NONE	

Source: Marketing survey of the banana sub-sector, Rwanda; Diversity distribution and selection criteria of Musa germplasm in Uganda; Evaluating the market opportunities for banana and its products in Tanzania; Discussions – Burundi and Kenya DG-IRAZ and Dr L Wasilwa, KARI

There are four main types of bananas grown in eastern Africa: cooking, roasting, brewing and dessert bananas. Banana production in Uganda and Tanzania is dominated by the east Africa highland cooking banana (*matooke*–AAA-EA). In Tanzania, cooking bananas constitute 60% of the production in the southern highlands and 80% of banana production in the Lake Zone area. The beer bananas found in the AAA, AB and ABB groups are the dominant type produced in Rwanda. In Tanzania beer bananas constitute about 10–15% of total banana production.

In Rwanda a survey by scientists from ISAR, IITA and INIBAP (ISAR/IITA, 2001) observed that banana production consisted primarily of brewing types (AAA-EA, AB and ABB), east African highland cooking types (AAA-EA), and dessert bananas (AAA and AB). Countrywide, brewing bananas (especially Pisang Awak, ABB) have been the predominant types for several decades. The varieties also consist of several cultivars.

In Rwanda most of the brewing bananas are for sale while about half of the cooking bananas are consumed at household level. The brewing bananas are therefore important sources of income, while the cooking bananas are an important food security crop in the country.

In Kenya, the most important banana types are the dessert and cooking types depending on the region. The cooking bananas are most important in Kisii region of western Kenya, while the dessert bananas are most important in eastern and central Kenya. The cooking varieties include Kiganda, Uganda green, ng'ombe, nusu ng'ombe, mutahato and Gradi Shisikame (Spilsbury DJ et al, 2002; MoA, 2005). However, Kenyan consumers are not as distinct as Ugandans when it comes to cooking bananas. Indeed most of the dessert bananas are also used for cooking in Kenya, especially in the central region. The main dessert varieties include apple banana (sukari ndisi), bokoboko, giant Cavendish, dwarf Cavendish, Chinese Cavendish, Gros Michel, Kampala, bogoya and muraru (Spilsbury DJ et al, 2002; MoA, 2005). Some of the bananas are of dual purpose especially in central Kenya where both cooking and dessert bananas are important.

Compared to dessert bananas, cooking bananas are the most cultivated in east Africa. However, Tanzania is more balanced between dessert and roasting with less beer bananas. Kenya does not have brewing and roasting bananas. Rwanda and Burundi produce more beer bananas than either cooking, dessert or roasting bananas. One reason advanced from the study in Rwanda was that beer bananas can withstand poor soil fertility and drought as compared to the others. But of course other cultural and social activities also play a role in the preference for brewing bananas.

As noted earlier, most of the countries in the region grow a mixture of a number of varieties of bananas, for example Uganda is said to have over 200 varieties of banana. Although actual data on production of each of the varieties is not available, the main varieties grown in each country are presented in Table 3.

In Uganda mbwazirume variety is mainly grown in the high elevation areas while nakitembe is grown in the low elevations areas (Smale M and Edmeades S; IPGRI, IFPRI, Jan. 2006). Other varieties include Kisansa, nakabululu and kayinja. Kayinja is a popular variety in central Uganda and is mainly used for brewing purposes.

Farmer-preferred varieties for each type vary from country to country although dessert bananas tend to be the same. Most of them are exotic as compared to highland bananas used for cooking or beer or roasting. In Table 3, farmer-preferred varieties of different types of bananas are presented. The information is based on previous studies and the discussions with the stakeholders in the countries under the study.

The preferred varieties as indicated per country are widely grown in the main banana growing regions.

Table 3. Farmer-preferred banana varieties by type of banana and country

Country/Type	Cooking	Beer	Dessert	Roasting
Uganda	Nakabululu Nakilembe Mwasirume Enyeru	Kayinja Bluggoe Mbidde	Ndizi/apple Kasubi Gros Michel	Gonja
Rwanda	Barabeshya Injagi Ingaju Incakara	Mazizi Umukora Intutu Kayinja (Pisang Awak)	Apple banana Gros Michel Cavedish	Gonja
Burundi	Kigande Other 5–6 varieties	Isige Igiberill Other 6 varieties	Apple bananas Cavendish	Gonja
Kenya	Ng'ombe Nusu Ng'ombe Uganda green Kisygame	NONE	Apple Cavadish Gros Michel	NONE
Tanzania	Entobe Mshale Mzuzu Kimalindi Nshahara	Nshembire Sirya Kambani/Kanana Kimalindi	Apple Kimalindi Ntwishe Kambani/Kanana Kisoge	Gonja Mshale Mzuzu Mkono wa tembo

Source: Diversity distribution and selection criteria of Musa germplasm in Uganda; participatory rural appraisal on the role of bananas in farming systems in Rwanda, 2000 and marketing survey of banana opportunities 2002; Evaluating the market opportunities for banana and its products in Tanzania, 2000; discussions with respondents during the field visit; DG-IRAZ in Burundi.

Characteristics for preferred varieties

The characteristics for preferred varieties are more or less the same with small differences based on the types of banana in question. For example brewing bananas should have a lot of juice and should be sweet, while dessert bananas should have longer shelf life, for example Gros Michel, and uniform yellow colour when ripe. The common characteristics of preferred bananas are listed below.

- Big bunches and long fingers.
- Colour and taste of cooking banana, for example yellow cooked banana is the most preferred in Uganda.
- Sweet taste and smooth texture.
- Long shelf life, for example Gros Michel
- Uniform ripening with yellowish colour for dessert bananas.
- Drought tolerance.
- Soil fertility tolerance.

- Pest and disease resistance.
- Marketability of the banana.
- Juice quantity and quality and sugar content for brewing bananas.
- Wind resistance.
- Maturity (early).
- Multipurpose (cooking, dessert and brewing).

Based on the above characteristics, AATF and partners must ensure that the preferred banana characteristics are retained during the development of the GM banana.

Main banana uses

Uganda

Bananas have traditionally been a major source of food and income from the sale of fresh bananas as well as various banana products. Banana beer is used for sale, domestic consumption and during cultural functions such as marriages and funerals. Banana leaves are sold or used domestically for covering food while cooking and some dishes are cooked wrapped in banana leaves. Banana fibres are used to make handicrafts and ropes for tethering animals and banana peels from all types of bananas are used as charcoal, livestock feed, salt and composite.

Bananas also have a variety of cultural values as enumerated by the officials of the Farmers Federation in Kampala and District Farmers Association Mukono. The cultural values include the following.

- Attachment of the Baganda to the banana resulted from the fact that the original Kabaka's wife came with a sucker of banana for food.
- In Palisa district, culturally dead bodies are washed on the leaves of Nakabururu variety of bananas.
- During dowry negotiations the groom is required to provide his prospective in-laws with banana beer.
- Brides return to their home after the honeymoon, and bring back a banana bunch and live chicken as an appreciation of her new husband.
- Pseudo stem juice is used to clean hands during burial ceremonies.
- After the burial of a man, a gourd of banana beer is given to the man who inherits the widow and once that is done no one else will approach her.
- Banana leaves are used for burying dead bodies.
- The cleaning of the dead body before burial is done with banana stem juice.

Some uses of various types of bananas in Uganda are shown in Table 4.

One of the consequences of the BBW has been significant changes in types of bananas produced and in uses of some types of banana witnessed between 2001 and 2004 (Aliguma and Karamura, 2006). There is a reduction in the number of households growing Kivuru, Mbidde, Ndiizi, Gros Michel and Gonja and there are changes in the use of bananas and banana products in about 90% of the households. There has been a reduction in the quantity of beverages with households growing Kayinja while Kivuru is no longer used for wine preparation but is eaten as food. More Mbidde is being eaten than brewed while fewer leaves from Kayinja plants are sold. There has been a reduction in contributions in terms of food, beer and juice to social functions such as weddings and funerals. No substantial changes were observed in the use of bananas as mulch, feed for livestock and material to make animal structures. It was also noted that majority of respondents in the study stopped eating bananas while others reduced the quantities consumed.

Table 4. Some traditional uses of various varieties of banana in Mukono District

Type	Uses
Matooke	Food, livestock feed, salt, cooking, leaves for funerals and fibre
Kahinja	Juice, brewing, fibre
Kivuru	Food, brewing, fibre
Mbidde	Juice, brewing, food during famine, fibre
Ndiizi/apple	Fruit, cakes, fibre
Bogoya (Gros Michel)	Fruit, food, fibre for roofing
Gonja	Food (cooked and roasted), juice, fibre
Kisubi	Juice, leaves, brewing, fibre

Source: Lucy Aliguma and E Karamura, 2006)

Kenya

Banana is mainly used as food, fruit, and a source of income. However, other uses include the following.

- Male flower buds of all bananas are used as a vegetable.
- Juice and jam are made from the dessert bananas.
- Handicrafts such as lampshades, hats, handbags and wall hangings are made out of banana fibre.
- In some communities, banana leaves are used for wrapping food while cooking and for keeping food warm.
- Banana is made into chips, dried and then milled into flour which is used to make cakes and bread.
- Bananas are also fried into chips which are sold commercially.
- Banana peels are used for livestock feed and salt.
- Banana leaves and stems are used as livestock feed.
- In western Kenya, a banana stem is buried instead of the body of a lost person.

Information collected from the Horticultural Research Station, Thika and Highridge Banana Farmers Marketing Association (HBMFA) indicated that bananas have different cultural uses in different communities. Some of the uses are: Mutahato traditional variety is used as medicine or weaning foods for children (*ndigu ya mwana*). The groom also sends it to the in-laws as a sign of marriage. Other traditional varieties used for marriage are muraru and mutore. Planting of bananas on the way and entrance is a sign of good respect and welcome to the visitor during weddings and other social functions. Uses of various banana varieties as indicated for the traditional varieties above are as follows.

Table 5. Uses of various varieties of bananas in Kenya

Variety	Uses
Grandnine/Williams/Valerie and Uganda green.	Fruit, food, fibre, good for processing into flour and stems are used for livestock feed
Kampala/Gros Michel	Fruit, food, fibre, leaves, stems for livestock feed
Giant Cavedish, Chinese Cavendish	Fruit, food, fibre, leaves and stem for livestock feed
Ng'ombe	Food, fruit, fibre, leaves for livestock feed, peels are dried and made into ash which used as traditional salt and livestock feed
Nusu ng'ombe	Food, fruit, fibre, processing and leaves and stems for livestock feed, peels as livestock feed
Mutahato	Fibres used as indicators (signs) to the venue of weddings, weaning food, fruit, stems and leaves used for livestock feed
Muraru	Fibres used as indicators (signs) to the venue of weddings, food, fruit, stems and leaves used for livestock feed
Mutore	Fibres used as indicators (signs) to the venue of weddings, food, fruit, stems and leaves used for livestock feed

Source: HBFMA/KARI, Thika

Tanzania

Banana is an important food and cash crop in the Kagera region around Lake Victoria, north eastern (Kilimanjaro), and southern highlands (Mbeya) of Tanzania. Cooking bananas are prominent along the Lake Zone, north and southern highlands, while dessert bananas are more prominent in eastern Tanzania and Zanzibar (Nkuba, JM et al, 2002).

In Arusha, apart from using bananas as food, fruit and a source of income, the bananas are also used for making wine by the Banana Investment Company based in Arusha. It uses all types of bananas – cooking, beer and dessert. Uses by various varieties in Arusha area are indicated in Table 6.

BBW has not been noticed in Arusha thus its impact is not yet felt. There are also limited diseases due to the altitude and the cold spell in Arusha area. In Kagera region where the disease was reported in May 2006, changes in livelihoods are beginning to take shape as infected fields are cleared. Farmers are pondering on alternative sources of food and income. Maize and sorghum are being considered as the main replacement for cleared banana fields.

Table 6. Uses of various varieties of bananas in Arusha

Variety	Uses
Mshale	Food (cooking and roasting), fruit, fibre, stem for livestock feed, leaves for wrapping food, making of wine
Ng'ombe	Food, fruit, fibre, leaves for different uses, stem as livestock feed, making of wine and banana flour.
Kimalindi	Fruit, making of wine, food, fibre, leaves and stems as livestock feed, and leaves for different purposes, banana flour
Williams and grandnine	Fruit, food, fibre, making of wine, leaves and stem as livestock feed and banana flour
Apple banana	Fruit, making of wine, flour for making cakes, leaves and stems as livestock feed, fibre
Mkono ya tembo	Food (roasting), fibre, making of wine, leaves and stem for livestock feed
Mkonosi mususu	Food (roasting), fibre, leaves and stem for livestock feed
Kibungara	Beer making, fibre, leaves and stem used as livestock feed

Source: Nkuba JM et al (2002). Evaluating the market opportunities for bananas and its products in Tanzania; Discussions with key informants during the field survey

Winnie Bashagi (2006) in her Kagera Trip Report summarised the uses of bananas for dessert, cooking, brewing and roasting bananas as follows.

- It is food and fruit and, in addition, the male buds are used as stoppers.
- Juice extract prepared from the tender core of the banana stem is used to treat kidney stones and in massage.
- The leaves of the bananas are used in many ways: as umbrellas, thatching houses; for wrapping food during cooking as bowl covers; table cloths, as temporary mats; covering earth ovens to hold in the heat; food can be wrapped and stemmed in banana leaves (food is boiled wrapped and tied inside the leaf; and frequently as disposable 'biological plates'.
- Banana chips produced from fried banana slices.
- Banana juice extracted from the corm and sometimes burnt into ashes and used as home remedy for the treatment of pimples and other skin diseases. Other people reported that honey is mixed with mashed banana fruit and used as treatment.
- In the past, some people smoked dried skin of banana peels believing that it is hallucinogenic and reduces depression.
- In western Kenya the dried peels are made into ash which is used as an indigenous salt.

- Bananas are used in alcohol production. The juice from the ripe fruit of the sweet varieties is drunk fresh or fermented to make local beer either with low alcohol or potent gin-like spirit.
- Banana fibre has numerous uses including: textile manufacture; making of ropes, string and thread; production of various handicrafts including mats, handbags, table mats, lampshades and hats.
- Bananas are used as an animal feed – leaves and stems are chopped and fed to cattle and pigs.

Rwanda

Rwanda like other countries in the Great Lakes region uses bananas for food (cooking and roasting), brewing, dessert and as a source of income. Banana beer is used locally both as a general drink especially in cultural functions such as weddings and funerals. Leaves are used to cover food while cooking. Fibres are used to make handicrafts and ropes for tethering animals. Banana peels from all types of bananas are used as charcoal, livestock feed, salt and composite.

Brewing bananas (genome groups AAA-EA and ABB) are the most widely grown and important cash crop in Cyangugu, Kigali Rural and Kivu Lake Border regions, while cooking banana (AAA-EA) is the most important staple and cash earner in Kibungo (Okech et al, 2005). The brewing bananas are mainly grown as cash crops while the cooking bananas have more household food security significance in Rwanda.

Interviews with farmers in the Lake Kivu area confirmed that brewing banana is the most important cash crop in the area and plays the dual role of income generation and assuring food security to the rural community. This important source of income is being threatened by the emergence of BBW in the area. Uses of various varieties of bananas are as indicated in Table 7.

The emergency of BBW in Gisenyi is changing livelihoods, with affected farmers looking for alternative sources of income and food. Those with cleared gardens have replanted with sweet potato or allowed them to lie fallow as a control measure for the disease.

Not much data exists for Burundi. However, the uses of bananas could be the same as for Rwanda.

Constraints to banana production

Banana production is affected by both biotic and abiotic constraints. Biotic constraints include diseases and pests, while the abiotic ones relate to soil, land availability, agronomic practices, marketing and transportation.

Table 7. Uses of various banana varieties in Rwanda

Variety	Uses
Barrabeshya	Food (frying, roasting, boiling, steaming), fruit, processing into flour, mixing in wine production, drying for storage later boiled and used, use of leaves and fibre
Injagi	Food, processing into flour, mixing in wine production, drying for storage later boiled and used, use of leaves and fibre
Incakara	Food, mixed with others to make wine, processed into flour, dried and used later, use of leaves and fibre
Ingaju Icyerwa	Food, mixed to make wine, processed into flour, dried and used later, use of leaves and fibre
Ingumba and Intutsi	Food, mixed to make wine processed into flour, dried and used later through boiling, use of leaves and fibre
Mazizi	Beer making, juice production, fruit, use of leaves and fibre
Umakara	Beer and juice making, fruit, processed into flour, use of leaves and fibre
Intutitu	Beer and juice making, fruit, use of leaves and fibre, processing into flour
Pisang Awak (Kayinja/ Gisubi)	Beer and juice making, use of leaves and fibre
Kamara masenge (Apple banana)	Fruit, brewing, cooking, fibre, use of leaves
Gros Mickel (Bogoya)	Fruit, fibre, use of leaves and stems
Poyo (Cavendish)	Fruit, food, fibre, use of leaves

Source: Various banana reports and discussions with key informants during the field survey

The disease constraints that affect banana production in the region include the following.

- *Panama disease* or *Fusarium* wilt is a soil fungus. The fungus enters the plants through the roots and moves up with water into the trunk and leaves, producing gels and gums. These block and cut off the flow of water and nutrients, causing the plant to wilt. Before 1960 almost all commercial banana production centred on the cultivar Gros Michel, which was highly susceptible to *Fusarium* wilt. The cultivar Cavendish was chosen as a replacement for Gros Michel because out of the resistant cultivars it was viewed as producing the highest quality fruit. A second race of Panama disease (Tropical Race 4-TR4) is a reinvigorated strain of Panama disease and was first discovered in 1992. This is a virulent form of *Fusarium* wilt that has wiped out Cavendish in several southeast Asian countries. The Cavendish cultivar is highly susceptible to TR4, and over time, Cavendish is almost certain to be eliminated from commercial production by this disease. Unfortunately TR4 is currently resistant to all known fungicides; the only known defense is genetic resistance.
- *Black Sigatoka* is a fungal leaf spot disease first observed in Fiji in 1963. Black Sigatoka (also known as black leaf streak) has spread to banana plantations

throughout the tropics due to infected banana leaves being used as packing material. It affects all the main cultivars of bananas and plantains, impeding photosynthesis by turning parts of their leaves black, and eventually killing the entire leaf. Being starved for energy, fruit production falls by 50% or more, and the bananas that do grow suffer premature ripening, making them unsuitable for export. Several resistant cultivars of banana have been developed, but none has yet received wide scale commercial acceptance due to taste and texture issues.

- *Banana Bunchy Top Virus (BBTV)* is spread from plant to plant by aphids. It causes stunting of the leaves resulting in a 'bunched' appearance. Generally, a banana plant infected with the virus will not set fruit, although mild strains exist in many areas which do allow for some fruit production. These mild strains are often mistaken for malnourishment, or a disease other than BBTV. There is no cure for BBTV. However its effect can be minimised by planting only tissue cultured plants (*in vitro* propagation), controlling the aphids, and immediately removing and destroying any plant from the field that shows signs of the disease.
- *Cigar end rot* was reported in the same areas with BBW in Rwanda. The disease affects the end of the banana fingers causing them to rot.
- *Banana Bacterial Wilt* is a new and more vigourous disease.

The main pests affecting banana production in Uganda include banana weevil (which affects about 40% of the banana crop) and nematodes. In terms of diseases the main ones include black Sigatoka (50%), BBW (up to 100%), *Fusarium* wilt (40%) and banana streak (25%).

In Tanzania, the main constraints to banana production include banana weevils, *Fusarium* wilt and BBW[2].

