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# FOREWORD

Kenya needs agricultural innovation for the simple reason that our people do not have enough to eat. In rural areas, few small-scale farmers grow enough food for their own needs and even fewer have a surplus to sell. Among the urban poor, 80% of family income is regularly spent on food. Malnutrition is widespread, and many families eat only one nutritionally unbalanced meal a day. Although conventional technology has gone a long way towards increasing food production, our crop yields are still low compared to world averages and they have not kept up with population growth. Biotechnology has a huge potential to increase food production and incomes, create jobs, protect our environment, and conserve biodiversity. It offers real hope not only to Kenya but also to the rest of the developing world.

Why apply biotechnology to banana? In Kenya this valuable resource has been largely overlooked, receiving little attention from farmers, researchers, or government, mainly because it has been viewed as a subsistence food rather than a cash crop. But the decline in the production of banana over the last twenty years has had a major impact on food security, particularly for subsistence farmers, and bananas have become an expensive item that many low-income groups can no longer afford. This decline has been brought about by a complex of diseases and pests, including black and yellow sigatoka, Panama disease, weevils, and nematodes. Environmental degradation, particularly declining soil fertility, has also played a part. The resulting shortfall in banana production by now affects up to 12 million people, approximately half the population of Kenya. We know, from looking at other tropical and sub-tropical countries, that our banana yields could be much higher.

Kenyan farmers themselves first pointed to the lack of clean planting material as the major limiting factor of banana production. Agricultural researchers have sometimes been justly criticised for overlooking the needs and interests of farmers when developing and introducing new technologies. Too often, the development of improved crop varieties and other innovations that are not appealing to farmers or do not fit into their production systems has cost considerable time, money, and momentum. This project worked hard to avoid such problems by conducting thorough research on farmers' constraints and varietal preferences as well as existing marketing and distribution systems. We also collected follow-up data to assess the impact of improved banana production on individual farmers and communities. Of particular significance was the decision to include a micro-credit program, which was a major influence on the success of the project. Without financial support, the majority of small-scale farmers would not be able to buy enough new planting material to make a substantial difference to their incomes. The micro-credit groups conferred many additional benefits on rural communities.

The success of the project has been astounding. Within three years, the demand for tissue culture banana plantlets has rocketed. Individual farmers have received a bumper harvest. For example, Esther Gachugu, one of our demonstration farmers, made US$300 in one day's sale–more than she would have earned in a year from her traditional banana orchard. Other farmers have been able to build new houses, send their children to school, or install water storage tanks. Individual successes are starting a ripple effect that will impact a much wider community. New business opportunities such as banana processing are now possible, and increased employment in banana production, distribution, and marketing is likely to improve living standards for a wide range of people. We hope the project will eventually lead to the development of export markets and the enhancement of regional trade, further increasing economic growth.

In some quarters the mistaken perception still exists that investing in new technology for developing countries does not produce good returns because of low, adoption rates and inadequate farm management. Of course, introducing new technology is seldom straightforward. But, this project has shown how a sound strategy that includes attention to technology transfer and education, can avoid these pitfalls. We have also demonstrated the value of public-private partnerships in developing appropriate technology and the importance of scaling up technology dissemination. Food insecurity remains a major threat to most rural communities in Kenya and other African countries. The tissue culture banana project demonstrates the potential of biotechnology to alleviate hunger by increasing food production and to reduce poverty among farmers as well as other sectors of the community. The project represents a unique learning experience for all involved in the dissemination of new technologies to small-scale farmers. The foundations laid by this project will make it easier to introduce other biotechnology innovations in the future. Overall, the project provides an opportunity for its donors and executing agencies to fulfil the responsibility they are charged with, to promote positive change and make a real impact on poverty and hunger in developing countries.

We are grateful to all the project's collaborating institutions, including ITSC for providing technical backstopping, DuRoi for providing the initial planting materials, ZEF for conducting the *ex-ante* socio-economic studies, GTL for providing planting material, and Wangu Investments and Beam Business Options for management support to the micro-credit scheme. We would also like to thank the many NGOs who provided additional support, and all the participating farmers for their great enthusiasm.

In December 2000 this project won First Research Medal in the Global Development Network awards for 'Science and Technology for Development'. From a total of 500 applicants in 94 countries, just five finalists had been chosen to present their submissions. The GDN Medals and Awards are sponsored by the Government of Japan and the World Bank and build upon other GDN activities, such as the Regional Research Competition and the Global Research Project. These activities seek to promote advancement in knowledge creation and capacity building in developing countries.

Such prestigious international recognition is certainly a source of great motivation and encouragement to carry on. And we intend to do just that!

**DR. ROMANO M. KIOME**
Director
Kenya Agricultural Research Institute (KARI)

**DR. FLORENCE WAMBUGU**
Director
ISAAA *Afri*Centre

Dr. Florence Wambugu, Director of ISAAA's *Afri*Centre, examines a tc banana crop.

**ISAAA's mission**

is to contribute to poverty alleviation, by increasing crop productivity and income generation, particularly for resource-poor farmers, and to bring about a safer environment and more sustainable agricultural development. Sponsored by public- and private-sector institutions, our objectives are the transfer and delivery of appropriate biotechnology applications to developing countries and the building of partnerships between institutions in the South (where the need is) and the private sector in the North (where most biotechnology innovations are developed and owned).

**KARI's mission**

is to develop and disseminate new technologies that are appropriate to the needs of Kenyan agriculture, where a widespread decline in yields is set against a background of increasing population. Its mandate is to increase productivity and post-harvest values, as well as promoting environmental conservation and agricultural sustainability. KARI aims to work proactively and in collaboration with all stakeholders to provide enhanced knowledge and creative solutions within a challenging environment.

# EXECUTIVE SUMMARY


The project *Biotechnology to Benefit Small-Scale Banana Producers in Kenya* was developed in response to the rapid decline in banana production in Kenya over the last 20 years. This decline was due to widespread soil degradation and the infestation of the nation's banana orchards with pests and diseases, problems further aggravated by the common practice of propagating new banana plants using infected suckers. The situation was threatening food security, employment, and incomes in banana-producing areas.

Thus the broad goal of the project was to make clean planting materials of improved banana varieties available to small-scale farmers, with the ultimate objective of helping to alleviate poverty and hunger. Tissue culture technology was considered an appropriate option to provide sufficient quality and quantity of such materials.

The project was facilitated by ISAAA and hosted by KARI. Careful project preparation included the selection of appropriate partner institutions in both the private and public sectors. A sound strategy for technology transfer and application was devised, with feedback and monitoring at all stages of the project—from the laboratory, through farmers, to consumers. Extensive field trials were conducted on farms as well as research stations, and demonstration farmers were recruited to disseminate the technology by example. A multidisciplinary approach was taken towards all project activities, and research and development were seen as integrated rather than as separate activities.

Results from the field trials were very positive: tc plants showed significant improvements in yields and growth statistics compared to plants grown from conventional suckers. Important data concerning the suitability of particular cultivars in different parts of the country were also collected. In general, farmers were very enthusiastic about the potential of tissue culture technology for banana production. They were particularly motivated by the capacity of the crop to generate additional income, which helped to change their perception of banana from a mainly subsistence resource to a viable cash crop.

An independent *ex-ante* impact study predicted that tissue culture technology applied to banana production could result in a substantial increase in yields, especially on small-scale farms. This finding was in contrast to the widespread belief that smallholders cannot benefit from modern biotechnology applications.

The project also incorporated technology diffusion research, which identified several potential constraints to the adoption of tc banana by Kenyan farmers, including:

- Relatively high cost of the tc plantlets compared to conventional suckers
- The need for a wide choice of varieties
- Gender issues
- Higher requirement of tc banana for labour and inputs
- Limited availability of clean land
- Limited established marketing and distribution systems

Accordingly, a pilot micro-credit scheme was introduced in response to the affordability issue of the tissue culture plantlets. This enabled small-scale farmers to purchase sufficient planting material to realise the benefits of the technology. The scheme follows the Grameen Group Approach and has been highly effective. Formation of micro-credit groups has brought wider benefits to the communities involved, such as education on banana orchard management and cooperation in distributing and marketing the crop.