In Rwanda, there has been a decline in banana production due to several factors, which include poor agronomy, declining soil fertility, pests and diseases, drought, wind and changes in the socio-economic environment. The main pests and diseases affecting banana production in Rwanda include weevils which affect cooking bananas and *Fusarium* wilt which affects the brewing type of bananas (Ferris S et al, 2002). BBW was reported in the northern part of Rwanda in early 2006 and is said to be the most devastating disease in the region. Another disease is the cigar end rot.

In Kenya, *Fusarium* wilt has so far been mentioned as the main disease and is said to have wiped out one of the most popular banana varieties (Kampala) in central Kenya. Other diseases include cigar end rot and Sigatoka. The main pests include banana weevils and nematodes. BBW has just been reported in western Kenya and its actual

2 At the time of the study BBW was only reported in the Lake Zone region in the districts of Muleba, Karagwe, Bukoba and Biharamulo. The disease was first reported in Biharamulo district in May 2006. It is said to have come from Uganda through contaminated male buds used to cap banana brew jerry cans.

impact is yet to be determined. Farmers also face a challenge of getting clean/disease-free planting material. The agronomic practices are also very poor (lack of pruning, limited or no application of fertilisers or manure, and poor soils).

The main banana production constraints include diseases and pests. The importance of diseases and pests in the surveyed areas in each country are presented in Table 8.

Table 8. Frequency of banana disease and pest incidence

Country	BBW	Weevils	Cigar end rot	Nematodes	Sigatoka	*Fusarium* wilt
Kenya (*western*)	74	12	2	6		
Rwanda	76.6	3.3	53.3			
Uganda	98				12	16
Tanzania (*LZ*)	100	10	0	0	18	92
Tanzania (*Arusha*)	0	30	1.8	0	0	

Source: Survey results

Table 9. Incidences of pests and diseases per country

Country	Pests and diseases
Kenya	Banana weevils, nematodes, panama, Sigatoka, bunch top, cigar end rot and BBW in Teso/Malakisi in Western Province.
Uganda	Banana weevils, nematodes, panama, Sigatoka and BBW widespread in the country.
Rwanda	Banana weevils, nematodes, panama, Sigatoka, cigar end rot, banana streak virus and BBW in Gisyenyi and now moving towards Kigali.
Tanzania	Banana weevils, nematodes, panama, Sigatoka, cigar end rot and BBW mainly in Kagera region.
Burundi	Pests were not mentioned, however panama, Sigatoka and bunch top virus were indicated by IRAZ. No survey has been done for BBW.

Source: Respondents and various study reports – Uganda, Rwanda and Tanzania

Control methods for banana pests and diseases

Banana weevils

Banana weevil damage results from larvae feeding and tunnelling into banana corms and pseudo stems. For the control of banana weevils farmers are advised to: use clean planting materials; paring of corms at planting; destruction of post harvest residues; trapping of adult weevils and killing them; good crop husbandry such as weeding, de-suckering, pruning, manuring and mulching to produce vigorous plants (Spilsbury, J et al, 2002). Farmers use ash in some cases as part of their indigenous knowledge in the control of weevils. In Kenya losses due to weevils are estimated up to 50% (Matin Qaim, 1999).

Nematodes

Nematodes are very small worms that cannot be seen with the naked eyes. They live and feed inside roots and corms thus destroying them. A root or corm damaged by nematodes shows reddish purple lesions or patches when split or peeled (Winnie Bashagi, 2006). Nematodes are an important banana production constraint worldwide. They are less easily recognised than weevils, the latter of which are sometimes incorrectly blamed by farmers for nematode damage. The cultural control of nematodes includes: crop rotation, use of clean planting materials – removal of roots and outer layer of the corm or blanching into hot water (55^{o}C) before planting; and soil amendment through weeding and manuring. The development of nematode resistant banana cultivars is a priority objective of the Uganda banana-breeding project (Spilsbury J et al, 2002).

Farmers' indigenous knowledge for control of nematodes include: the use of natural repellents planted in the banana orchards and trees which attract nematodes but make them sterile (discussions with officials of Uganda National Farmers Federation (UNFF)). Hence it could be useful to investigate this further since it provides good alternatives for the control of nematodes.

*Panama (*Fusarium *wilt)*

Panama (*Fusarium* wilt) disease is caused by a soil fungus and it enters the plants through the roots and moves up with water into the trunk and leaves, producing gels and gums. These plug and cut off the flow of water and nutrients causing the plant to wilt. The spread of the disease is through boots, clothing and tools if the farmer moves from one plantation to the other. It is worse when traders are allowed to harvest bananas from one farm to another.

Fusarium wilt is prevalent on introduced banana cultivars that are used primarily as dessert banana, for example Gros Michel, sweet banana and beer bananas such as kayinja. To avoid this disease, the susceptible varieties can be replaced with resistant cavendish varieties. Symptoms of the disease have been observed on endemic AAA highland banana cultivars, which were previously considered to be resistant to the disease. Wilt of highland cultivars was observed at altitudes greater than 1,300m above sea level, and mainly within 30m of homesteads (Spilsbury J et al, 2002).

Cultural control of this disease includes: sanitary practices and use of pathogen-free planting material. Development of resistant cultivars and widespread implementation of appropriate management strategies are highly recommended.

Black Sigatoka

Black Sigatoka is common in plantations in wetlands especially around Lake Victoria. It affects all of the main cultivars of bananas and plantains impeding photosynthesis by turning parts of their leaves black and eventually killing the entire leaf. Being starved for energy fruit production can fall by 50% or more and the bananas that grow suffer premature ripening, making them unsuitable for marketing (Winnie Bishagi, 2006).

The disease is an air borne fungal and causes incomplete fruit filling. It is sensitive to altitude and temperature hence it's absent at elevations above 1,450m and where mean minimum temperatures exceed 15°C (Spilsbury J et al, 2002).

The best cultural control is good crop husbandry as it leads to a more vigourous plant that can outgrow the attack. Development of resistant cultivars by the Banana Programme in Uganda has resulted in a GM cultivar awaiting controlled testing.

The cultural controls described above are more for small subsistence or backyard planting. Commercial banana farms apply inorganic inputs such as chemicals for the pests and diseases.

Cigar end rot

Farmers in Gisyenyi, Rwanda have devised ways of controlling the disease by tying the male bud at an early stage. According to what farmers and scientists say the method is effective. The problem could be reduced if the spacing was widened to reduce congestion.

Banana *Xanthomonas campestris* pv *musacearum* Wilt Disease

Banana Bacterial Wilt (BBW) is caused by *Xanthomonas campestris* pv *musaceareum* which resembles isolates from *ensete* wilt. The disease was first noticed in Mukono in the year 2001. The disease is spread mainly by insects and also by use of infected tools. Ratoon crops arising from infected mats are severely diseased and often wilt before producing bunches or produce bunches with rotten fruits. Once established in a locality, the disease can spread rapidly (up to 70 km per year) and is difficult to eradicate thereafter. Without proper management, yields in affected areas are reduced to virtually zero.

BBW symptoms

The consultants obtained information from documents in the affected countries of the Great Lakes region. This was augmented with discussions with scientists, farmer organisations and extension agents. The consolidated information from these sources indicated that the symptoms of the BBW were: folding, yellowing and breaking or drooping of leaves; premature and uneven ripening of the fruit; shrinking or wilting of the bracts of the male bud sometimes could rot but stay on the plant (in some cases it could drop); the oozing of a yellowish substance from the stem when cut, blackening or staining of the fruit pulp; stony fruit; and the fingers sometimes rot on the stalk. The affected fruits cannot be used by humans or livestock and the affected stools do not always die, new suckers emerge looking health but usually become infected from the mother plant rarely reaching the flowering stage (Lucy Aliguma and Karamura, 2006).

The first symptoms of BBW include discolouration at the tip of the flower and withering of the flower bracts. This suggests the bacterium may be air or insect borne. Rain droplets and movement of planting material may also contribute to transmitting the infection.

Other symptoms include yellowing, wilting and premature ripening in young plants. When the banana is cut, a pink-purple colouration confirms presence of the disease. Even in some cases where these other symptoms fail to show, the colouration is always seen. The plant dies within a month from the first appearance of any of the symptoms.

The studies carried out in Uganda have shown that *Xanthomonas* wilt seems to indiscriminately and aggressively attack many of the varieties of banana. It affects both highland and exotic (dessert/beer) bananas. However, the effects are more on kayinja, kavuvu and ndiizi varieties. These are mainly grown in Mukono and Kayunga districts where BBW was first reported.

The disease can easily be confused with *Xanthomonas axonopodis*. Furthermore in an infected area it is necessary to find out if all the isolates are *Xanthomonas campestris pv musacearum*. Disease isolates were collected from Uganda, Rwanda, DRC, Kenya and Tanzania and sent to CABI Bioscience, in the United Kingdom, for analysis. Both fatty acid analysis and Biolog tests confirmed the presence of *Xanthomonas campestris*. Further analysis with rep-PCR using ERIC and BOX primers confirmed the presence of *Xanthomonas campestris* pv *musacearum* in all isolates. The bacterium is known to cause wilt of *ensente*, a variety of bananas found in Ethiopia. Thus, a link has been established between the diseases in the two countries. As yet, though, little is known about the bacterium. Therefore, the main control method for the disease is to burn the infected crops. In conclusion, at present there is only one strain of BBW in eastern Africa.

Spread of BBW disease

BBW was first reported in 2001 in Mukono district, Uganda (Lucy Aliguma and E Karamura, 2006) and has since spread to 33 districts in the central, eastern and western regions (Figure 2). The disease has also been reported in the Democratic Republic of Congo, Rwanda and more recently has been identified in Tanzania and Kenya.

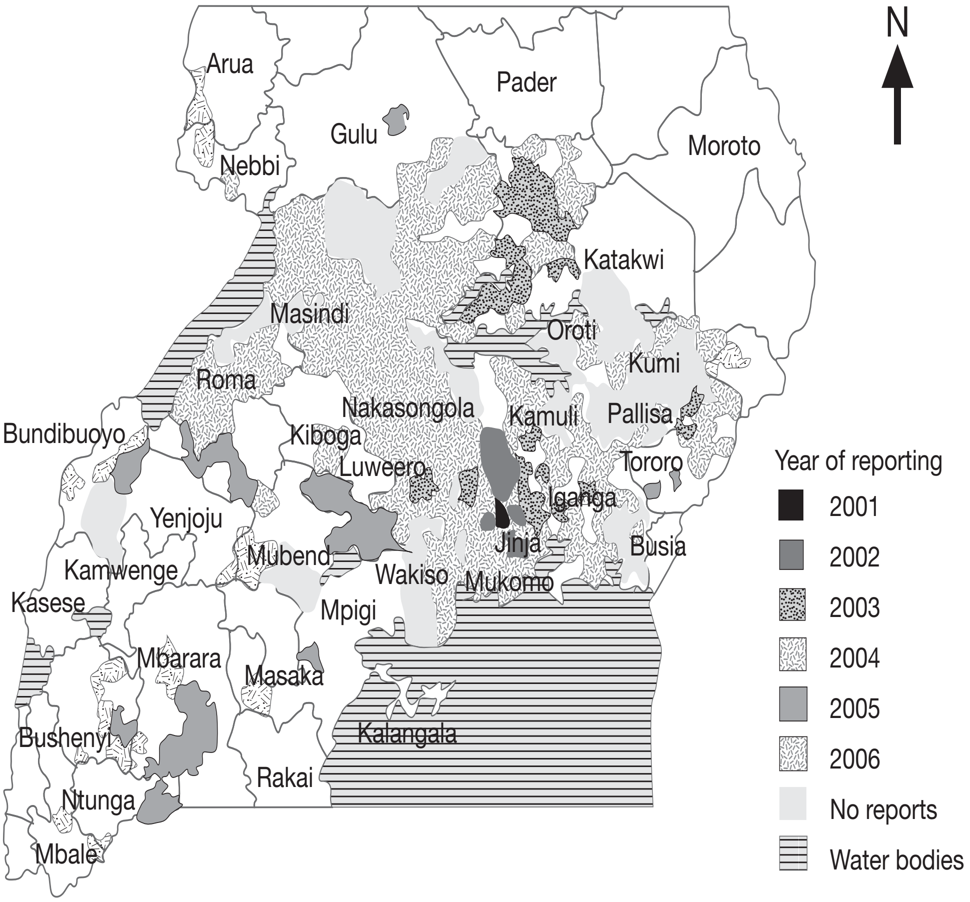

Figure 2: *Distribution of BBW by sub-county in Uganda as of June 2006*
Source: National Banana Programme, Kawanda Agricultural Research Institute

In Tanzania, BBW has been reported in the Kagera region (Figure 3). It was first observed by farmers in Biharamulo in 2003, Karagwe in 2005, and Muleba and Bukoba districts in 2006. As in Rwanda and Uganda, farmers did not report the disease until a public campaign by the Ministry of Agriculture, Food Security and Cooperatives was put in place asking farmers to report any symptoms of the disease. After cases were reported by farmers, the ministry undertook a rapid survey in May 2006 in the affected region and 517 households were found to be affected by the disease.

By May 2006, 41,933 affected banana mats had been uprooted in Muleba district alone. Other districts in which uprooted mats were reported are Bukoba (81), Karagwe (93) and Biharamulo (20).

The disease has been reported as follows in the Great Lakes region:

- In Uganda, it was first reported in 2001 in Mukono, spread to Kayunga and other central Uganda districts. It has now been reported in the main banana growing areas in the south western region.
- In Tanzania, it was first reported in May 2006, but farmers said they first noticed the problem in 2003. It is believed to have originated from Uganda. It has only been reported in the western region of Kagera. The national programme is unsure of whether it is present in other parts of the country. A campaign is under way to establish if the disease is also present in other areas of the country.
- In Kenya the disease was first identified by a joint team of CRS/IITA/KARI working under the C3P project in September 2006 in Teso (Amagoro and Chakol divisions) and in Bungoma in Malakisi (one field). It is said to be widespread in Teso. Farmers said they only noticed it in April 2006, while others said they had noticed it as early as 2005. There is high likelihood that the disease originated in Uganda as the divisions are located along the highway from Uganda through Malaba.
- In Rwanda, the problem has been identified in Gisenyi area along the DRC border. Despite efforts to control it, it has continued to spread.
- Burundi has not yet reported the disease. The C3P project being implemented by IITA and CRS in the region should be able to determine if the problem exists in Burundi.

BBW control measures

BBW has posed a major challenge to governments, researchers, farmers and development agencies as there is no effective method of control yet. In Uganda, the government has set aside resources to develop and execute control measures focusing on raising awareness about the disease in local communities and disseminating information on how to control it. To do this, the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) constituted a task force to formulate both short and long term strategies and action plans to respond to the disease while at the same time involving research and development activities emphasising continuous monitoring, generation

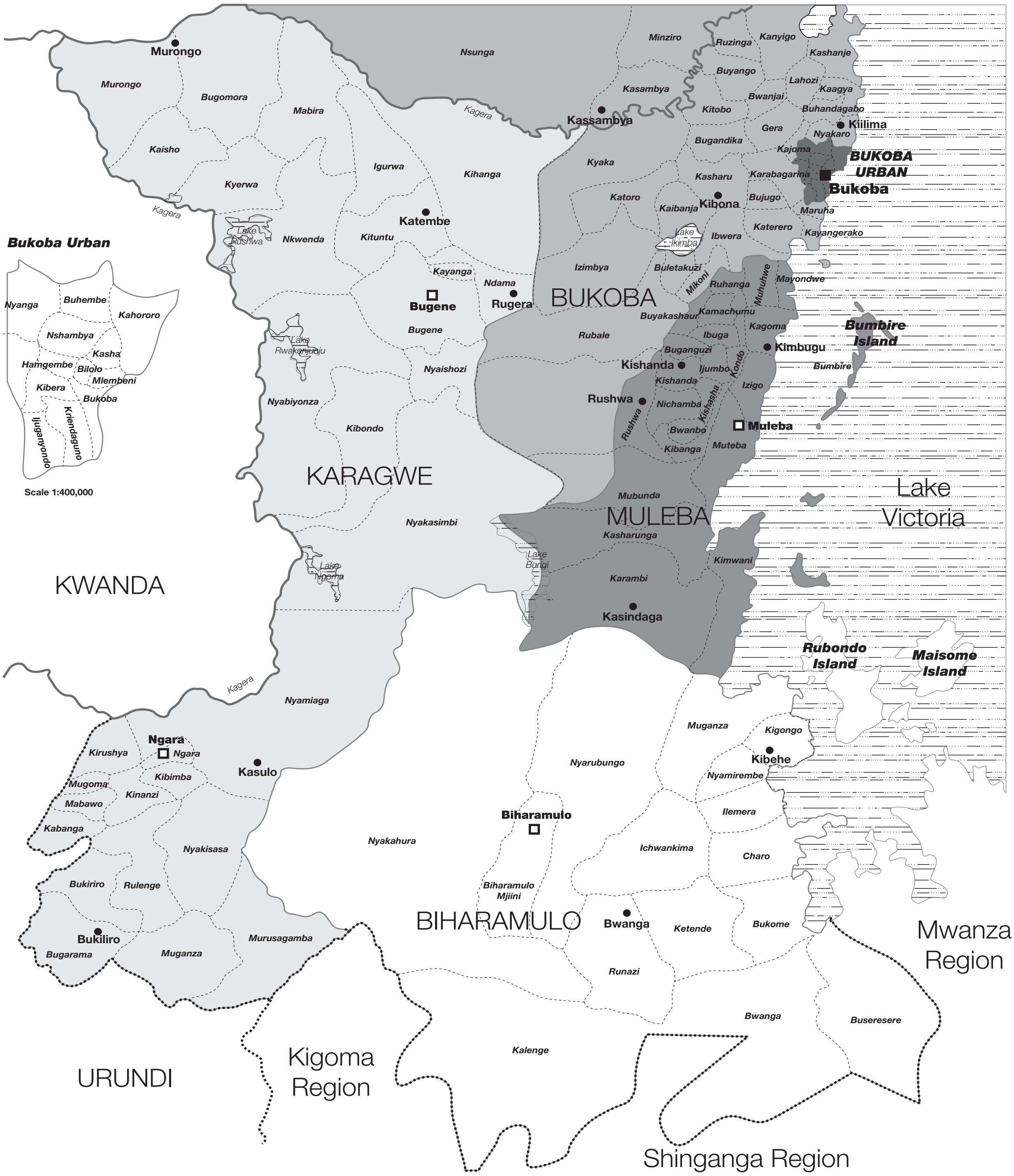

Figure 3: *The map of Kagera region showing BBW affected areas*
Source: Maruku Agricultural Research and Development Institute, Bukoba

and dissemination of information and empowering of stakeholders to control the disease. For the short term measure a BBW working group is in place and comprises representatives from MAAIF, National Agricultural Research Organisation (NARO), National Agricultural Advisory Services (NAADS), Agricultural Sector Programme Support (ASPS), Agricultural Productivity Enhancement Programme (APEP), ECOTRUS and USAID. The group aims to create a rapid response to the disease while research is gearing up on long term solutions. The overall objective of the campaign is to raise awareness on how to recognise the disease and on the spread and control.

There is a campaign to promote control of BBW through rigorous debudding, early removal of diseased plants and cleaning of farm tools to reduce new infections and limit the spread of the disease. Through the effort of the working group, the following recommendations have been passed on to extension staff to work with farmers to control the disease[3].

- Cutting down the affected plants and suckers and uprooting the corms to avoid further sprouting.
- The cut plants/suckers and uprooted corms should be buried within the plantation or burned. In some cases farmers are advised to place the leaves on the ground and pile the stems/suckers, roots and fruits on top and cover them with soil so that they rot. This reduces the labour of digging a hole.
- No plant should be removed from the plantation.
- Routinely breaking all the male buds off plants using a forked wooden stick or hand as soon as the fruits have formed. This may reduce the spread of the disease by insects. Metallic tools should not be used from one plant to another unless it is disinfected.
- Family members, traders and labourers should disinfect their tools before harvesting bananas.
- Keeping livestock out of the banana plantations as their feet might spread the disease.

Other measures being implemented include the following.

- Peeling the bananas on-farm before transporting them to the ceremony for cooking. This reduces the spread.
- Not harvesting diseased plants.
- Banana leaves should not be allowed to leave infected fields.
- Applying a mixture of urine, ash and pepper or a mixture of cow and human urine with *Omwetango* leaves fermented for a week have been used by farmers but with no good results.

Debudding was reported to be the easiest control method, while cutting down plantations as well as uprooting and burying or burning infected plants from the infected mat was reported to be labour intensive (Lucy Aliguma and E Karamura, 2006). The practice therefore is being applied by few households in Mukono district in Uganda and Gisenyi in Rwanda. The application of indigenous knowledge and organic pesticides has failed to stop the spread of the disease. According to Aliguma and Karamura (2006) most farmers do not use the bleach solution since it is expensive and the use of fire was found to be cumbersome. It was also reported from the study that few households have received technical advice on how to control BBW.

3 Rwanda and Tanzania have replicated the control methods from Uganda.

The Mukono District Farmers Association together with NAADS has trained farmers on how to control the spread but both organisations are focused on their members. The Association even established farmer groups to help each other but this has not been effective (Mukono District Farmers Association and District NAADS office). Most of their efforts were concentrated on the provision of seeds for annuals to plant in areas where plantations were cut down. Several other organisations like APEP and NARO have also been involved but only to a small extent.

Therefore BBW is a real threat to the banana industry because all banana varieties are susceptible to the disease and if it is not given the attention it deserves, the industry in the Great Lakes region could collapse thus affecting households' food security and income. The prescribed cultural control measures have not stopped the spread or eliminated the spread of disease.

Figure 4. *A portion of banana field cleared to control BBW in Mukono District, Uganda*

Figure 5. *A banana plant infected with BBW in Mukono District, Uganda*

Knowledge and practice of control methods by a few farmers have had some impact in reducing the spread. However, total eradication of the disease has not been achieved in any of the affected areas. Figure 4 shows a field that has been cleared of bananas as a measure to control BBW in Mukono. The field was then replanted with tomatoes which have so far been harvested. Incidentally the disease resurfaced on the other side of the remaining banana field (*see* Figure 5 of infected banana taken on the opposite side of the field). This means the disease cannot be eliminated and clearing of whole plots expose some households to food insecurity and therefore a long term effort should be focused on developing genotypes with resistance to BBW through biotechnological and conventional methods. Developing of transgenic banana genotypes provides a good opportunity while scientists should continue to evaluate genotypes with capacity to escape the disease as an interim measure.

Despite the recommended control methods, the disease has been spreading in other parts of the country and even in the neighbouring countries. For example whereas in

2004 there was no report of BBW in southern Uganda, it was reported in a few places in the region in 2005 (Aliguma and Karamura, 2006) and, by June 2006, most of the areas had been affected by the disease (Figure 2). This means that even though the cultural approach is slowing the spread of the disease, it is far from eradicating it. There is therefore need for long term effective measures for controlling the disease.

Losses associated with BBW

There is no doubt that BBW is the most devastating disease to hit banana production in the Greater Lakes region. In areas where it was reported five years ago, it has changed crop production patterns, income sources and means of livelihoods. In Mukono and Kayunga districts, for example it was shown that banana production for certain varieties declined by between 80% and 100%, with the most affected being gonja, kayinja and ndiizi. Volumes of traded bananas in the region had also reduced by up to 75% (Karamura, 2006). There has also been change in importance of crops grown with maize and beans becoming more important. Between 2001 and 2004, the area under banana in Mukono and Kayunga declined from 52% to 26% and from 54% to 35%, respectively. Banana is an important crop for brewing in Uganda and the most important varieties for brewing are the most affected by BBW; in the two districts of Mukono and Kayunga income from brewing activities declined by 95% between 2001 and 2004.

Overall, the banana programme in Uganda estimates that bananas valued at over US$ 35 million were lost due to BBW in 2005 alone. This is despite a heavy campaign to control the spread and effects of the disease in the country.

The economic costs of the disease include labour used in debudding and removal of affected plants, and value of affected plants.

In Rwanda, BBW was reported in early 2006 after a public campaign to raise awareness on the disease. It is estimated that 800,000 people are currently affected by BBW in Rwanda. Whole orchards and affected stools have been cleared in the most affected parts of Gisenyi. This is a big loss in terms of incomes as most bananas in Gisenyi are used for brewing which is an important income source. Interviews conducted during this mission revealed that the disease was noticed as early as 2003 in Rubavu Nyamyumba District in Rwanda. Estimated costs of the disease in the survey areas in Rwanda include losses of up to 100% of the crop by single farmers. In monetary terms, individual farmers had lost up to RF 10,000 each. Costs of control of the disease ranged between RF 200 and RF 500 for debudding and RF 1,000 and RF 12,000 for uprooting. The overall loss is estimated at US$ 500,000 in Gisenyi region in Rwanda.

In the Kagera region in Tanzania, large areas have been cleared of banana crop as a measure to control the effects and spread of BBW. Farmers in this area lamented that they had to uproot their only source of livelihood (food and cash) and felt extremely vulnerable to food insecurity. In Tanzania, the losses are estimated at US$ 350,000.

Research work on banana in eastern Africa

In the past, breeding efforts in banana have succeeded where one of the parents being used in the crossing is a diploid and produces viable pollen. But even then seed set is normally very poor. Hybridisation of banana however began in the Honduras in the 1920s by the Fundación Hondureña de Investigación Agrícola (FHIA) and resulted in the development of FHIA varieties resistant to *Fusarium oxysporum f. cubanse* or the Panama disease. In east Africa, Uganda has been the only country that has had a functional conventional breeding programme which was initiated in the 1990s. The aim has been to produce varieties resistant to black Sigatoka, *Fusarium* wilt, banana weevil and nematodes. Crosses have been made between local diploid varieties and introduced germplasm such as calcutta. Since most high yielding highland bananas are sterile, improvement through conventional means is difficult. Efforts are being made to incorporate disease resistance in the east African highland bananas through genetic engineering methods. During the last three to four years cell suspension culture methods have been optimised for a wide range of varieties.

Banana research work in the region is very limited. Only Uganda and Tanzania have banana research programmes within their national research programmes. The Uganda banana research programme is the most advanced in the region, with activities including biotechnology work.

One of ASARECA's networks (BARNESA) is supporting networking research initiatives in the region and provides a vital link between national banana programmes and the international centres such as INIBAP and IPGRI for acquisition of genetic material. IITA is also involved in research work on bananas in the area of farming systems, diseases and pest control, and marketing research.

The Uganda banana programme has been working on development of a Sigatoka disease resistant variety using genetic approaches and has succeeded in developing a resistant variety which is awaiting contained field trial at Kawanda.

Why transformation

- The banana plant has long generation periods; conventional breeding takes long to produce hybrids, genetic engineering will shorten the period required to breed for disease resistance.
- Various ploidy levels existing among cultivars, that is AAA, AA, ABB and AB, makes introduction of exotic traits through conventional breeding difficult.
- Most east African highland bananas are triploids and therefore sterile.
- No variety has so far been identified as being resistant to BBW; all banana varieties are susceptible.
- The negligible degree of out-crossing between banana varieties makes gene flow inconsequential.

Transformation protocols

The proposed *Agrobacterium* mediated transformation

Agrobacterium tumefaciens is a soil borne bacterium that uses natural genetic engineering processes to subvert the host plant cell's metabolic machinery. It converts some of the host's organic carbon and nitrogen supplies to produce nutrients called opines which it metabolises (Tempe and Schell, 1977). Parasitised cells are induced to proliferate and results into crown gall tumour disease. The crown gall is a direct result of the incorporation into the host's genome of a region called the transfer DNA or T-DNA which is part of a large (150–250 kB) circular Ti (tumour inducing) plasmid, carried by *A. tumefaciens*. An understanding of this natural transformation process, together with the realisation that any foreign DNA placed between the T-DNA border sequences can be transferred to plant cells, led to the construction of the first vector and bacterial strain systems for plant transformation (Hooykaas and Shilperoort, 1992).

Since the first record on a transgenic tobacco plant expressing foreign genes (Fraley et al, 1983), great progress in understanding *Agrobacterium* mediated gene transfer at the molecular level has been achieved. *A. tumefaciens* naturally infects only dicotyledonous plants and methods for *Agrobacterium* mediated gene transfer into monocotyledonous plants have only recently been developed for rice (Hiei et al, 1994; Cheng et al, 1998), banana (May et al, 1995), maize (Ishida et al, 1996), wheat (Cheng et al, 1997), and sugarcane (Enríquez-Obregón 1997, 1998; Arencibia et al, 1998). A thorough analysis of the strategies for practical application of this methodology has been published (Birch, 1997).

Until 1995, it was generally assumed that the sequences between the left and right borders of the T-DNA were the only transgenic elements transferred to the recipient host. Ramanathan and Veluthambi (1995) and Kononov et al (1997) demonstrated that plasmid backbone sequences beyond the borders of the T-DNA could also be integrated along with the genes of interest. Experiments by Kononov et al (1997) demonstrated that plasmid backbone sequences could be integrated into the host genome coupled with either the right or left border sequences, or as an independent unit unlinked from the T-DNA. Matzke and Matzke (1998) state that backbone sequences that join T-DNA and host DNA appear to be especially deleterious for gene expression, an observation supported by the authors' finding that backbone fragments separated from T-DNA have been found associated with stably expressed transgenes.

Plants transformed independently with the same plasmid will commonly have different levels of expression, a phenomenon that is not always correlated with copy number (Gelvin, 1998). Instead, differential expression of transgenes has been attributed by some to 'positional effects' whereby the position of the T-DNA integration site in the host genome affects the level of transgene expression. However, other research has indicated that factors in addition to, or other than, the position of the site of integration contribute to the level of transgene expression (Gelvin, 1998). This is particularly true of the variable arrangements that transgene sequences may take in the host genome. T-DNA can integrate into the host genome in patterns other than as a single copy at a single site. Multiple copies in direct or inverted repeats and other complex patterns may occur. The presence of multimeric T-DNA inserts, especially inverted repeat structures, is strongly linked to the phenomenon of transgene silencing (Gelvin, 1998). Variable expression of transgenes or gene silencing is a ubiquitous phenomenon in transgenic plants whether produced by direct DNA uptake or *Agrobacterium* mediated transformation. Gene silencing can result from interactions between multiple copies of transgenes and related endogenous genes and is associated with homology-based mechanisms that act at either the transcriptional or post-transcriptional level (Matzke and Matzke, 1998).

Silencing that results from the impairment of transcription initiation is often associated with cytosine methylation and/or chromatin condensation (Fagard and Vaucheret, 2000), while post-transcriptional silencing (co-suppression) involves enhanced RNA turnover in the cytoplasm (Matzke and Matzke 1998). A third category of silencing has also been proposed for the consequences of positional effects where flanking plant DNA and/or unfavourable chromosomal location exert a silencing effect on the transgene (Matzke and Matzke, 1998). According to Matzke and Matzke (1998), this type of silencing reflects the epigenetic state of host sequences flanking the insertion site or the tolerance of particular chromosome regions to insertion of foreign DNA.

Agrobacterium transformation protocols for *Musa*

The genus *Musa* has in the past proved to be recalcitrant to transformation. In genetic engineering of crops, there are two methods commonly used for transformation; the microprojectile bombardment method or the *Agrobacterium tumefaciens* mediated transformation. Both methods have been developed for transformation of east African highland banana. In the genus *Musa*, Becker et al (2000) reported successful transformation using microprojectile bombardment of cell suspensions. But microprojectile transformation had its own problems. Only a few copies of the DNA carrying the genes of interest are inserted in the cells and there are plenty of rearrangements. *Agrobacterium tumefaciens* mediated transformation is the preferred method for many crops since it has several advantages over the bombardment method such as transferring only one or a few copies of the target genes at high efficiency and with minimum cost and transferring large fragments of DNA with minimum rearrangements. The first protocol to transform *Musa* was developed by Ganapathi et al (2001) using embryogenic cell suspensions. Use of cell suspensions is however lengthy, cultivar dependent and produces chimeras. May et al (1995) and Tripathi et al (2002) developed protocols for transforming *Musa* using shoot tips rather than cell suspensions. Protocols that use shoot tips are applicable to a wide range of banana cultivars irrespective of their ploidy levels and are not genotype dependent (Tripathi et al, 2003). These are the transformation systems that are currently being tested and optimised by Tripathi and the IITA group at NARO, Kawanda (Tripathi et al, 2004).

The following recommendations were made by scientists from Uganda, Rwanda and Tanzania about using genetic engineering (GE) to transfer BBW resistance to local bananas.

- The biology, including the epidemiology of the disease, should be studied.
- Other means of control, be they cultural, agronomic or use of biocontrol agents, should be evaluated before embarking on GE.
- Integrated pest management (IPM) should be given a chance before embarking on GE. IPM measures are likely to forestall the rate of resistance development.

From the preceding literature, the present proof-of-concept needs to address the following issues.

- Are the backbone sequences of the T-DNA borders likely to be integrated? What other DNA sequences are likely to be carried by the backbone DNA?
- Is the use of the two plasmids likely to influence gene expression?
- Where is the T-DNA likely to be integrated?
- Is T-DNA likely to be integrated as one or many copies, since this will affect expression?
- Is gene silencing likely to be an issue? This needs to established at the proof-of-concept level since it may be a very expensive undertaking if the expression is suppressed.

If the proof-of-concept establishes that gene silencing may be a problem, AATF and IITA need to evaluate the possibility of stopping the current transformation and consider other options (genes).

Progress on transformation of banana at IITA

Transformation work for BBW (Bcm) at NARO in Kawanda started in the year 2004 with the arrival of Dr Tripathi from IITA in Ibadan. Initial work used embryogenic cell suspensions as the explant. This according to Dr Tushemereirwe is the standard recommended method. Dr Tripathi and her group are developing a proof-of-concept for BBW (Bcm) using the meristematic tissue based transformation system. In this method, apical shoot tips have been transformed with binary vector pCambia 1201 having hygromycin gene as the selectable marker and GUS-INT as the reporter gene. The researchers have already acquired two plasmid constructs each having one of the proposed genes for transformation. The two constructs being used to test the proof-of-concept are 11kb and 13kb long and are under CaMV35S constitutive promoter with NOS terminators. Transient expression of the B-glucuronidase gene has been attained. Transformed explants have been regenerated in hygromycin and stable expression verified through GUS histochemical assay. Molecular analysis of the GUS gene has been confirmed through PCR and southern blot analysis. There are several issues worthy of consideration as follows.

- Is it possible to acquire a selectable marker that is not antibiotic instead of hygromycin?

- How about using plant based promoters instead of CaMV35S?
- Will meristematic tissues such as apical shoots present chimeras?
- Before proceeding on with the proof-of-concept, would it not be more useful to fully study the mode of transmission of BBW since this is not yet well understood?
- How many copies of the gene are likely to be inserted (are there chances of rearrangements and/or multiple insertions)?

On the first issue, antibiotic selectable markers such as hygromycin have raised a lot of human health concerns. Equally the use of CaMV35S promoter which is a virus promoter may raise concerns among civil society organisations.

The presence of chimeras normally presents technical challenges in the transformation process.

On the last issue, low copy number is an indication that the gene is stably inserted. Many gene copies imply that there are instability and gene rearrangements. These factors will influence gene expression. The number of copies is not in the control of the scientist during transformation. If the scientist finds that she/he has many copies of the gene then it is an indication that the gene is not stable.

Figure 6 presents a decision making tool for the transformation process for the transgenic banana. AATF needs to scout for other genes which can be used if the current genes under proof-of-concept do not work.

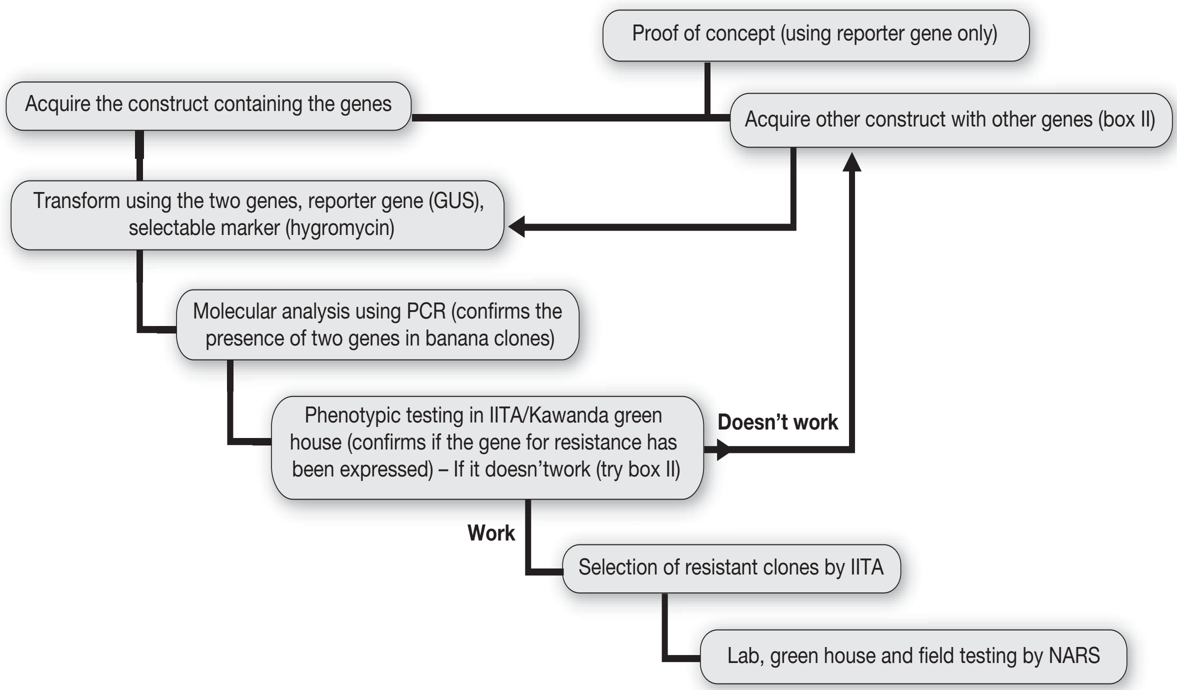

Figure 6. *Proposed decision making model for the banana transformation process*

Proposed genes for transformation from Academia Sinica

IITA and NARO in Kawanda have proposed to use *pflp* Ferodoxin-like ampipathic protein (*pflp*) isolated from sweet pepper (*Capsicum annum*) by Dr Feng of Academia Sinica in Taiwan (Huang et al, 2004; Feng, 2005; Ger et al, 2002). The ferrodoxin gene *pflp* is assisted by a second gene, *hrap* that confers hairpin-mediated hypersensitive response to dicots such as tobacco, tomato, potato, broccoli and orchids and to monocots such as rice. The ferrodoxin protein *pflp* depletes iron whereas the *hrap* protein triggers the hypersensitive reaction (Dayakar et al, 2002). Huang et al (2004) isolated and patented two proteins *Ap1* and *hrap* which in transgenic tobacco exhibits too many virulent pathogens. In rice, the genes have been shown to work efficiently against the *Xanthomonas* disease (Tang et al, 2001). Plasmid vectors having *pflp* and *hrap* and being driven by CaMV35S constitutive promoter have been constructed. There are plans at Academia Sinica to construct other plasmid vectors using plant-like promoters such as rubisco synthase, sucrose synthase and stilbene synthase (Feng, 2005).