Due to its considerable success, the project will be continued into a second phase. This will seek to overcome adoption constraints and to establish a self-sustaining system of production, distribution, and utilisation of tissue culture banana plantlets, which will provide long-term benefits for farmers and further entrepreneurial opportunities for the private sector. More varieties will be offered and the project will be extended to new areas within Kenya and across the East Africa region.

Increasing banana production has the potential to improve the standard of living of many small-scale farmers, while making a staple food more affordable for the urban poor. The surplus created by tc banana farming is likely to lead to an increase in demand for other goods and services, exerting a positive effect on the whole economy and creating new business and employment opportunities. Furthermore, improved banana orchard management has important environmental benefits, particularly in regards to soil conservation. Knowledge gained during the project has also enhanced Kenya's national biotechnology capacity, paving the way for the more rapid dissemination of future biotechnology innovations. The unprecedented success of this project suggests its usefulness as a model for improving the performance of other commodities in different communities. Overall, the project irrefutably demonstrates that biotechnology is a powerful tool for battling poverty and hunger in the developing world.

# 1. INTRODUCTION

## 1.1 Banana—A Valuable Resource

In Kenya, as in other parts of the tropical and subtropical developing world, banana is a highly important food crop. Around 63% of the world's banana production originates in Latin America and the Caribbean, where a large proportion is exported. Africa is also a major producer, contributing 35% of world production, but it exports very little. The East Africa region produces almost half of Africa's banana crop, providing a staple food and source of income for an estimated 20 million people (INIBAP, 1991).

Banana is an attractive crop for small-scale subsistence farmers for several reasons:

- Banana is a popular food and provides a good source of carbohydrates, vitamins, and minerals. It has long been regarded as an ideal baby food.
- Surplus production provides a reliable source of income—further contributing to household security.
- Production begins within 12 to 18 months of planting and good yields can be produced for ten years or more, with a low labour input.
- Once the crop is established, harvesting can occur continuously throughout the year, rather than over a short seasonal period.
- Under optimum conditions, banana can outperform many other crops in terms of yield per hectare.
- Banana is suitable for intercropping and provides soil stability and shelter for other plants. It is thus a valuable crop for environmental conservation.

But despite its versatility, banana production has its problems. Not just in Kenya but throughout the tropics, a lack of awareness about new technology and of the benefits of applying inputs, together with a rising incidence of pests and diseases, seriously limits yields.

## 1.2 Banana Growing in Kenya

In Kenya, banana covers an estimated 2% of the country's total arable land, an area equivalent to 74,000 hectares (MALDM, 1997). The crop is predominantly grown by small-scale farmers, who have an average banana holding of just 0.3 hectares (Qaim, 1999). Traditionally, banana has been a staple food for both rural and urban populations, -and it also provides a source of income for the small-scale producer. However, a substantial proportion (24%) of the nation's banana crop is still produced on a subsistence basis, i.e. the bananas are consumed on the farm where they are grown (Qaim, 1999).

Bananas are grown widely, from sea level to around 1800 metres, mainly in the areas of greatest rainfall. The main centres of production are Nyanza, Central, Eastern, and Western Provinces (Table 1). There is a wide range of different varieties, with factors such as local tastes, eating habits, marketing considerations, and environmental conditions influencing their distribution. In general, the East Africa highland cooking bananas (AAA) and the Apple Banana (AB) are predominantly grown in Nyanza and Western Provinces. In Central and Eastern areas, the dessert bananas, mainly Cavendish (AAA), predominate, although local cultivars such as Muraru also exist (Nguthi, 1999).