It is important to find out if the crops carrying gene(s) have so far been commercialised in Taiwan or elsewhere in the world. If this is the case, then it is possible that the expressed resistance is durable and that environmental and human health concerns have been addressed. This minimises concerns that may be raised on the transgenic banana from these genes. The team has not been able to find evidence of commercialisation of the gene.

Target varieties for transformation

Research at the National Agricultural Research Organisation (NARO) in Kawanda has identified several varieties that represent the wide range of banana germplasm in Uganda for initial transformation. According to the head of the banana programme at NARO, varieties that may be transformed for BBW resistance include cooking, dessert and beer types. Cooking types consist of Mbwazirume and Kibuzi widely grown in the highlands, and Nakitembe grown in the lowlands. Other not very popular varieties include Kisansa and Mpologoma. Dessert type consist of ndiizi (apple banana), Gros Michel (Bogoya) and Kabana 3. Beer types include kayinja and kilometre-5. Due to the large number of banana varieties grown in Uganda and in east Africa in general, it appears prudent that transformation targets more than one genetic background. However, transforming many varieties for the same trait is likely to pose several problems.

- It is costly.
- It provides genetic uniformity that may contribute to vulnerability and susceptibility to the pathogen leading to breakdown of the resistance.

This report proposes that the issue of which types and varieties need transformation should be a national decision through consensus at the national programme in consultation with farmers, policy makers and other interested stakeholders.

Laboratory and human capacity for transformation work

Although laboratory and human resource capacity for transformation work exist in the region, they differ from country to country. Tables 10–15 summarise both the laboratory and human capacities currently in place in the various biotechnology laboratories in east Africa.

Kenya

Table 10 shows that the biotechnology laboratory of KARI is quite advanced and has staff, experience and equipment to conduct both molecular breeding and genetic transformation. In the past five years, the lab has had two transformation experiences, one with sweet potato together with Monsanto and the other one which is still ongoing on *Bt* maize together with CIMMYT with funding from Syngenta. This lab is the only one in the region with a functional biosafety greenhouse. Needless to say, Kenya is perhaps the only country among the five, with nearly government approved biosafety guidelines and regulations. The lab is capable of participating in banana transformation, should the need arise since by the time of conducting this study BBW was not a very important disease in Kenya. It is worth noting that KARI in general does not have a banana breeding programme. This laboratory has the capability of producing future banana transgenics but the dissemination process should be taken up by private companies such as GTL or JKUAT, with a higher TC capacity. The staff at the KARI biotechnology centre expressed the view that from their experience with sweet potato, they would prefer to conduct transformation in their own laboratories, even if a central facility to do is established in eastern Africa. They would not wholeheartedly leave the job in the hands of a central laboratory but would conduct it in tandem.

Table 10. Technical capacity at the Biotechnology Centre, KARI, Kenya

Total technical staff	Relevant staff	Students in training	TC crop & equipment	Molecular experience/ equipment	Transformation experience/ equipment
PhD-5 Msc-5 Technicians-8	3 (1 virologist, 1 breeder, 1 biotechnologist)	1 Post doc 3 PhD 4 Msc (Biotech) 2 Msc (Biosafety)	1. Protocols for banana, sweet potato, cassava, pyrethrum 2. Lamina flows-4, 2 growth chambers, greenhouse 3. 500,000 bananas/ year	1. SSRs for maize streak/QPM 2. QTL mapping-maize 3. PCR/silver staining	1. Sweet potato transformation now successful 2. *Bt* maize with CIMMYT 3. Cassava transformation in collaboration with DurnWorth Institute 4. Well established biosafety greenhouses

Source: Field survey interviews and observations

Tanzania

MARI in Mikocheni (Table 11) has a fairly substantial physical and human capacity in biotechnology, drawing most of its experience from both coconut and cashewnut research. The current research is in the use of marker assisted selection in cashew and coconut traits having participated in producing the first molecular map of coconut. Although not working in banana transformation, MARI is planning in the very near future to embark on transforming cassava for CMD with the help of IITA. The lab also has a TC capability and so it is well placed to disseminate future banana transgenic products. MARI staff suggested that they would for the time being prefer to have the transformation of banana to be done centrally at Kawanda, but with a scientist from MARI attached to work alongside the IITA/NARO staff. MARI also felt that their scientist should only spend time at Kawanda during the actual transformation (maximum two years) and should return home to do the lab, greenhouse and field testing of the transgenic banana.

Table 11. Technical capacity at MARI in Mikocheni, Tanzania

Total technical staff	Relevant staff	Students in training	TC crop & equipment	Molecular experience/ equipment	Transformation experience/ equipment
4 PhD 3 Msc 7 Technicians	2 PhD (1 virologist & 1 breeder) NB: Virologist not aware of BBW	3 PhD 3 Msc	1. Protocols for banana, coffee, coconut, cassava, pyrethrum 2. Lamina flows-2 3. 2 growth chambers, greenhouse 4. 500,000 bananas/year	1. RADPs/RFLP/ QTL mapping for coconut 2. 7-PCR thermal cyclers 3. Agarose & silver staining	1. None 2. Expected in cassava for Cassava Mosaic Disease (CMD)

Source: Field survey interviews and observations

The University of Dar es Salaam (Table 12) needs time to develop both its physical as well as human capacity in biotechnology. The two departments of botany, and molecular biology and biotechnology may need to marshal their resources in order not to duplicate efforts. They are currently not involved in any banana or transformation work and they cited MARI as their major collaborator in the country. They are however building capacities in the teaching of risk assessment and management in the region.

Uganda

Kawanda Research Institute has the only laboratory in the region that is actively working on BBW and other banana diseases (Table 13). In addition it has a vibrant TC lab that

Table 12. Technical capacity at the University of Dar es Salaam, Tanzania

Total technical staff	Relevant staff	Students in training	TC crop & equipment	Molecular experience/ equipment	Transformation experience/equipment
2 PhD (in molecular taxonomy) 2 Msc	1 PhD	1 PhD 2 Msc in biosafety	1. No TC activities	1. Iso-electric focusing 2. 3-PCR thermal cyclers 3. Agarose and silver staining	1. None 2. 1 lab and 1 greenhouse being upgraded for biosafety 3. UDS coordinates regional biosafety course

Source: Field survey interviews and observations

Table 13. Technical capacity at NARO, Kawanda in Uganda

Total technical staff	Relevant staff	Students in training	TC crop & equipment	Molecular experience/ equipment	Transformation experience/ equipment
1. IITA staff – 7 PhD 2. NARO staff – 5 PhD 3. 7 MSc 4. 5 Technicians	1. IITA – 2 PhD (2 biotechnologists) 2. NARO– 3 PhD (1 biotechnologist, 1 breeder, 1 pathologist) 1 diploma technician	1. 4 Msc in biosafety 2. Offers short courses in TC – regional and local	1. Protocols for banana 2. Lamina flows - 4, 3. 4 growth chambers 4), greenhouse	1. SSRs for beans 2. QTL mapping-beans (CIAT) 3. PCR/silver staining 4. Western	1. Banana transformation proof-of-concept developed 2. Successfully transformed black Sigatoka 3. Uses cell-suspension/ meritems 4. Technical committee on BBW exists 5. Establishing biosafety greenhouse

Source: Field survey interviews and observations

liaises with Agro-Genetics Company[4]. It also has two scientists at PhD level trained Belgium on transformation of banana. One of them, has successfully transformed banana for black Sigatoka resistance. NARO has a strong partnership with IITA who have placed two of their scientists at Kawanda (Dr and Mrs Tripathi) to specifically transform banana for BBW resistance. In addition, one NARO scientist who is leading the banana research in the country is working with the IITA group. NARO is the only

4 This is a private company located about 20 kilometres outside Kampala which is involved in propagation of TC material for various crops (bananas, coffee, tea, cassava, yams) and forest trees. The company also collaborates with biotechnology scientists from Makerere University. It has previous experience in technology transfer, having participated in a FARM-Africa, MATF project on banana tissue culture dissemination between 2003 and 2004.

institution in eastern Africa with a strong banana breeding programme. This group is now finalising the proof-of-concept for BBW. Clearly, any transformation work for BBW must be based at NARO Kawanda. At the moment, the biosafety greenhouse is under construction and the guidelines and regulations are nearing completion.

Burundi

Burundi as a country does not have a national banana research programme (*discussions with ISAB-Director General*), but IRAZ which is a regional research institute covering Burundi, Rwanda and DRC has a mandate for conducting banana research work. The institute has, however, been facing financial and human resource capacity problems since the breakout of civil war in the Great Lakes region. A number of scientists were killed during the war and others fled the institute. Currently, the institute is only funded by Burundi and has limited capacity as shown in Table 14. IRAZ, however, has a substantial TC capacity for banana and has conducted regional courses in this area. It also has room and buildings for any future work. Staff at IRAZ were of the view that transformation be conducted centrally at Kawanda, but their staff should be given training opportunities while the work is ongoing. AATF, however proposes to train only one IRAZ staff, which for the moment would be inadequate for the lab. IRAZ also needs to invest in equipment.

Table 14. Technical capacity at IRAZ in Burundi

Total technical staff	Relevant staff	Students in training	TC crop & equipment	Molecular experience/ equipment	Transformation experience/ equipment
1 PhD scientist Technicians-2	1 PhD	None	1 autoclave, 2 growth chambers, 1 screen house producing 60,000 plantlets, but has capacity for 500,000	Unused electrophoretic equipment	None

Source: Field survey interviews and observations

Rwanda

Rwanda is far from establishing any biotechnology research for bananas and lacks both human and physical capacities to do so (Table 15). Though banana is a very important crop in Rwanda and BBW a serious disease that allegedly has invaded the country from DRC, ISAR has had no banana breeding programme and has a limited number of staff (two scientists) working with banana. There are also very few scientists in training and the one active scientist (Sveta) is soon going for studies in South Africa on soil research. At Ruhengeri, a TC lab is being built and by the time of visit, the lab was hosting TC banana normally raised at Rubona, since Rubona was undergoing renovation. The ISAR Director General and the PS, Ministry of Agriculture had serious doubts about transforming banana for BBW resistance. The PS, a former scientist with IITA at Kawanda, expressed the view that alternatives to transformation should be sought to combat BBW.

Table 15. Technical Capacity at ISAR in Rwanda

Total technical staff	Relevant staff	Students in training	TC crop & equipment	Molecular experience/ equipment	Transformation experience/ equipment
2 Msc, one going for PhD studies, one in SA (Pathologist) 3 technicians – 1 based at Rubona, 1 at Ruhengeri, 1 at Kibonga	2 Msc – 1 training in soil/ agronomy, 1 pathologist	1 Msc in SA	1. Under construction at Rubona (lamina flow, autoclave, fridge, freezer) 2. Banana activities at ISAR –Ruhengeri – TC lab also under construction	None	None

Source: Field survey interviews and observations

Product development capability

In this feasibility study we consider product development capability to include laboratories working with construct development, status of IPRs, human resources, technical capacity, biosafety and legal frameworks[5]. These factors are important in considering where and how the transformation process should be conducted.

It is very clear from the interviews that several institutions were of the view that a central transformation facility be established preferably at NARO/IITA since these two institutions are currently leading the way in BBW transformation. As noted elsewhere KARI and MARI expressed the view that the participating NARS be involved right from proof-of-concept stage. This report suggests that all NARS be involved during the actual transformation at NARO, Kawanda but after two years, their scientists relocate to their countries to conduct lab, greenhouse and field biosafety trials. Given that Rwanda, Burundi and DRC do not have laboratory and human resource capacity, it would be necessary to build the capacity at IRAZ within the first two years to be able to conduct lab, greenhouse and field biosafety trials. At the same time there should be a push for the three countries to finalise their biosafety policies.

At the phenotypic testing stage, it should be possible to make a decision if the genes *pflp* and *hrap* are the right genes for BBW or not before proceeding. This report suggests that the three NARS institutions that have the highest capacity for biotechnology, that is NARO, KARI and MARI-Tanzania, be the lead institutions in transformation. It is hoped that the other two institutions, IRAZ and ISAR, invest in building both human and physical capacities at this time. IRAZ could still send a scientist to NARO, Kawanda for training.

5 How do we develop a transgenic banana for the region and how do we deploy it?

Only three countries in the region have biosafety guidelines and frameworks at the moment. These are Kenya, Uganda and Tanzania. In Kenya, the process of legislating biosafety frameworks is very advanced. They already have five components consisting of biotechnology law, biosafety law, regulatory agencies, biosafety bill and policy and have already transgenic trials approved for *Bt* cotton, cassava, recombinant rinderpest vaccine, transgenic sweet potato and *Bt* maize. Uganda and Tanzania have established at least national biosafety and institutional biosafety committees. At the time of visit, Burundi was in the process of developing biosafety guidelines. This therefore means that by the time transgenic banana will be on the scene at least the majority of the eastern African countries will have set biosafety regulations. As the East African Community gathers momentum to encompass all the five countries, it is the duty of the NARS involved to call for the harmonisation of the biosafety regulations across the borders for ease of having to move transgenic banana from country to country should the need arise.

Deploying transgenic eastern Africa highland banana with BBW resistance like any other breeding effort is likely to be faced with the issue of breakdown of resistance. This report suggests that AATF and NARO/IITA continue to scout for other resistant genes with the idea of pyramiding these genes as they work on the two genes from Academia Sinica. To complement resistance breeding for BBW, AATF should acquire and make available other gene constructs to the NARS laboratories with capacity for transformation.

NARS and their extension agencies need to find better ways of enhancing their interactions using perhaps the TC experience. There is no other credible way of deploying transgenic banana rather than through TC technology. Farmers and farmer groups, therefore, should be encouraged to set up their own independent nurseries. Private TC laboratories should be encouraged to take over the role of disseminating TC banana.

Technology deployment

The current TC approach for disseminating non-GM tissue culture (TC) banana materials may be one way to deploy transgenic bananas in the region. There are both international and local public and private sector institutions promoting non-GM TC bananas. The institutional arrangement will involve private labs, research and development (R&D) institutions, farmer organisations, and government extension service.

In Uganda, Agro-Genetics Technologies Limited (AGTL) collaborated with NARO and NAADS in the distribution of TC banana material to farmers. In Kenya and Tanzania, ISAAA is one of the international public institutions which has tried to support all aspects of technology in the entire value chain of bananas. It has worked with KARI, JKUAT and GTL in Kenya and Seliani Agricultural Research Institute in Tanzania to organise farmers to access and use non-GM TC banana materials.

With limited capacity of public research facilities, the high delivery capacity of TC material lies with private labs in the region. In terms of the rollout plan there are a few limitations with respect to vegetatively produced crops such as cassava and bananas due to the informal exchange of planting materials. These limitations challenge monitoring, unlike *Bt* maize whose rollout will use normal seed systems in countries such as Kenya[6]. Without such a formal system in place for GM bananas or GM cassava, monitoring becomes difficult. For instance, the Kenya Plant Health Inspectorate (KEPHIS) is yet to establish mechanisms for monitoring tissue culture planting materials. At the same time, farmers have expressed concern over the quality of planting material obtained from a private company in Kenya[7]. This problem could be addressed through a mechanism of monitoring the production of TC material in the laboratory. Also, there is a need for developing a mechanism for addressing farmers' concerns as well as creating farmer confidence in TC material. One option is to set up satellite TC nurseries in close proximity to farmers. Establishment of demonstration plots alongside the TC satellite nurseries should complement these.

While satellite TC nurseries will reduce the cost of transport, the demonstration plots will create confidence in farmers. JKUAT and GTL have established satellite nurseries. KARI, Thika has also been involved in setting up Farmer Field Schools (FFS) in the promotion of non-GM TC bananas. In particularly, FFS are involved in training farmers on agronomic and post-harvest handling practices including spacing, desuckering, ripening technology, and handling techniques to avoid bruising during transport.

In Uganda, AGTL in collaboration with Bucadev has established satellite nurseries and demonstration plots – which are also used for macro-propagation.

The current TC laboratories in the region have different capacities as enumerated below.

(a) Kenya: The major laboratories producing TC banana are GTL, JKUAT, KARI in Thika (NHRC) and Biotechnology Centre – NARL. GTL being a private laboratory has the highest TC capacity not only in Kenya but also in the region (Table 16) with a potential of 20 million plantlets per year. However, farmers and researchers who have in the past planted GTL plantlets complained that most of them suffered from somaclonal variation simply because of over-culturing. GTL has extensive links with KARI but not with JKUAT.

(b) JKUAT has had a sustained production of TC banana in the past but standards seem to be declining with the departure of the lead scientist. JKUAT may have to lease the facility to a private firm to maintain the production. JKUAT has established nurseries with farmer groups where material is hardened before being delivered to other farmers. The KARI-NHRC Thika laboratory is very small and has other priorities besides banana such as flowers and macadamia. The lab however is situated in a banana growing area.

6 Kenya has an established formal system and channels of deploying this technology to farmers. Although the system still faces some challenges, these are being monitored by the Kenya Plant Health Inspectorate (KEPHIS).

7 Some respondents attributed this problem to somaclonal variation resulting from over subculturing.

(c) Uganda: The two major TC laboratories are Agro-Genetics and NARO, Kawanda. There is a strong collaboration between GTL and NARO with NARO advocating that the role of disseminating plantlets through TC belongs to Agro-Genetics. Agro-Genetics, a private laboratory, has established nurseries with farmers not only in Uganda but also in Rwanda. Agro-Genetics, though private, has had financial support from USAID, UNDP and FAO without which the proprietor admitted it would not have been able to operate.

(d) Burundi: There are two private laboratories, Agro-Biotech and Phytolab. In addition IRAZ and the University of Burundi are producing some TC banana. In terms of capacity, the two private labs are better equipped and have established links with farmer groups.

Table 16. Tissue culture laboratories and their capacities

Laboratory	Technical staff	TC crop/varieties /other activities	Equipment	Capacity of plantlets/year	Collaboration
Genetic Technologies Limited (GTL), Kenya	1 Msc (MD), 1Bsc 20 technicians – lab, 10 – greenhouse	Banana (Grand-9, Williams, Cavendish), Pineapple,	Lamina flows (10) Autoclaves (7) Culture rooms (5) Greenhouse (13) 400 litres of media/day	500,000–20,000,000	KARI, ISAAA, DuRoi, Ministry of Agriculture
Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya	2 PhD, 2 Msc students, 2 technicians (1 lab, 1 greenhouse)	Banana (Virus indexing) – grand – 9, Williams, giant and dwarf Cavendish	Lamina flows (6) Autoclaves (4) Culture rooms (4) Greenhouses (1)	500,000–1,000,000	IITA (Endophyte research), KARI
National Horticultural Research Centre, Thika–KARI, Kenya	3 Msc 2 diploma holders	Banana, (Kampala, Giant Cavendish, Grand 9, Rakatan) flowers, macadamia	Lamina flow (1) Autoclave (1) Culture room (1) Greenhouse (1)	20,000	BTA, GTL, JKUAT
Agro-Genetic Technologies Limited, Uganda	1 Msc (MD) 1 PhD (part time) 6 technicians (A-level)	Banana (Mpologuma, Kisanza, Mbwazirume), Pineapple, Coffee	Lamina flows (4) Autoclaves (2) Culture rooms (4) Greenhouse (2)	4–5 million	IITA, NARO
Agro-biotech, Burundi	1 PhD (MD), 6 technicians	Banana (beer varieties)	Lamina flows (4) Autoclaves (2) Culture rooms (2) Greenhouse (1)	60,000	IRAZ
Phytolab, Burundi	1scientist, 4 technicians	Banana (beer varieties)	Lamina flows Autoclaves Culture rooms Greenhouse	60,000	University of Liege, University of Gambleau, University of Burundi

Source: Field survey interviews and observations

Agricultural, Environmental and Human Health Considerations

Risk assessment of genetically modified plants aims at identifying and evaluating the risks associated with the release and cultivation of these plants in comparison with a counterpart that has a history of safe use. In countries with established regulatory programs for environmental risk assessment of transgenic plants, there are common safety concerns that must be addressed on a case-by-case basis before commercialising a transgenic plant.

Agricultural factors likely to be influenced by transformation

In an attempt to evaluate risks that may be associated with transforming banana to BBW resistance, several characteristics have to be considered and they include:

- consumption and uses of the crop plant;
- regional/national breeding, seed production, and agronomic practices;
- reproductive biology of the crop plant, with details on pollination, mechanisms for dispersal of pollen and seed, and any other means of gene escape;
- occurrence and viability of intra-specific, inter-specific and inter-generic hybrids;
- details on the centres of origin and genetic diversity for the plant species;
- details on the ploidy of the cultivated crop, its progenitors and any sexually compatible species;
- distribution and ecology of related species or feral biotypes, including any evidence of weediness;
- common diseases and pests;
- potential interactions with other organisms such as pollinators, mycorrhizal fungi, animal browsers, birds, soil microbes and soil insects;
- trade and market access risks.

The key questions therefore to be addressed in regard to unintended risks are:

- Does the reproductive biology of the banana allow cross pollination and therefore seed-set?
- Are there any known wild relatives of the banana that are sexually compatible with the cultivated varieties?
- Is there any chance of gene flow between cultivated and wild bananas?
- Is BBW found both on cultivated and wild relatives of the banana?
- Will transgenic banana be used interchangeably with non-transgenic ones?
- Are they likely to pose any risks not associated with the non-transgenic banana?

- Will transgenic banana affect regional and international banana trade and market access?
- Will the transgenic banana be acceptable by consumers?

These concerns are addressed here below.

Elsewhere in this report, it has been emphasised that even among the existing banana varieties cross pollination is not possible since most are triploids and therefore sterile. There is no chance for any cross pollination and no evidence for intra-specific, inter-specific and inter-generic hybrids being formed. Though the east African region is considered to be a secondary centre of origin, reported wild relatives or feral biotypes and these are not sexually compatible with the cultivated varieties. Given the reproductive biology of the plant there is very little chance for gene flow to take place between cultivated banana and wild relatives. There is therefore no risk of 'weediness' since there is no gene flow. Transforming local banana cultivars for BBW resistance will not pose any risk of 'weediness'.

The last two issues address the concept of substantial equivalence; how will transgenic banana react to other diseases or pests compared to untransformed banana?

Environmental considerations arising from transformation

It is necessary to critically examine the source of genes that will be used to transform banana to BBW resistance. The donor organism in this case is sweet pepper. The question that needs attention before the transformation itself is:

- Does the donor organism itself or members of its genus exhibit pathogenicity or environmental toxicity or pose any danger to human health?
- Will BBW resistance lead to expression of new or modified proteins?
- Does the donor organism carry gene sequences such as promoters, introns, terminators or any other sequence that is likely to have negative effects on the environment?
- What will be the effect of the expressed proteins?
- Will the physiochemical and biological properties of expressed protein differ from those of the original donor organism (functional equivalence)?

To be able to assess the environmental safety of a genetically engineered plant one must be familiar with not only the biology of the plant itself and the trait being incorporated but also with the agricultural practices employed in its cultivation. The concept of familiarity is key to identifying and evaluating environmental risks that may be associated with the release of a genetically engineered plant. The concept is also important in forming management practices that may be needed to manage recognised risks.

In case of the banana, reported wild relatives or feral biotypes in eastern Africa are few and given the reproductive biology of the plant there is very little chance for gene flow to take place between cultivated banana and wild relatives. As most of the east-African highland bananas are triploids (AAA) no chance for any cross pollination and no evidence for intra-specific, inter-specific and inter-generic hybrids being formed exists.

Environmental safety concerns yet to be addressed in case of banana transformed for BBW resistance are:

- stability of the genetic modification
- gene transfer to unrelated plants
- secondary and non-target adverse effects

These concerns would need to be addressed during the confined trials of the transgenic banana.

Human health issues likely to be influenced by transformation

The human health concerns are:

- Is transformation likely to alter the nutritional composition of the banana?
- Will there be unintended changes in concentrations of various natural toxicants or anti-nutrients?
- Will there be changes in bioavailability of key nutritional components?
- Is the protein being expressed the product of inserted genes?
- Will transformation result in changes in metabolic pathways of major nutrients?
- Will transformation result in more toxic proteins and lead to increased food allergens?

In mitigation, the following tests may be recommended to be undertaken:

- nutritional composition tests;
- *in vitro* studies to establish the metabolic fate of expressed proteins in human and animal gut system;
- animal tests.

There are several key questions to be addressed in assessment of unintended risks, be they agricultural, environmental or human health issues that may be associated with the introduction of BBW resistance into the east African banana background such as the following.

- Does the reproductive biology of the banana allow cross pollination and therefore seed-set?
- Are there any known wild relatives of the banana that are sexually compatible with the cultivated varieties?
- Will transgenic bananas be used inter-changeably with non-transgenic ones? Are they likely to pose any risks not associated with the non-transgenic bananas? This concept of substantial equivalence is yet to be established in regard to BBW transformation.

The concept of substantial equivalence is yet to be established in regard to transformation for BBW resistance. Applying the concept of substantial equivalence requires that sufficient analytical data be available in the literature, or be generated through experimentation, to allow effective comparison between the transgenic plant and its traditional counterpart. There is no data yet produced here or in cases where *pfpl* and *hrap* have been used in transformation for other diseases in rice, tobacco or orchid. Nevertheless, the introduction of BBW resistance is unlikely to change the current agricultural practices of the east African highland banana which will continue to be cultivated under the same agronomic conditions. There is therefore no opportunity for disruption of the ecosystems with the introduction of BBW resistance. The banana will continue to be propagated vegetatively and inter-planted with other crops such as maize, beans, cassava and sweet potato.

Environmental safety concerns yet to be addressed in case of banana transformed for BBW resistance are:

- stability of the genetic modification
- gene transfer to unrelated plants
- secondary and non-target adverse effects

These concerns would need to be addressed during the confined trials of the transgenic banana.

Perception on GM banana technology

For the development and promotion of GM technology in the countries of the Great Lakes region, an understanding of the perception of the different stakeholders is important since it could pose a bottleneck. The study commissioned by AATF aims at using GM technology to control BBW, hence there was need to assess perception on GM technology. The study interacted with the different stakeholders including scientists, policy makers farmer organisations and private sector[8]. Some of their responses were captured during the discussions and are indicated herebelow on a country-by-country basis.

Kenya

In Kenya, the team interacted with the Assistant Director for Horticulture and Industrial Crops at the KARI Biotechnology Centre and her deputy. Staff of Jomo Kenyatta University of Agriculture and Technology (JKUAT); the National Horticultural Research Centre Thika; Highridge Banana Farmers Marketing Association (HBFMA); Genetic Technologies International Ltd (GTL); and International Services for the Acquisition of Agri-Biotech Applications (ISAAA). Each one of the stakeholders above had similar perceptions with limited differences. Table 17 gives perceptions on GM technology in Kenya as captured during the discussions with the various groups.

8 Mainly entrepreneurs operating tissue culture banana laboratories and traders in banana to seek their views on potential consumer concerns on introducing transgenic banana.

Scientists at KARI were also concerned about the transformation being left to international institutes without close involvement of national research institutes. They gave an example of the sweet potato transformation work which was being carried out in South Africa, Dunford and at KARI. South Africa and Dunford never succeeded partially because they really did not own the project but KARI succeeded. They argue therefore that the transformation work should be carried out at different centres in the region and not just confined to one laboratory. On the other hand USAID does not think having the work done in different sites will be cost effective and instead argues for laboratory work being conducted at a centre of excellence (Kawanda) and results being applied regionwide.

Table 17. Perceptions on GM technology in Kenya

Stakeholder	Perceptions on GM technology
KARI – Biotechnology Centre and Horticultural and Industrial Crops Department	Farmers have no problems growing GMO crops. They rely on scientists to provide the required information. GM banana for Gros Michel could be highly acceptable. Creation of awareness was cited as a pre-condition for success.
Jomo Kenyatta University of Agriculture and Technology (JKUAT)	Although the GM technology is technically or scientifically proven, ethical and environmental questions were raised. This hitches on creation of awareness.
Horticultural Research Centre, Thika	It was agreed that if Gros Michel were transformed, it would be widely accepted. However, safety issues were raised. Secondly, the agronomist raised the issue of terminator gene. Once again they raised the issue of awareness as key to the adoption of GM technology.
Highridge Banana Farmers Marketing Association (HBFMA)	The Association agreed that if the GM technology will come as tissue culture material, it would be easy for adoption since farmers are now aware of TC technology. The worry that was raised was regarding the terminator technology, which they believe would interfere with their local varieties. They also agreed that if Gros Michel was transformed farmers will adopt it fast. They finally emphasised the need to create awareness if the technology was to be adopted.
Genetic Technologies International Ltd (GTL)	The GM technology is acceptable but responsible applications of the technology are needed.
International Services for the Acquisition of Agri-Biotech Applications (ISAAA)	The technology is acceptable but it should be demonstrated through safety assessment that the food produced is safe. The long term impact is not known. Creation of awareness is key to adoption of the technology.

Source: Field interviews with various respondents

The scientists who are practicing or involved in the technology tend to be positive – Biotechnology Centre raised no concerns. However, other scientists in JKUAT, KARI Thika and ISAAA raised the issues of safety, terminator technology and environmental concerns. ISAAA also mentioned the issue of long term impact of the technology. These were however personal views.

The Assistant Director in charge of Horticulture and Industrial Crops at KARI as a policy maker emphasised that farmers need the technology but what is lacking is the awareness about the technology.

Farmers on the other hand as represented by the HBFMA, do not mind the technology if it can solve their production problems especially for Gros Michel. But their fear is on terminator technology.

Uganda

The respondents in Uganda included Uganda National Farmers Federation, Mukono District Farmers Association, APEP, NAADS, KARI Kawanda, UNCST and IFPRI. Their perceptions were captured as indicated below.

The issue of scientists being the main block to adoption is still clear in the Uganda case (Kawanda and NAADS). However, policy makers as in the case of UNCST appear open for improvement. The Farmers Federation is more concerned about the cost of the technology, health and environment, but they are open for the technology. Farmers Association on the other hand has problems with the terminator technology, which came with hybrid maize in some areas in Uganda.

Rwanda

In Rwanda, the issue of GMOs has not raised a lot of debate except for relief food that is usually received. The team however interacted with the Director General (DG) ISAR, ISAR scientists, Permanent Secretary, Ministry of Agriculture, staff of RADA and Dr Rukazambuga from the Faculty of Agriculture, University of Rwanda, Butare Campus. Their responses were quite similar – better die tomorrow than today. This means that the country can go for GMO if there is no alternative. The perception was generally negative due to inadequate information. The DG for example indicated that since the banana plants are sterile, the issue of environmental pollution is mitigated. There were no consultations with farmers as majority have no idea about GMOs.

The Director General of ISAR and PS, Ministry of Agriculture, raised concerns about the efficacy of the gene wondering if it has worked elsewhere or in other crops. They were also not sure whether transformation of banana was a priority at the time.

Burundi

In Burundi the team interacted with the DG-IRAZ, DG-ISABU and his scientists, and staff of two privately owned TC laboratories in Bujumbura. Unlike Rwanda, they raised the health and safety, and terminator technology issues, which can destroy their local varieties. The DG-ISABU was not against GMO technology so long as a risk assessment is carried out. DG-IRAZ indicated that scientists at the University of Burundi are divided. Some are for GMO while others are not. It was suggested that creation of awareness or provision of information on GMOs be carried out if the technology has to be adopted. Like Rwanda, farmers were not consulted since they do not have any information about GMOs. Awareness is low.

Table 18. Perceptions on GMO technology in Uganda

Stakeholder	Perceptions
Uganda National Farmers Federation	GMO can be accepted so long as the issues of environment and health are taken care of. The federation also raised the fear of the unknown. It was concerned about the cost of seed or planting materials and suggested that seed be subsidised to enable many farmers participate. They also suggested that farmers should be involved at certain stages of technology development. The federation is willing to disseminate the technology when ready since it has a nationwide structure.
Mukono Farmers Association/ APEP	The association raised the issue of terminator technology, which they said could wipe out their local varieties. This came up on the issue of maize and now it has touched on bananas. In some localities farmers thought TC bananas were GMOs hence they uprooted them at night. Some farmers said that some scientists are not trusted because they are associated with multinationals.
NAADS	Perception that GMO technology is the domain of multinationals creates negative feelings about GMOs.
Kawanda (KARI)	The director of Kawanda cautioned the team against asking farmers direct questions about GM in relation to bananas. He felt this could lead to negative reaction to useful banana technologies being introduced. He gave an example in which farmers refused to accept TC banana material thinking they were GMOs. However, he indicated that farmers rely on local scientists for information and if they come up with technologies farmers will have no problem of adopting them. Secondly, it was stated that scientists are to blame for the misconception on GMOs. They are the ones that recommend or suggest alternative ways to solve the problem of food production, rather than use GMO technology.
UNCST	GMO technology is precise hence so long as laid down procedures are followed there is no problem. Modernisation of agriculture is basically talking about biotechnology and GMO technology. The issue of contradictory GMO debate is now less in Uganda. However the issue of awareness creation is important.
IFPRI	Positive about GMOs but on a case-by-case basis.

Source: Field interviews with various respondents

Tanzania

The situation in Tanzania is like Kenya and Uganda. Some scientists involved are positive about the technology while others are not. Dr Mbwana of the Selian Regional Research Station and TPRI all in Arusha are for biotechnology and GMO. However, the Director of Research in the Ministry of Agriculture was of the opinion that other options need to be tried first and that Tanzania would welcome genetic transformation if her scientists were fully involved in the transformation process. Once again farmers visited in Arusha area did not know much about GMOs, hence they could not give any perceptions. The team was also informed with official confirmation that the Minister of Agriculture had publicly denounced GM technology.

Based on the perceptions indicated by the stakeholders consulted, it is clear that farmers could embrace the GMO technology that will address their priority constraints like BBW or *Fusarium* wilt in Kenya. However, they fear the terminator technology, which has been raised through the debate on GMOs. Policy makers tend to be open and so long as procedures developed to the use of GMOs are followed, they do not mind their introduction and/or use.

Scientists on the other hand can determine the success of the technology but some are not convinced about the GM technology's safety, environmental impact and long term aspects.

If AATF aims at succeeding in the use of the identified gene, the creation of awareness on GM technology is paramount and this can be done while the technology is being developed. It will help pave the way for commercialisation. Farmers in Rwanda, Burundi and to some extent Tanzania have no idea about GMOs. Hence dialogue and provision of information to all stakeholders will provide conducive environment for adoption of GM technology. The focus should be on scientists, policy makers, extension workers, farmer organisations and NGOs before engaging farmers who will require the involvement of the above stakeholders.

Finally, local scientists should be involved in the development of the technology to create the necessary confidence of the stakeholders in GMOs.

Economic Cost of Banana Bacterial Wilt

In the words of a banana farmer in Mukono District in Uganda, 'Other diseases such as *Fusarium* wilt affect bananas partially and one is able to harvest something, but BBW destroys the entire banana bunch.' The level of loss of the BBW in the Great Lakes region has not been explicitly calculated but in Uganda it is estimated that US$ 35 million worth of crop was lost in 2005 alone to the BBW (interview with Head of Banana Programme, Uganda). In Tanzania where a rapid assessment was conducted in the Lake Zone region about 42,000 plants have been destroyed because of BBW. This translates to about US$ 350,000 loss. In Rwanda the level of loss has not been properly documented but based on information gathered during this mission, the loss is in the region of US$ 0.5 million. In Kenya the loss has not been documented as the disease was only discovered during the performance of this study.

In Tanzania the cost of BBW includes cost of hired labour to uproot infected stools, family labour used in searching and uprooting of infected stools, loss of banana fields that have been affected, cost of replacement crop, losses associated with leaving the land fallow for the recommended period[9]. There is also the cost of lost income opportunities. In one farm in Tanzania, a farmer who first noticed BBW on his farm in January 2006 had by end of August uprooted 35 stools, at a cost of Tshs 500 per stool. The farmer estimated that each of the stool represented a loss of three bunches of bananas at an average price of Tshs 2,500 per bunch. The loss in expected revenue from the sale of the bananas was Tshs 262,500 (US$ 207), while the cost of uprooting was Tshs 17,500 (US$14). This is a big loss to a farmer in a country where 36% live below the poverty line and per capita income of US$ 700 (World Fact Book). The estimated cost of loss of bananas alone in Tanzania is in excess of US$ 350,000[10]. Added to this is labour costs of budding, cutting and uprooting (Tshs 50–1,000) per stool for uprooting only) estimated at US$ 40,000. Costs include loss of capital as the land lies idle after uprooting the banana crop.

Similar costs can be predicted for Rwanda and Kenya where the bacteria wilt has been reported and similar methods of control are being applied. However, the costs are much more for communities in which banana is an important food or income crop.

Market accessibility risk assessment

When introducing GM crops, one of the concerns that countries take into consideration is the potential market access risks. This calls for analysis of potential export mar-

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9 The recommended period for letting the land to lie fallow to control the bacteria wilt is 6–18 months. It was observed that most of the plots were not immediately planted with other crops because most farmers did not have alternative seeds or had not made up their minds what to grow. Given that in most banana growing areas the land holdings are very small, farmers incur high levels of opportunity costs for letting land lie fallow and this has exposed a majority of the farmers to food insecurity.

10 This is from a loss of 42,127 stools estimated to have been uprooted by end of June 2006 in a period of less than three months.

ket risks especially to countries in which market access for GM crops could be limiting. The EU which is one of the main export destinations for agricultural products from the Great Lakes region is one of the regions in which market access for GM crops has been a primary concern.

Embracing banana GM technologies could also affect intra-regional trade in bananas if some countries decide to adopt the technology while others reject the technology or do not have biosafety policies in place.

Since banana is sterile (it does not cross pollinate), we do not expect it to affect other crops or even other banana varieties other than those which have been directly transformed. In this respect we do not expect that other agricultural commodities exported from countries adopting GM banana should have market access problems. However, experience has shown that some exporters have had similar problems even in cases where there was no chance of cross pollination.

The question therefore is what would be the market access implications for countries that embrace banana GM technology to address the BBW problem? To address this concern we consider the historical exports of bananas to EU and also intra-regional trade. We also provide a different scenario in which we consider all the agricultural commodity exports to EU that may face market access as a result of adopting GM banana technologies.