**Figure 1. The provinces of Kenya.**

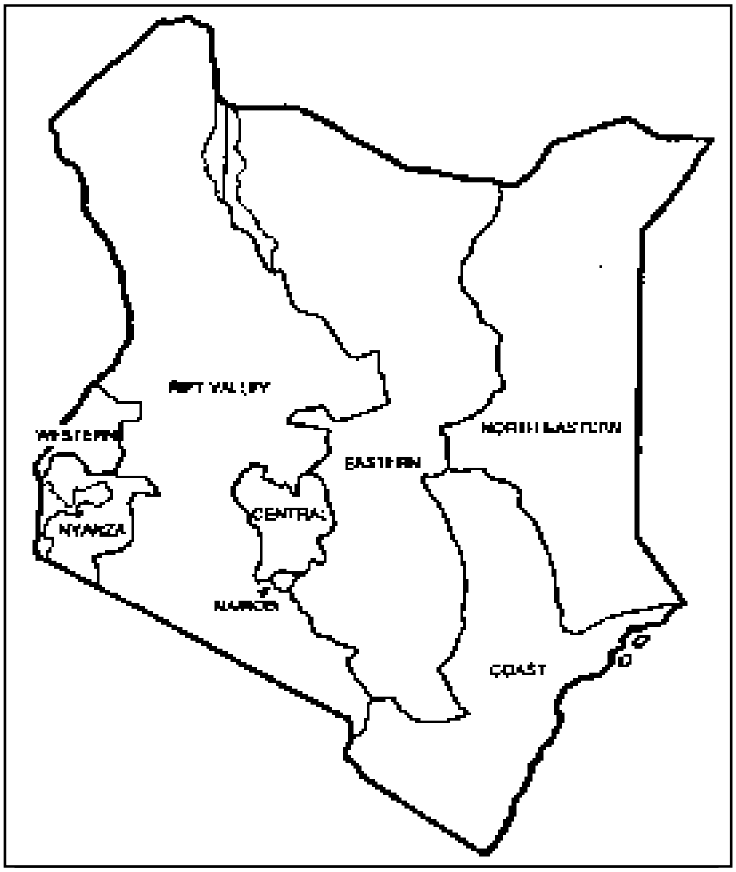
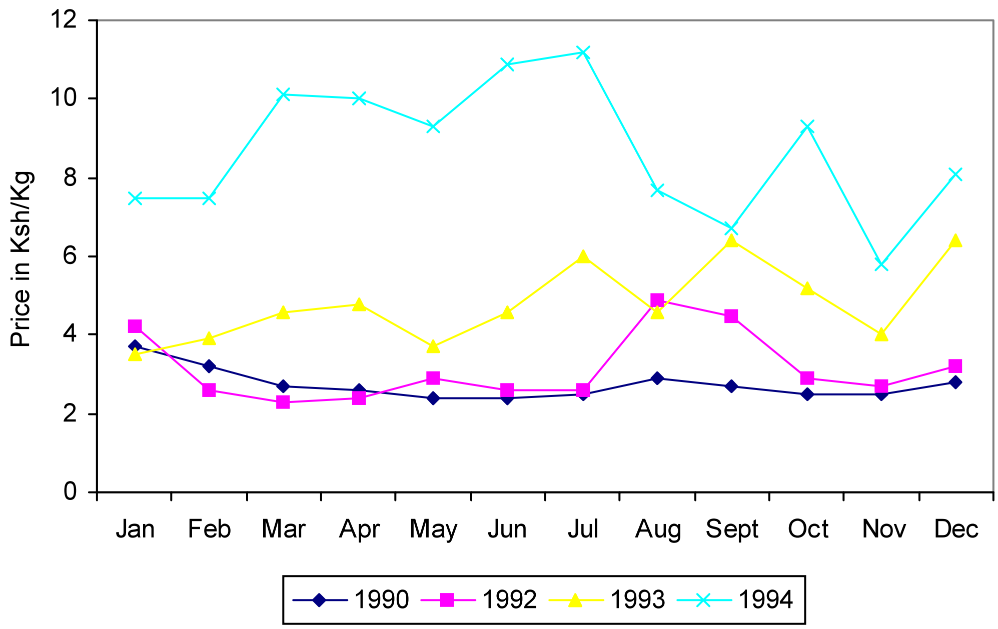