Exports of bananas outside the Great Lakes region are limited and highly erratic. Analysis of exports of bananas to the EU only indicated limited amounts exported to Great Britain by Uganda, a limited amount of exports to Belgium (8,000MT/year) by Rwanda and a limited amount of exports by Kenya[11].

The value of export trade of bananas is very limited with Uganda leading with export of bananas valued at US$ 850,000[12] in 2004 (UN-COMTRADE). This is the highest export recorded for Uganda since 1995. Most of the exports are to the region, especially Kenya and Rwanda. However, it should be noted that regional exports are much higher than reported because of the informal cross border trade. Rwanda's exports are valued at about US$ 30,000 annually of which over 98% is to Belgium (UN-COMTRADE website).

There is no other country in the region with significant banana exports to the EU. The low volumes of exports of bananas to the EU are insignificant when compared to the potential gains from adopting transgenic banana, which is in the excess of US$ 40 million per annum[13].

11 Total exports of bananas by Kenya in 2004 were valued at US$ 60,237 of which bananas worth US$ 38,875 were exported to the United Arab Emirates and bananas worth US$ 5,422 were exported to Great Britain.

12 US$ 475,000 of the exports were to Kenya and US$ 327,000 to the United Kingdom.

13 This is based on estimated current annual losses of bananas in the region as a result of BBW.

Kenya imports 8,000MT of bananas annually from Uganda of which Gros Michel constitutes about 80–90% and 800MT from Tanzania. This is the recorded trade which implies that the actual imports could be 2 to 3 times the reported volumes. Rwanda also imports about 20,000MT of cooking bananas annually from Uganda.

If these export values are compared to the value of losses as a result of the BBW problem, which is estimated at US$ 35 million in 2005, for Uganda alone then it is clear losses due to the disease far outweigh the risks of market access.

Since a higher percentage of the trade is within the region, it is important to ensure that a regional approach to biosafety is put in place in the process of implementing a banana transformation activity.

Cost benefit analysis of biotechnology research

Melinda and De Groote (Bioline International, November 2003) assert that biotechnology innovations that hold greatest promise for poor people in Sub-Saharan Africa are those that:

- tackle economically important biotic or abiotic problems that are not easily addressed through conventional plant breeding or pest control methods;
- pose little risk of endangering trade through exports to countries that do not accept transgenic products; and
- can make a difference in the welfare of smallholder farmers as sources of both food and cash.

The first criterion asserts that to be cost-effective, biotechnology tools should demonstrate a comparative advantage relative to other tools or tool combinations. To target traits effectively and result in popular crops, genes must be inserted into well adapted genetic backgrounds that are either conventionally bred or farmer-selected. The second criterion acknowledges that genetic engineering of important export crops makes them vulnerable to trade disputes, regulations and political lobbies outside their borders (Nielsen et al, 2001).

The third criterion recognises that the vast majority of smallholder farmers in Sub-Saharan Africa consume part of their food crops and many are net consumers. Market liberalisation has progressed unevenly and eventfully in a number of Sub-Saharan Africa countries. Farm families in these countries often face high and variable input as well as output prices, scrambling to meet their cash needs through numerous sources (Bryceson, 2002). Because food occupies a large proportion of their budget and they respond relatively more to price changes in terms of quantities demanded, both urban and rural consumers in these countries will benefit many times more from the price decreases that accompany technological change than will those of richer countries (Pinstrup-Andersen and Cohen, 2001). Reduction of crop loss and yield increase can therefore lead to a significant income increase (Melinda and De Groote, Bioline International, November 2003).

As demonstrated in this report, BBW is one of the most devastating diseases to hit the banana industry in the region, threatening livelihoods of millions of smallholder farmers who depend on the crop either as the main food crop, cash crop or both. Conventional methods have not been successful as demonstrated by the spread of the disease in Uganda in a span of only five years. Efforts to control it have been unsuccessful and households have been forced to change cropping patterns and look for alternative sources of income as a result of the disease. Scientists across the region agree that a long term solution needs to be found, and GM technology has potential to provide a solution.

As demonstrated above there is little or no risk on trade and exports of bananas or other agricultural commodities as a result of adopting GM banana technologies since there is very limited export trade of bananas from the region. Again given that banana is a sterile crop, transformation can be initially targeted at varieties that are of regional importance and not necessarily the types that are exported outside the region. This would ensure farmers maintain their food security status as well as trade regionally.

In order to gauge the potential of commercialising the transgenic banana technology, the study team posed a number of questions, first they sought to find out if farmers were already accustomed to purchasing banana plantlets. The tissue culture technology provided an excellent opportunity for this exploration. It was realised that in Kenya and Uganda, the demand for TC banana was very high and in fact the current enterprises could hardly meet the demand. In Tanzania and Burundi, farmers were also accustomed to using improved banana technologies although there was a good measure of either free access or subsidised purchases by donors.

In Rwanda, there was no evidence of tissue culture banana trade although one of the TC banana entrepreneurs in Burundi claimed to have sold several times to Rwanda through orders by the Non-Governmental Organisations (NGOs).

Prices at which farmers were buying the hardened banana TC material ranged from Kshs 80–120 in Kenya, Ushs 1,000–1,200 in Uganda, Tshs 1,000, and BFR 1,000 (US$ 1) in Burundi[14]. For the farmers who have been affected by BBW we tried to find out what prices they would be willing to pay for BBW resistant material if it was available. The responses are summarised in Table 19.

The TC banana business in the region is estimated at 1.2 million plantlets per annum and it is expanding. This is based on the need for purchase of disease free material. With the advent of the BBW, production of BBW resistant material would even have higher demand both from direct purchase by farmers as well as purchase by NGOs to distribute to farming communities in which banana is an important food crop. This

14 In Burundi over 90% of the suckers are sold through NGOs which then distribute to farmers for free as part of food security among farming communities affected by civil war (interviews with TC enterprise in Bujumbura).

however, assumes that AATF and partners will have dealt with the negative perception of GMO technologies.

Table 19. Prices at which farmers purchase TC bananas or are willing to purchase improved banana suckers

Country	Average price at which farmers would buy BBW resistant material	Price range for which farmers would pay for BBW resistant material	Current price at which farmers are buying banana TC material
Kenya[15]	Kshs 40 (western)/ Kshs 100 (Central)	Kshs 0–200	Kshs 80–120
Uganda	Ushs 838	Ushs 0–2,000	Ushs 1,000–1,200
Tanzania	Tshs 890	Tshs 0–2,000 (mode 1,000)	Tshs 1,000
Rwanda[16]	0	–	Not applicable
Burundi	–	–	BFR 1,000

Source: Field survey

To estimate the potential benefits, we first assume that a working GM banana technology resistant to BBW will take a minimum of five years to develop and another three years to set up commercial production of suckers for distribution to farmers. The actual commercialisation therefore will start on the ninth year of the initial investment. It is also assumed that the current TC laboratories will be utilised and therefore no further investment in TC laboratories will be required.

Other assumptions include the following.

- The initial investment for the genetic modification of the banana and development of tissue culture material is US$ 5 million.
- A 3% interest rate is charged on the initial investment.
- It will take eight years to develop a GMO banana product and that commercialisation can start in earnest in the ninth year.
- The GM TC banana material will be sold at US$ 1.2[17] per piece.
- Three levels of cost of production for the TC material US$ 0.9; US$ 0.7 and US$ 0.6 a piece[18]. This implies the following respective gross margins for the TC material; US$ 0.3; US$ 0.5 and US$ 0.6.
- Assuming commercialisation starts in earnest in the ninth year at initial stocks of 500,000 suckers each for Uganda, Kenya and Tanzania and 300,000 suckers for Burundi and 200,000 suckers each for Rwanda and DRC. Then this would mean 2.2 million suckers in the first year are sold.

15 In western Kenya where the field survey was carried out, farmers had not been introduced to tissue culture bananas.

16 Farmers in Rwanda where the survey was carried out were not aware of tissue culture bananas.

17 This is the approximate selling price of disease free TC material in Uganda, Tanzania, Kenya and Burundi. We assume that this price should hold or a higher price should be charged given this is disease resistant as opposed to disease free technology.

18 The current cost of producing planting ready TC materials by the existing enterprises in the region is US$ 0.7, while in South Africa it is much lower at US$ 0.2. We assume the disease resistant material will cost more because of additional high level handling costs.

- The demand for the GM TC banana will grow at 15% annually.

An initial investment for the technology of US$ 5 million at an interest rate of 3% translates to a cumulative cost of US$ 6.33 million in the ninth year when commercial production can start.

At US$ 1.2 per TC plantlet the gross revenue from sale of TC plantlets in the fist year of commercialisation will be US$ 2.64 million and increasing to US$ 16.24 million in the fourteenth year of commercialisation.

If the cost of production is at US$ 0.9 per TC, the gross margin in the first year would be US$ 792,000, and US$ 1.32 million if the production cost is US$ 0.7 and US$ 1.584 million if the production cost is US$ 0.6.

If production cost can be kept at US$ 0.6 per TC and sale price maintained at US$ 1.2 per TC, it would be able to achieve a breakeven point of total project investment in the twenty-second year since its inception or the fourteenth year after commercialisation (Figure 7). This is a very unlikely situation as this cost of production is unlikely to be achieved as it is below the current production cost of the conventional TC bananas.

With a production cost of US$ 0.9 and US$ 0.7, the project will only breakeven within the twenty-two year project period if the principal sum is underwritten as a public expense and only the interest rate repaid. For the production cost of US$ 0.7 per TC and considering only the interest cost, the breakeven point occurs on the second year of commercialisation of the product or eleven years after the start of the project, while at US$ 0.9 product cost, which is a more realistic assumption, the breakeven point occurs on the twelfth year of commercialisation or the twentieth year of the project.

However, it is important to note that these revenues would only be realised in the ninth year of initial investment in the transformation work. Commercialisation of the technology would be profitable only if the initial investment of the transformation work estimated at US$ 5 million is donor funded.

With an initial investment of US$ 5 million for transformation work and annual cumulative interest rate of 3%, the principal plus the interest in the ninth year when commercialisation work begins would be US$ 6.5 million and increase to US$ 9.3 million in the twenty-second year. It would be difficult to recoup this investment through the sale of TC material.

However, if only the interest rate is to be repaid without the principal, then the investment should be able to pay back in the eleventh year of initial investment assuming a gross margin of US$ 0.5 on sale of TC material, and in the twentieth year of initial investment assuming a gross margin of US$ 0.3. The latter is considered more realistic as it represents 25% gross margin compared to the former which represents 41.6% gross margin.

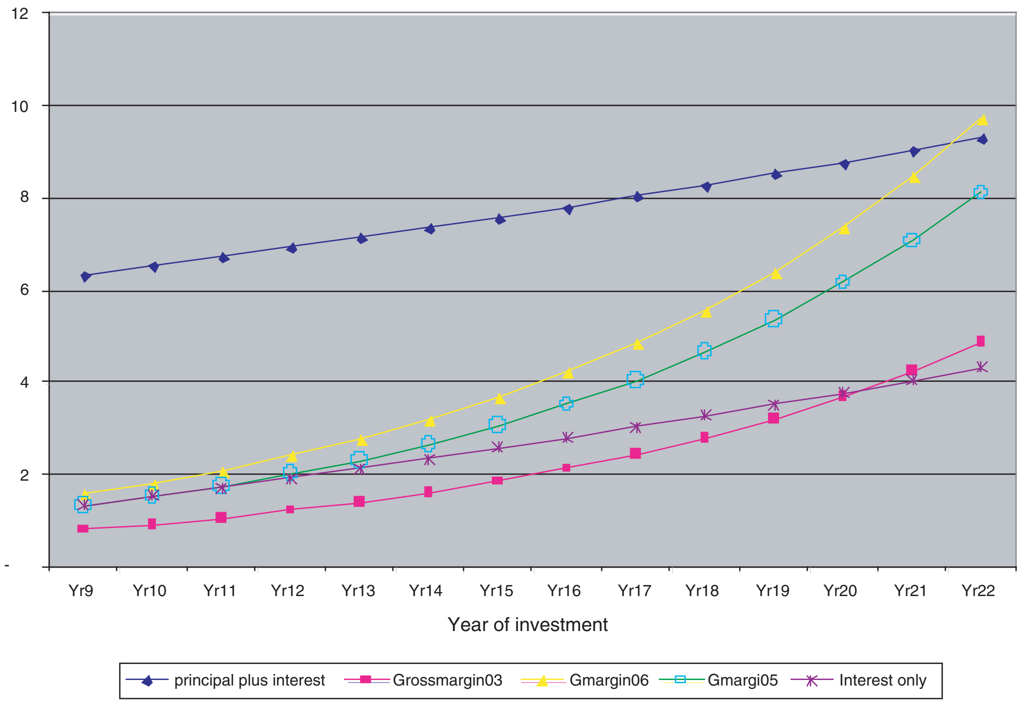

Figure 7: *Breakeven points for commercialising GM banana against BBW under different gross margin scenarios.*

Note: The graph shows breakeven points under different gross margins (0.3, 0.5 and 0.6) based on two options (i) principal plus interest repayment and (ii) repayment of interest on principal only.

Technology deployment

Efforts to address biotic and abiotic banana diseases have led to the development of tissue culture bananas which provide farmers with disease free planting material. It is important to note that even though the planting material is disease free, it is not pest or disease resistant. Thus TC material will still be affected by diseases and pests including banana bacterial wilt disease. In central Kenya, farmers narrated to the research team how their favourite banana (Kampala) was wiped out by Panama disease.

Poorly developed markets for planting material, weak institutions for diffusing it, or the extreme poverty and cash flow problems faced by many smallholder farmers in Sub-Saharan Africa have often thwarted their ability to benefit from varieties that perform well in their fields (Smale, M and De Groote H, November 2003, Bioline International). In Kenya, institutional weaknesses have affected the diffusion of TC technologies in bananas. They include lack of a commercialisation strategy for the TCs especially among the public institutions. Also lacking is a well resourced extension package for deployment of the technology. This has led to a situation in which demand exceeds supply, and supply of poor planting material by the private sector in an effort to meet demand.

In Kenya there are three institutions dealing with tissue culture technologies, JKUAT, KARI and GTL. One of the TC enterprises does not have good public reputation after it supplied farmers in Kisii with material that did not perform well in the field. Farmers in central Kenya also had similar concerns. KARI's TC production is limited at 20,000 suckers a year, while JKUAT is capable of achieving 240,000 suckers a year but has been producing 120,000 (50% of the potential capacity).

In Uganda, Kawanda, Makerere University and Agro-Genetics Technologies Limited (AGTL) are the main suppliers of TC banana planting materials. AGTL is a private enterprise established based on a niche identified to supply farming communities with disease free clean planting materials. Agro-Genetics started its tissue culture business with bananas, but has since diversified into others crops, such as pineapples and has established protocol for aloe vera. The laboratory has a capacity to produce about 4 million TC banana plantlets per year. They have established 13 nurseries (distribution centres) in the main banana growing areas. AGTL thinks the BBW in the country has been aggravated by poor banana production management. Mr Erostus Nsubuga, the director of AGTL, says there is a big confusion between TC and GMO and that some farmers are shunning TC materials thinking they are GMOs. This statement reinforces the fact that there is still mis-information about GMOs and therefore the need to create more public awareness. Nsubuga believes that GM is the next technology in agriculture production and welcomes collaboration with like minded institutions.

Proposed banana delivery pathways

While the proposed hub for developing transgenic banana varieties is the IITA which is housed at Kawanda Agricultural Research Institute (KARI) in Uganda and serves as the integrator of transformation activities, Figure 8 shows that the whole programme is actually a complex network consisting of many actors in the development and deployment of banana varieties with resistance to BBW in the countries under review. During the stage of technology development, AATF will play key roles of brokering the technology and coordinating the relevant knowledge networks. Upon development of appropriate banana varieties, successful delivery of varieties, in terms of both TC bananas and suckers to farmers or clients, is critical. From this stage, this report proposes two technology delivery pathways.

The first pathway is public sector research centres such as nurseries of relevant public universities and national agricultural research institutes (NARIs). The public nurseries will interact with technology developers/originators and biosafety regulators to validate the relevant banana varieties for certification and environmental release. In so doing, they will need to scale up their TC production facilities and set up community based ('satellite') nurseries and demonstration plots that involve farm families (or groups of them) and other intermediaries for testing and adopting the technology. These nurseries and demonstration plots will also raise awareness and increase access of TC banana planting material (from satellite nurseries) and banana suckers (from demonstration plots) to farmers and intermediaries.

However, there will be need for managers of satellite nurseries and demonstration plots to work closely with Plant Health Inspectorate Services and other policy makers to establish regulatory mechanisms (including self regulation) to ensure good quality TC banana planting material and banana suckers are available to farmers (or groups of them), entrepreneurs and their supporting organisations.

The second pathway followed in the private sector has similar elements as in the public sector described above, except that technology developers/originators or brokers will need to enter into specific agreements with the private labs. In general, the agreement will stipulate conditions under which the private labs will receive the technology from IITA/NARS, adapt and distribute it to farmers and intermediaries. Of particular relevance will be the agreed unit prices of transgenic TC banana and banana suckers to ensure that the planting materials remain the same as those of non-GM TC.

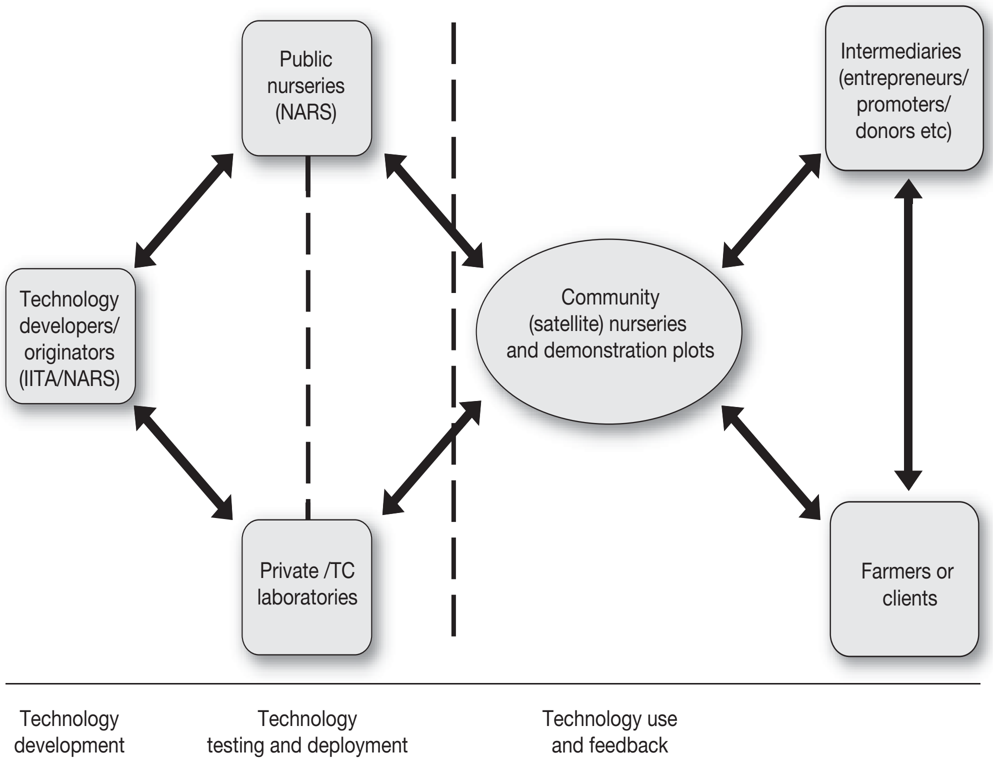

Figure 8. *Proposed transgenic banana delivery pathways.*

In the study, it was discovered that even at the current level, many farmers find the unit price of over US$ 1 for a TC banana plantlet expensive. This is exemplified by the low volume of TC banana plantlets produced and distributed to smallholder farmers by private labs as compared to their existing capacity. Apparently, institutional procurements including donors, government ministries and NGOs have accounted for the largest proportion of non-GM TC banana plantlets distributed to farmers. To increase farmer adoption of banana varieties with resistance to BBW, there is need to mobilise and strengthen public procurements from public and private nurseries as well as set up appropriate micro-credit schemes for banana farmers and entrepreneurs.

Policy and Institutional Arrangements

Policies and biotechnology research priorities

All the countries under review recognise the role of biotechnology in addressing the problem of declining agricultural and food production. However, there are concerns about biotechnology in terms of safety of humans and the environment. Most of the respondents generally agreed that these concerns are based on the fear of the unknown – especially because of limited information. They also raised socio-economic concerns such as the implications of intellectual property rights (IPRs).

Intellectual property rights

Kenya has well established Intellectual Property Rights (IPR) regimes in terms of Plant Variety Protection (PVP) and Industrial Property Act. In Uganda, there is an IPR regime in terms of the Patent Law of 2003. Like Kenya's PVP, the law does not allow patenting of life forms. Also the relevant institutions do not have the capacity to manage IPR issues, which calls for a need to put in place a sound institutional framework (East African Community, 2006).

The rest of the countries under review rely on their Seed Policy Act. Nonetheless, the proposed technology is royalty-free. Consequently, it does not raise serious post-release IPR concerns. In other words, the project will provide free access to planting material, as is the case with the International Network for Improvement of Banana and Plantain (INIBAP) materials. Under such arrangements, only acknowledgement is sufficient. However, public research organisations are increasingly under pressure to sign Letters of Agreement or Material Transfer Agreements (MTAs).

The proposed transgenic bananas will be developed as a public good – especially through the International Institute of Tropical Agriculture (IITA) and the National Agricultural Research Systems (NARS). From IITA or the NARS, the private sector tissue culture labs will require signing an agreement stipulating that the unit price of GM tissue culture (TC) banana planting material will remain the same as the current non-GM banana TC material. This means that the main concern of GM bananas relates largely to biosafety issues.

Institutional arrangements

The National Agricultural Research Systems (NARS)[19] defined within a broader perspective of innovation systems (IS) may comprise of national, regional, international

19 We have adopted a broader 'Innovation Systems (IS)' definition of the 'NARS' and not the conventional definition, which often separates the NARS from IARCs and CGIAR.

public/private sector research institutions, universities, profit-making organisations, NGOs, producer organisations, individual and private companies – all operating in a country and engaged in integrated agricultural research and development (R&D) activities.

For the purpose of this feasibility study, organisational representatives in six institutional categories involved in agricultural R&D activities were interviewed (Table 20). These include universities, national research institutions, supra-national research organisations, the private sector, Non-Governmental Organisations (NGOs), Community Based Organisations (CBOs), policy and regulatory agencies and donors.

Universities and research and development institutions provide education/training, research and extension services. These include Jomo Kenyatta University of Agriculture and Technology (JKUAT) and the Kenya Agricultural Research Institute (KARI).

Table 20. Policy and institutional arrangements

Country/actor	National research institutes	Supra-national research organisations	Private sector	NGOs/ CBOs/ farmer association	Policy and regulatory agencies	Donor agencies
Kenya	JKUAT, KARI	ISAAA BECA	GTIL	BTA, Highland	NCST, KEPHIS, KIPI	Rockefeller World Bank IDRC
Uganda	Makerere NARO	ASARECA BIO-EARN PBS INBAP	Agro-Genetics	Bucadev	UNCST MoA (Seed Act)	USAID KILIMO
Tanzania	UDSM SUA MARI Maruku	–	Banana Investment Company	–	COSTECH TPRI TOSCA (Seed Act)	Farm Africa
Rwanda	ISAR	IRAZ	–	–	RADA, MoA (Seed Act)	USAID
Burundi	ISABU	IRAZ	AgroBiotech Phytolab	–	MoA (Seed Act)	

Source: Field survey

In Uganda, the R&D institutions are Kawanda Agricultural Research Institute (KARI) and Makerere University[20]. In Tanzania, the R&D institutions include University of Dar es Salaam (UDSM), Sokoine University of Agriculture (SUA), Mikocheni Agricultural Research Institute

20 Relevant staff of Makere University were not interviewed due to lack of time.

(MARI), Maruku and Seliani Agricultural Research Institutes. Other R&D institutions are University of Rwanda and ISAR in Rwanda; and ISABU in Burundi.

Supra-national research organisations are located in a particular country and have a sub-regional, regional or international mandate. These include the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) in Kenya; the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA), IITA and INIBAP, East African Regional Programme and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development (BIO-EARN), and Program on Biosafety Systems (PBS) in Uganda; and IRAZ in Burundi.

Private companies are firms that develop and distribute planting material, other inputs, equipment and packaging material to farmers. This category includes intermediaries that bring banana growers into contact with markets. The private labs include Genetic Technologies International Ltd (GTL) in Kenya, Agro-Genetics in Uganda and Agrobiotech and Phytolab in Burundi. Banana Investment Company is a winemaking entity in Arusha, Tanzania.

The NGOs, CBOs and farmer associations collect, analyse and diffuse information on agricultural technologies and link markets to banana growers. In Kenya, these organisations include Biotechnology Trust Africa (BTA) and Highridge Banana Growers and Marketing Association (HBGMA). Others were Bucadev and Uganda National Federation of Agricultural Producers (UNFAP).

Government ministries and agencies formulate and implement relevant policies and regulations. In accordance with the biosafety protocol, National Biosafety Focal Points (NBFPs) are located in ministries responsible for environment in the countries under review. The rest of biosafety activities are distributed in different government ministries.

In Kenya and Uganda, agencies that regulate biotechnology are largely hosted in the secretariats of National Council of Science and Technology (NCST). In Tanzania, there are relatively many agencies involved in the regulation of biotechnology. These include Tanzania Commission for Science and Technology (COSTECH), Tropical Pesticides Research Institute (TPRI) and Tanzania Official Seed Certification Agency (TOSCA). Some of these agencies are located in different government ministries. Rwanda Agricultural Development Agency (RADA) and the Ministry of Agriculture (MINAGRI) represent this category in Rwanda while the Ministries of Agriculture and Environment represent this category in Burundi.

Donor and other financial institutions provide funding for agricultural R&D. These include USAID, KILIMO Trust, World Bank, Rockefeller Foundation, IDRC and Farm Africa. Key representatives of some of these organisations were interviewed on the basis of their contributions to the development and deployment of banana technologies in the countries under review.

National biosafety framework

National biosafety framework components

National Biosafety Framework (NBF) has the following components[21]: a) policy, b) regulation, c) systems for handling GMO applications; d) systems pertaining to monitoring, inspections and enforcement, and e) public awareness and participation. This study only highlights the status of NBF components in Kenya, Uganda and Tanzania where efforts have been made towards completion of NBF. However, it is important to set the discussion of NBF within the framework of the Cartagena Protocol on Biosafety (CPB), a global provision on biosafety that supports safe handling, transfer and use of living modified organisms (LMOs) (Jaffe, 2005; East African Community, 2006). The protocol came into force in September 2003 and over 133 countries have ratified it (http://www.biodiv.org/biosafety/signinglist.aspx?sts=rtf&ord=dt). Although all the countries under review have ratified the Cartagena Protocol, only Kenya, Uganda and Tanzania have established basic frameworks for biosafety, including National Biosafety Committees (NBC) that act as technical regulatory bodies for biosafety[22]. In particular, the three countries are at different stages of establishing their NBFs[23].

The advent of modern biotechnology offers tremendous potential benefits to developing countries. At the same time, its introduction carries with it potential risks in terms food and health safety, environmental, socio-economic, political and ethical concerns. These concerns have formed the basis for the development and implementation of biosafety frameworks aimed to ensure the safe application of biotechnology in the sub-region.

In 1998 Kenya NCST produced the regulations and guidelines for safety in biotechnology for the establishment of the National Biosafety Committee (NBC) and Institutional Biosafety Committees (IBS) as well as identification of the National Biosafety Focal Point (NBFP) as the NCST. Under the framework of the UNEP/GEF Biosafety Enabling Activity, a NBF was developed based on an assessment of the status of biotechnology and biosafety in the country in 1999. Kenya signed the CPB on 15 May 2000 and ratified it on 24 January 2002 [24].

The Uganda NCST, which serves as the Secretariat of the National Competent Authority of National Biosafety Framework, established the country's National Biosafety Committee (NBC) in 1996. The country is a signatory to the CPB, which it signed on 24 May 2000 and ratified on 30 November 2001. Under the UNEP-GEF project, the NBC is putting in place the basic foundations of a sound biosafety system.

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21 For example East African Community (2006)

22 See Greg Jaffe (2005) for a comparative analysis of biosafety regulatory systems in east Africa.

23 The following summary paraphrases biosafety reports of individual east African countries. For details see the relevant sections of Draft Report (East African Community, 2006).

24 See also Traynor and Macharia, 2003; Kenya National Council of Science and Technology, 2006a and 2006b)

Like Kenya and Uganda, Tanzania signed and ratified the CPB and has received assistance from UNEP-GEF to develop its NBF.

Rwanda and Burundi have ratified the CPB but are yet to make much progress in the development of biosafety policies, regulations and guidelines. This is partly attributed to the political crises that these countries have experienced leading to loss of infrastructure and human resource capacity. It is also evident that policy makers and scientists in these countries exercise caution towards the development and introduction of GMOs. In both countries the ministries responsible for environment play an influential role on biotechnology debates. In Rwanda, for example, the Ministry of Environment is reputed for having done an excellent job of mobilising the citizens to maintain a clean environment. Also, unlike Kenya and Uganda where there are many activists, the citizens of Rwanda are loyal to the political leadership. According to one respondent, '… this means that if the political leaders, who are largely technocrats, accept biotechnology, the pace of its development in the country will be much faster. In this context, the many respondents argue that once the east African countries have tested and accepted the technology, there will be no need for Rwanda or Burundi to repeat the process.

However, the respondents insist on being cautious about biotechnology in spite of being aware that once GMOs are released in one country, they could easily spread into the neighbouring territory through formal or traditional seed exchange systems. This was the general consensus reached at the East African Community Stakeholder Consultative Workshop to Develop a Draft Common Regional Policy on Genetically Modified Organisms that was held between 12 and 14 September 2006 in Entebbe, Uganda. The stakeholders agreed that '… it was the right time to commence harmonisation of regional policies for biotechnology and biosafety to enable development of a coordinated mechanism that exploits synergies amongst and is supported by complementary national frameworks' (East African Community, 2006).

Institutions hosting NBF

As mentioned earlier, The east African countries of Kenya, Uganda and Tanzania are at different stages of institutional capacity for supporting NBF. In Kenya and Uganda, the NBF has been developed and is hosted by the National Council of Science and Technology (NCST). Some respondents claimed this is more facilitative especially in terms of coordination of activities and the speed of processing applications.

In Tanzania, apart from the National Biosafety Focal Point (NBFP) which is located in the ministry responsible for environment as is the case in other east African countries, biosafety activities are distributed among different agencies, some of which are located in different ministries. In the perspective of policy makers in Tanzania, the motivation of having multiple hosting institutions of NBF is to ensure checks and balances in the system[25].

25 See Vice President's office (2004)

In the words of one policy respondent, '… its main purpose is to separate 'players' and 'referees' so that promoters and regulators of technology are not located in the same institution(s)'.

Table 21. NBF hosting institutions

Country/hosting institution of NBF	Policy	Bill	Guidelines
Kenya	Kenya National Council of Science and Technology (KNCST)	Kenya National Council of Science and Technology (KNCST)	Kenya National Council of Science and Technology (KNCST)
Uganda	Uganda National Council of Science and Technology (UNCST)	Uganda National Council of Science and Technology (UNCST)	Uganda National Council of Science and Technology (UNCST)
Tanzania	Ministry of Science and Technology	Ministry of Environment	Ministry of Science and Technology
Rwanda	Ministry of Environment	NA	NA
Burundi	Ministry of Environment	NA	NA

Source: Field survey

In his view the most important thing is to ensure that the process is well coordinated and efficient in terms of processing applications. '… in particular, the regulatory bodies in Tanzania have established strict procedures and time frames of processing the applications.' However, these institutional arrangements are yet to be tested for efficiency and timeliness. It is also important to note that although in Kenya and Uganda most of the biosafety approval agencies are hosted by the respective NCST, Kenya has made more approvals. This shows that in addition to institutional arrangements for NBF, there are other factors, which might influence the approval process. These include existence of legal framework, biosafety containment facility, competent personnel, supportive policy environment and an emergent 'home-grown' technology to motivate formulation of regulation. This was well said by a senior scientist at Kawanda in Uganda: 'The black Sigatoka story is driving the construction of biosafety lab because one needs an activity to spearhead biotechnology programmes.'[26]

Status of biosafety applications

As mentioned earlier, the countries under study are at different stages of establishing and operationalising NBFs. Kenya has the most developed NBF with five applications having been approved for confined trials. The National Biosafety Framework in Kenya involves policy, biosafety regulations and biosafety guidelines. Policy is already passed by the cabinet and is waiting to be gazetted. The draft law has been prepared at the Attorney General's (AG) office and waiting to be tabled in parliament for debate.

26 See http://www.bio-earn.org/resource%20book/Home.htm

Biosafety Guidelines by the NCST, which facilitate the biosafety process have already been developed. In particular, the country has a good experience of applying NBF components to some GMOs in the region because it has gone through the entire process of biosafety applications, that is, from laboratory testing to confined field trials. The approved applications include:

(i) transgenic sweet potato (confined greenhouse)
(ii) Bt maize (confined field trials)
(iii) transgenic cassava (confined green house)
(iv) Bt cotton (confined field trials)
(v) Rinderpest (confined field trials).

The Uganda NBF consists of a draft policy that is ready for the Cabinet. The policy provides a framework for research and mechanism for commercialisation of GMOs in the country. For instance, the Ugandan National Biosafety Committee (NBC) has evaluated and approved two applications: *Bt* cotton and transgenic banana against black Sigatoka for confined trials. According to some respondents, the NBC is yet to issue a permit pending meeting the following conditions: a) agreement specifying roles of collaborating research parties, b) operation procedures of moving transgenic banana from lab to greenhouse to field, and c) construction of biosafety greenhouse.

Table 22. Status of National Biosafety Framework

Country/component	Policy	Bill	Guidelines
Kenya	Draft at cabinet	At Attorney General	Being applied (5 approvals)
Uganda	Draft at UNCST	Draft at UNCST	Being applied (2 approvals)
Tanzania	Draft at Ministry of Science and Technology	Existing National Environmental Act	Developing Guidelines at Ministry of S&T
Rwanda	Draft at Ministry of Environment	None	None
Burundi	Draft at Ministry of Environment	None	None

Compared to Kenya, the Uganda approval process for environmental release and commercialisation has been slow. This, according to respondents at the UNCST, is attributed to lack of a legal framework, which is still in draft form. Respondents believed that the completion of a biosafety policy and its attendant legal framework would speed up the approval process in the near future. Also, plans are under way to build containment facilities at the Kawanda Agricultural Research Institute (KARI). On its part, Kenya has biosafety containment facilities at the Kenya Agricultural Research Institute (KARI) and the University of Nairobi.

Tanzania has developed some components of the NBF, which serve as a basic guide to the implementation of the biosafety system in the country. Its NBF works in tandem with the National Biosafety Guidelines and Biosafety Regulations. The latter is anchored in the country's Environmental Management Act No. 20 of 2004 (Vice President's Office, 2005, 2004, 2003).

Role of development partners

Development partners including the United Nations Environmental Programme-Global Environment Fund (UNEP-GEF), BIO-EARN and PBS have played complementary roles to support the development of biosafety regulations in eastern Africa countries.

- UNEP-GEF is responsible for the implementation of the biosafety protocol.
- BIO-EARN provided capacity training in biotechnology and biosafety (or biopolicy).
- On its part, PBS has supported operationalisation of biosafety regulations.
- ECABIO/ASARECA provides grants for biotechnology research and development.

Towards regional bio-policies

The rapid spread of BBW in the eastern and central Africa countries of Kenya, Uganda, Tanzania, Rwanda, Burundi and DRC has underscored the high potential of transboundary movement of living organisms — whether modified or not. The CPB, to which all the countries under study have ratified, aims to regulate the transboundary movement of Living Modified Organisms (LMOs) in order to '… derive maximum benefits from modern biotechnology while at the same time protecting human health and biodiversity from potential risks posed by LMOs'.

These countries have established basic frameworks for biosafety and National Biosafety Committees (NBCs) to act as technical regulatory bodies for biosafety. '…The NBC and other relevant regulatory bodies recognise the advantages for regional cooperation/coordination in biosafety issues without loosing their national sovereignty'. '… The development of efficient and effective regional biosafety frameworks (RBFs) is not only likely to accelerate application of research and development (R&D) in biotechnology in the region, but also to ensure safe access to new products and technologies developed elsewhere'. For instance, during this feasibility study we also found that the main '… challenge being faced in the region is building the necessary human and infrastructure capacities to conduct both [banana transformation and product evaluation] including science-based risk assessments'. Due to lack of necessary human and infrastructure capacities in Rwanda and Burundi, policy makers and scientists suggested that transformation of bananas be done in Uganda and Kenya while product evaluation could be done in all the other countries. This requires a regional approach with different entry points based on the country's situation in terms of technical and regulatory capacity. At the same time there is need to build capacity in all the countries to undertake tissue culture and participate in field trials of transgenic bananas.

This is in line with the consultative workshop that was organised by the EAC Secretariat, ASARECA, PBS and bodies responsible for biotechnology and biosafety in the respective east African countries at Entebbe in Uganda between 12 and 14 September 2006 as an initial step to harmonise biosafety framework in the region. However, this requires coordinated efforts so that all areas for cooperation are well explored. Of particular relevance to this feasibility study is resource mobilisation for developing and deploying transgenic bananas to the majority smallholder farmers in the region.

Mobilising resources for transgenic bananas

One of the challenges cited by policy makers and scientists is the declining public funding for agricultural research in the target countries. For instance the ratio of government relative to donor sources of funding is skewed towards donor funding. Donors account for the largest proportion of funding to agricultural R&D and especially with respect to agricultural biotechnology research. Another challenge cited by respondents was that most of the agricultural research and development funding comes in the form of short term collaborative projects. The effort to develop alternative sources of funding such as levies on commercial crops has not been a sustainable means for resource mobilisation. In Tanzania, the government has abolished the system of raising levies on export crops such as coconut and cashewnuts because it was considered a burden to farmers.

Other initiatives to set up bodies to commercialise technologies and services generated by public research institutes such as agricultural research investments (ARIs) at KARI (Kenya) have not been successful to achieve the required 20% of the revenue mainly due to lack of business acumen in the management of such public enterprises. Consequently, the countries of the region have recognised the need for increasing public funding.

In this context, the target countries are reforming R&D funding by establishing competitive research grant schemes. Uganda has set-up an agricultural research fund or grant, which is advertised to researchers. In particular, the Ministry of Agriculture through Uganda National Agricultural Research Organisation (NARO) has developed a National Research Bill for promoting technologies in the country.