**Table 1. Average banana production statistics for the provinces of Kenya (1996-97).**

| Province | Area (ha) | Production (t) | Yield (t/ha) | Production (t) |
|---|---|---|---|---|
| Central | 16, 913 | 169,316 | 10.0 | 16.5 |
| Coast | 5,743 | 55,341 | 9.6 | 5.4 |
| Eastern | 9,669 | 97,144 | 10.0 | 9.5 |
| Nairobi | 48 | 409 | 8.5 | 0.0 |
| North Eastern | 271 | 1,522 | 5.6 | 0.1 |
| Nyanza | 30,234 | 574,740 | 19.0 | 56.1 |
| Rift Valley | 2,688 | 39,781 | 14.8 | 3.9 |
| Western | 7,800 | 86,107 | 11.0 | 8.5 |
| **TOTAL** | **73,366** | **1,024,360** | **14.0** (average) | **100.0** |

In recent years, the banana growers of Kenya have become more reliant on the cash generated by this crop. This has occurred especially in areas where incomes from more traditional cash crops (such as coffee) have declined. Most small-scale farmers, however, maintain traditional production systems and achieve only meagre yields. The nation's average banana yield is only 14 tons per hectare, a figure less than a third of the crop's potential under the favourable conditions of the humid tropics (Qaim, 1999). Over the last twenty years, banana production has fallen (MOA, 1994) and prices have risen dramatically (Figure 2). Bananas no longer provide a ready supply of nutritious food and cash, which threatens food, employment, and income security in banana-producing areas.

**Figure 2. Average retail prices of banana in major markets in Kenya, 1990-94.**




*Source: Agricultural Statistics Section, Central Bureau of Statistics, 1994*

The poor banana yields in Kenya can be attributed to a number of factors:

- Lack of clean planting material (the most important factor)
- Pests and diseases
- High rate of population increase. This has reduced available land per family and has limited the opportunity for pest and disease control by fallowing and crop rotation
- Lack of awareness among farmers of the technology available to improve yields and control pests and diseases
- Low levels of management
- Decline in soil fertility

The recent decline in yields can largely be attributed to the infestation of Kenya banana orchards by pests and diseases (Table 2). Current management practices that use infected suckers to grow new plants

*Many of Kenya's banana orchards are infested with pests and diseases.*

exacerbate this problem. For farmers seldom buy new planting material; instead, new banana stems are grown from suckers of possibly diseased material obtained from old plants on the same farm or from nearby farms and markets. This practice continues due to the lack and high cost of clean planting material and because farmers are unaware of the need for such material. Furthermore, traditional control measures such as fallowing are often no longer practical due to high population pressures on the land. More recent approaches, such as the use of chemical pesticides, are prohibitively expensive and are undesirable on environmental and human health grounds. Inadequate land for crop rotation among smallholder farmers and the intensification of agriculture have also contributed to diminishing soil quality and reduced productivity.

Unlike export-oriented banana-growing regions of the world, in Kenya the crop is managed mostly as a food security crop. Banana growing is often the responsibility of the female members of the household, who

**Table 2. Principal pests and diseases affecting Kenya's banana orchards.**

| Pests | Diseases |
|---|---|
| Weevils<br>*Cosmopolites sordidus* | Fusarium wilt (Panama disease)<br>*Fusarium oxysporum* f. sp. *cubense* |
| Nematodes<br>*Radopholus similis*<br>*Pratylenchus goodeyi* | Black sigatoka leaf spot<br>*Mycosphaerella fijiensis* |
| | Yellow sigatoka leaf spot<br>*Mycosphaerella musicola* |
| | Cigar-end rot<br>*Verticillium theobromae*<br>*Trachysphaera fructigena* |

*Source: World Bank, 1996; Ministry of Agriculture-Kenya, 1994.*

harvest this continuous food and cash crop under very low input regimes. In 51% of cases, bananas receive no inputs at all—they are not treated with any chemicals or manure (Qaim, 1999).