These schemes, however, are experiencing initial implementation challenges. For example the establishment of Ksh 60 million for competitive research grants by the Government of Kenya was not properly communicated to the public. This, according to many respondents at KARI, is attributed to the fact that these funds were placed under the Commission for Higher Education which has no relevant prior experience of managing research grants. Another initiative for alternative funding is the World Bank supported Kenya Agricultural Productivity Project (KAPP). The project is in the early stages of supporting value addition and market oriented production in Kenya. But it does not directly support the development and deployment of biotechnology and especially transgenic bananas.

With respect to the crisis associated with BBW, there are a few ongoing initiatives. One of them is the Crop Crisis Control Project (C3P) that focuses on addressing the African Mosaic Virus (CMD) and Banana Bacteria Wilt (BBW) in the region. This 18-month project is funded by USAID at US$ 2,270,000 and implemented by the Catholic Relief Services (CRS) in collaboration with IITA and the NARS. The project will address the food crisis in the region by providing food aid, planting material and agronomic practices to the affected families.

It will also set up institutional arrangements at the international, regional and local levels which could support the deployment of transgenic bananas or other emergent agricultural technologies.

Table 23. Banana projects and funding

Project/funding	Key element(s)	Target countries	Funding sources	Level of funding (US$)
1. Crisis Crop Control Project (C3P)	- Food aid - Agronomics - TC materials	Region	USAID	2,270,000
2. Banana Bacteria Wilt (BBW)	Disease control	Uganda	Kilimo Trust	612,000
3. Endophyte by IITA	Biocontrol of banana weevils	Region	Various	NA
3. Bio-fortification by IITA	Nutrition enrichment of bananas	Region	Various	NA
4. New programme	General	Rwanda, Burundi and DRC	Belgium	NA
5. New programme	General	Region	Australia	NA

Source: Field interviews

In Uganda, Kilimo Trust in collaboration with GATSBY has provided £320,000 for the control of BBW. The control measures applied are largely cultural and sanitary. These funds are also used to create BBW awareness among banana farming communities.

Other initiatives on banana research include Belgium and Australian education/training and research institutions. These programmes are in the initial stages of development and do not focus on biotechnology research in bananas. This means that there is need for well structured and efficient coordination of actors to achieve complementarities so that banana research needs and funding are effectively prioritised. Given several actors (including those in Belgium and Australia) that are providing technologies, it will be useful to network in order to identify where their research activities spillover to biotechnology. For instance, there is research work on banana endophytes by IITA in the region.

AATF may also play a great part in mobilising funds for the control of BBW in collaboration with ASARECA and INIBAP. This, according to an interview with Michael Hall of USAID, is because few donors are willing to provide funding for banana transformation at the country level. Although global banana players such as Dole and Chiquita are not involved in banana production in the eastern Africa countries, it may be useful for AATF to explore and stimulate their potential business interests in this region with respect to bananas. Overall, there is need for a well developed commercialisation strategy that involves the private sector from the outset of the project for effective technology development and deployment.

Linking farmers to service providers

It is very important for AATF to link farmers to the various service providers in the value chain of bananas as the example below in Kenya illustrates. An interview with members of the Hyridge Banana Growers and Marketing Association (HBGMA) presents useful lessons from the perspective of users of TC planting material and producers of bananas.

Table 24. Highland Banana Growers and Marketing Association views on linkages

Institutional category	Name of institution	Function	Performance
University	Jomo Kenyatta University of Agriculture and Technology	Source of TC material.	Average
National research	Kenya Agricultural Research Institute (KARI)	- Source of TC material - Agronomy - Post-harvest handling	Strong
Supra-national research	ISAAA	- Technology brokerage - Mentoring	Very strong
Private sector research	Genetic Technology Labs	- Source of TC material.	NA
NGOs/CBOs/farmer associations	Kenya National Federation of Agricultural Producers	Farmer empowerment	Average
Policy and regulatory agencies	–	–	–
Extension and education	Ministry of Agriculture	- Extension services	Weak

Source: Field interviews with HBGA members

The association, which has 500 members, was formed three years ago as a self-help group consisting of several groups from three districts: Maragua, Murang'a and Kirinyaga. The group has undergone many learning experiences. In so doing, the association has formed linkages with different providers of technology and services. The table shows the association's performance assessment of collaborators in terms of strengths and weaknesses in their functional linkages with the association.

The performance ranged from 'very strong' to 'weak'. On the one end, the association considered their functional linkage with the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) to be very strong. ISAAA is one of the international organisations which has tried to support all aspects of technology transfer in the entire value chain of bananas in Kenya. This was attributed to the mentoring role ISAAA played in linking the association to other private and public partners in the banana value chain. On the other end, the association considered their link with the Ministry of Agriculture to be very weak due to poor extension services they receive from the Ministry. Overall, the table shows areas of weak functional linkages that can be strengthened to achieve high institutional efficiencies in the banana value chain.

Lessons learned on banana TC technology deployment

The International Service for the Acquisition of Agri-Biotech Applications (ISAAA), offers important lessons from the perspective of a broker of technology in the public domain. In particular, its contribution in moving banana technology from the laboratories to farmer fields offer useful insights on institutional linkages with respect to AATF's initiative of deploying transgenic bananas to smallholder farmers.

ISAAA aims to set up institutional mechanisms to help farmers improve income and alleviate poverty.

ISAAA Afri-Centre collaborates with the African Biotechnology Stakeholders Forum (ABSF) which houses the innovation centre. The centre collaborates with Eastern and Central Africa Biotechnology and Biosafety (ECABIO) programme of ASARECA in responding to national and sub-regional programmes in eastern and central Africa. ISAAA Afri-Centre currently supports tissue culture banana and clonal forestry projects. It negotiated with producers of these technologies to be donated without cost in terms of liability redress. ISAAA collaborated with KARI and GTL in Kenya and DuRoy and ITSC in South Africa to import TC banana planting material from South Africa as *in vitro* plantlets to be hardened in Kenya. It worked closely with KARI, GTL and JKAUT to set up satellite nurseries in some farming communities where TC materials could be hardened to reduce the cost of transport. ISAAA also worked with private sector nurseries in Kenya including Wangu Women Farmers Group, and Catholic Dioceses of Embu and Murang'a.

Following the introduction of TC bananas, it was realised that many smallholder farmers could not afford to pay for seedlings. As a result, ISAAA initiated a microfinance system by negotiating with a strategic firm (K-Rep) to manage the micro-credit scheme using a group guarantee system. K-Rep subsequently turned the scheme into a revolving fund.

ISAAA in collaboration with the Kenya Agricultural Commodity Exchange (KACE) strengthened the market linkages. However, KACE had a capacity problem to deal with large volumes of bananas especially with respect to paying farmers. There was also the issue of poor grading and handling of bananas by farmers. Given post-handling problem of bananas, ISAAA in collaboration with other actors is looking into the issue of value addition in bananas. In this way, ISAAA can address the problem of institutional efficiencies in the banana value chain.

Summary and Conclusion

The Banana Bacterial Wilt (BBW) is a major threat to banana production in the Great Lakes region and it has become clear that conventional and cultural control methods are not effective. This underlines the need to move fast and ensure a long term solution is found. Due to the nature of the banana plant, conventional breeding for disease resistant varieties would take a long time, and this reinforces the need for exploring the transgenic option.

It has been established through this study that the loss in banana is over US$ 40 million annually and an investment of about US$ 6 million in the next ten years has the potential to save the banana crop.

The region has the necessary laboratory facilities and qualified human resources to undertake the transformation work. Containment laboratories for controlled trials exist in Kenya, one is almost complete at Kawanda and Tanzania is in the process of completing its laboratory at Mikocheni.

Farmers, scientists and policy makers are supportive of any initiative including the transgenic option for solving the BBW problem in the region. However, they have expressed the need for safe deployment of the technology. If at this stage the genes are found not to be working, then IITA/AATF should look for and use alternative genes.

The transformation work at Kawanda by IITA is now at the proof-of-concept stage using reporter genes. The proof-of-concept is positive as indications are already pointing. The next stage of molecular analysis should indicate whether the genes are likely to work or not. However, it is only at the phenotypic stage where a firm decision can be made as to whether the genes are working or not.

The countries under study are at different stages of preparing policy and legal frameworks. Kenya has an advanced NBF and has so far approved five applications for confined trials. Uganda has approved two applications for confined trials while Tanzania has partly developed draft components of the NBF. The problem of BBW requires a regional approach on biosafety – and especially with respect to transboundary movement of LMOs. There have been several projects to support NBFs in the region including UNEP/GEF responsible for the implementation of biosafety protocol, BIO-EARN for capacity training in biotechnology and biosafety and PBS for operationalisation of regional Biosafety regulations. The respective NCST offices in the sub-region ensure the functional synergy of UNEP/GEF, BIO-EARN and PBS.

The mechanism of rolling out transgenic bananas will likely be tissue culture (TC) material. With limited capacity of public research facilities, the high delivery capacity of TC material lies with private labs in the region. However, the private labs have a problem of ascertaining quality. For instance, farmers experienced quality problems with TC banana materials obtained from one of the enterprises in Kenya which was attributed to the problem of soma-clonal variations due to over sub-culturing. There is need for a law to regulate production of TC materials.

Regarding IPR and price of TC banana material, the main concerns related to whether or not consumers are going to share the costs of developing and deploying GM TC material. This has cost implications especially with respect to the issue of affordability. Indeed, R&D costs that push up prices of GM TC banana material from the existing levels will reduce its uptake. The existing system of exchanging germplasm in the region is exemplified by BARNESA, which has loose linkages and is formalised by a 'letter of agreement' or 'acknowledgement'. Indefinite IPR issues and limited capacity training, communication and infrastructure support characterise the system. But with the increased role of private sector labs in the deployment of TC bananas, there is need to develop a strategy for commercialising GM TC bananas. This is likely to help farmers increase the value attached to bananas if the production is effectively linked to value addition and marketing. Also through organised markets, the unit prices of TC banana plantlets can be reduced if there is high volume of planting material delivered to farmers. One of the key recommendations is the need to combine nurseries and banana orchards where farmers observe and also buy planting material. In essence, there is need to build up volumes and networks for effective technology deployment. Equally important is setting a micro-credit based on group guarantees.

The successful development and deployment of transgenic banana to address the problem of BBW in the region under study requires a well structured and efficient coordination of key actors to achieve complementarities. In this respect, there is need to network with other technology providers and development partners working on banana research and development. This is important in the sense that there are several non-GMO research projects on bananas in the area, which have spillover effects on transgenic banana research. Examples include banana endophyte and biofortification projects, which are being implemented by IITA and other collaborators. Specifically, efforts should be made to prepare regional project proposals in collaboration with organisations such as ASARECA and INIBAP/BARNESA.

Recommendations

This study recommends the following.

1. Transformation work currently at Kawanda proceeds as recommended by scientists, policy makers and the farming community in the region.

2. There is need to ensure involvement of scientists from all countries in the region although the bulk of the work should be carried out at Kawanda which has the necessary facilities. If the genes are confirmed to be working at the phenotypic testing stage, this report recommends that the next stage of selection of resistant clones

should be done by IITA at Kawanda, while at the same time Kenya and Tanzania carry out their own selection of resistant clones for confined field testing.

3. AATF/IITA need to identify other genes that can be used to continue the transformation work incase the current genes are found to be ineffective against BBW. The decision as to whether to continue with the current genes should be made after the phenotypic testing results are obtained.

4. Given the high losses of banana crop estimated at US$ 40 million per annum (and increasing), it is economically justifiable to invest in the transgenic work. The principal investment of the transformation work should be underwritten by a grant from a donor, while the interest rate can be repaid through proceeds from the sale of the transgenic technology.

5. Although the study has presented information on the main types and varieties of bananas currently produced in the region and also provided information on important traits of each, it is recommended that a more thorough and participatory approach be used in selecting bananas for transformation. The choice of which types and varieties of bananas to be transformed should be made at the national level and should involve relevant policy makers, researchers, TC laboratories, farmer organisations and traders. This will facilitate buy-in for the transformed products.

6. The efforts of UNEP-GEF should be complemented to accelerate the establishment and operationalisation of NBFs in the Great Lakes region. Equally important is to support the recent efforts of the East African Community (EAC) Secretariat, ASARECA, PBS and other bodies to harmonise the biosafety framework in the region.

7. The effective deployment of transgenic bananas in the region requires a regional approach with different entry points based on a country's situation in terms of technical and regulatory capacity. At the same time, there is need to build capacity of all the target countries to undertake tissue culture and participate in field trials of transgenic bananas.

8. The transgenic technology is still highly negatively perceived and there is a lot of myths and negative publicity about it especially by the civil society. There will be need to invest in public education to counter the negative perceptions. This should target not only the general public but also policy makers and scientists.

Recommended mechanisms for technology deployment

Using micro-propagation and macro-propagation to deploy transgenic bananas to farmers

The mechanisms of rolling out transgenic bananas are micro-propagation and macro-propagation. The former entails the use of TC material from public and private laboratories while in the latter suckers from TC banana orchards established in the farming community are used.

Establishing satellite nurseries and demonstration banana orchards in farming communities

One option for increasing small farmers' access to TC banana is to set up satellite TC nurseries in close proximity to farmers. The establishment of demonstration banana orchards should complement these satellite nurseries. While satellite TC nurseries will reduce the costs of transport, the demonstration plots will be used as a source of suckers as well as an advertising/promotional tool.

Involving micro-credit institutions in supporting technology adoption through credit schemes

Based on ISAAA's experience upon the introduction of TC bananas in Kenya, it was realised that many smallholder farmers could not afford to pay for seedlings. Consequently, ISAAA negotiated with K-Rep, a micro-credit institution, to support technology adoption through credit management by use of group guarantee system. It also became apparent that such a scheme would be more successful if there were efforts to transform smallholder banana farmers from subsistence to commercial or semi-commercial production through strong links to markets.

Roles of NARS and private labs

Role of NARS

With limited public research capacity, the high delivery capacity of TC material lies with private labs in the region. Thus, the specific role of NARS will be to facilitate private TC labs to do the following:

- Move TC banana from labs to the farmers' fields by organising farmers into groups to set up and manage satellite nurseries and banana orchards – as a source of suckers.
- Train farmers on nursery management, agronomic and post-harvest handling practices.
- Establish mechanisms for monitoring TC banana planting materials at the labs and farm levels to ensure good quality plantlets and products.
- Provide public awareness that targets different stakeholders.
- Mobilise other service providers and link them to farmers in order to improve efficiency in the banana value chain.

Role of the private sector

The specific roles of the private sector in technology deployment include the following:

- Form close networks with farmer organisations and other intermediaries to increase the volumes of TC banana materials delivered to farmers.
- Establish mechanisms for self regulation to ensure good quality TC materials for farmers.

- Explore business opportunities of establishing nurseries in the main banana producing areas where the banana farming communities play a major role.
- In collaboration with public sector and other development agencies such as NGOs, link farmers with potential micro-credit institutions, value adding and marketing agencies.
- In the initial stage, there is need for an organiser of markets. This is similar to the role played by ISAAA in addressing the problem of institutional efficiencies in the banana value chain.

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Annex I: Terms of Reference

The general objective of this assignment is to research and compile a comprehensive feasibility study report on the development, testing and deployment of transgenic banana with resistance to banana bacterial wilt (BBW) in Sub-Saharan Africa.

Specifically the terms of reference are to:

1. evaluate the technical feasibility of banana improvement against banana bacterial wilt (BBW) through genetic transformation and eventual deployment in smallholder farm environments of Sub-Saharan Africa, taking into account infrastructure, human resource, product capability and policy requirements

2. conduct cost-benefit and break-even analyses to enable documentation of economic benefits and market demand associated with deployment of transgenic banana in Sub-Saharan Africa

3. determine prospects for raising necessary financial resources critical for development and deployment of transgenic banana in target countries of the Great Lakes region of Africa

4. assess socio-cultural factors likely to influence development and uptake of transgenic technology including consumer preferences and acceptability of transgenic banana with traits for BBW resistance in Sub-Saharan Africa

5. critically evaluate and demonstrate whether the proposed project on improving banana against BBW is capable of being implemented and deployed safely with minimum adverse effects to human health, agriculture and the environment.

Annex II: People Interviewed

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Table 25. Banana production by country

Banana production		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Burundi	Production (MT)	1,421,407	1,544,498	1,542,640	1,399,143	1,511,370	1,513,997	1,548,897	1,602,979	1,600,000	1,600,000
	Area (ha)	260,000	295,000	295,000	295,000	295,000	295,000	300,000	300,000	300,000	300,000
	Yield (MT/ha)	5	5	5	5	5	5	5	5	5	5
Kenya	Production (MT)	222,867	250,313	528,793	564,148	548,836	513,884	542,156	536,500	509,688	510,000
	Area (ha)	22,217	25,634	37,565	37,751	37,643	37,154	38,788	39,078	39,799	40,000
	Yield (MT/ha)	10	10	14	15	15	14	14	14	13	13
Tanzania	Production (MT)	130,180	128,180	120,820	167,160	150,320	140,540	155,883	150,400	150,400	150,400
	Area (ha)	49,640	48,200	48,280	66,940	50,600	60,700	76,981	65,000	65,000	65,000
	Yield (MT/ha)	3	3	3	2	3	2	2	2	2	2
Uganda	Production (MT)	580,000	590,000	590,000	595,000	600,000	610,000	610,000	615,000	615,000	615,000
	Area (ha)	120,000	130,000	130,000	130,000	130,000	135,000	135,000	135,000	135,000	135,000
	Yield (MT/ha)	5	5	5	5	5	5	5	5	5	5

Source: FAOStat, website
Note: Rwanda banana production is extremely limited and not reported by FAO[27]

27 Field reports indicated that 90% of bananas grown in the northern and western parts of Rwanda are the beer type, while in the south the most produced bananas are the dessert and cooking types. It also emerged that a lot of bananas (cooking) are imported from Uganda.

Table 26. Plantain production by country

Banana production		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Kenya	Production (MT)	222,867	250,313	528,793	564,148	548,836	513,884	542,156	536,500	509,688	510,000
	Area (ha)	22,217	25,634	37,565	37,751	37,643	37,154	38,788	39,078	39,799	40,000
	Yield (MT/ha)	10	10	14	15	15	14	14	14	13	13
Rwanda	Production (MT)	2,002,000	2,105,000	2,248,419	2,625,485	2,897,433	2,212,250	1,784,058	2,784,870	2,407,837	2,469,740
	Area (ha)	310,000	325,000	349,906	405,264	410,323	360,470	363,249	358,863	360,000	363,383
	Yield (MT/ha)	6	6	6	6	7	6	5	8	7	7
Tanzania	Production (MT)	520,720	512,720	483,280	668,640	601,280	562,160	623,531	601,600	601,600	601,600
	Area (ha)	198,560	192,800	193,120	267,760	202,400	242,800	307,922	308,000	308,000	308,000
	Yield (MT/ha)	3	3	3	2	3	2	2	2	2	2
Uganda	Production (MT)	9,012,000	9,144,000	9,303,000	9,318,000	8,949,000	9,428,000	9,732,000	9,888,000	9,605,000	9,900,000
	Area (ha)	1,512,000	1,524,000	1,538,000	1,553,000	1,570,000	1,598,000	1,622,000	1,648,000	1,656,000	1,670,000
	Yield (MT/ha)	6	6	6	6	6	6	6	6	6	6

Source: FAOStat

Note: FAO does not report plantain production for Burundi.

1 In western Kenya where the field survey was carried out, farmers had not been introduced to tissue culture bananas.

2 Farmers in Rwanda where the survey was carried out were not aware of tissue culture bananas.

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