Bananas have no commodity board or growers' association to promote research, distribute new varieties, or encourage marketing (unlike major cash crops such as tea and coffee). Instead, marketing channels are made up of individual producers selling small surpluses in local markets, while larger quantities are distributed via an informal chain of private traders or brokers to reach urban consumers.

The banana industry in Kenya therefore has great potential for improvement. Yet as long as farmers persist in propagating infected suckers, yields will continue to decline. An alternative source of clean planting material through tissue culture (tc) biotechnology, together with education on how to manage the plants, has the potential to lead to a dramatic improvement in yields, income, and overall standards of living.

## 1.3 Biotechnology in Banana Production

The advent of laboratory methods of micropropagation provides new opportunities for the rapid multiplication of pathogen-free planting materials in vegetatively propagated crops such as banana. Tissue culture is a relatively simple technique that has been used for commercial banana propagation in several countries, including Costa Rica, Israel, and South Africa, since the mid-1980s.

The basis of the technology is the ability of many plant species to regenerate a whole plant from a single shoot tip. The tiny shoot-tips are first dissected into small pieces under sterile conditions, then placed into a growth medium containing carbohydrates, macro and micro-nutrients, and other hormones. Different hormones are added at different stages to enhance various processes of growth, such as shoot initiation, multiple shoot formation, and rooting induction. These hormones induce vigour, commonly referred to as 'hormonal kick', bringing the parent material to a juvenile stage and causing remarkable physiological changes that influence the agronomic characteristics of the emerging plant. The cycle of division can be repeated 7 to10 times to produce up to 2,000 plants from the initial shoot-tip. Any further increase in production (above 2,000 plants) is undesirable since it is associated with the risk of somaclonal variants.

Tissue cultured banana plantlets have several advantages over traditionally propagated sucker material (Robinson, 1994):

- The sterile conditions of tissue culture eliminate pests and most diseases.
- Large numbers of healthy plantlets can be produced in a relatively short time,

*Banana undergoing tissue culture propagation.*

allowing rapid introduction of new germplasm.
- The resulting plants are more productive, reach maturity earlier, bear higher yields of bananas, and have shorter intervals between harvests.
- The plants are of uniform size and will all reach maturity at the same time. This facilitates orchard management and allows harvesting of the crop within the same month. If they use sufficient irrigation, farmers can produce off-season, facilitating commercial marketing and providing a substantial cash income.

There are, however, some drawbacks that could limit the uptake and profitability of tissue culture material:

- Tc plantlets are much more expensive to produce than conventional suckers. Price reductions are likely as the scale of *in vitro* production rises, but the price is likely to remain prohibitively high for many small-scale farmers.
- Tc plantlets require more labour and inputs than farmers currently give to their banana crop. To realise higher yields, manure and water are essential during the growth phase. Pesticides to disinfect the soil may also be needed.
- The occurrence of somaclonal variants (off-types) has frequently been reported (Israeli *et al.*, 1995) and can lead to undesirable features such as dwarfing. The mutation rate can be kept low by reducing the number of multiplied shoots per ex-plant. Thus, a balance must be found between a high rate of production (reducing the cost per plantlet) and keeping mutations to a minimum. This means that private companies mass-producing tc plantlets must exercise tight quality control to ensure that the balance is kept.
- Viruses, such as banana bunchy top and banana streak virus, can still be transmitted through tc plantlets. Although viruses are not a significant problem in Kenya at the moment (Hull, 1997; Kung'u, 1998), there is a risk that they could be brought into the country through imports of infected *in vitro* material.

The application of biotechnology to the Kenya banana industry therefore has enormous potential to improve yields and the standards of living of resource-poor rural farmers. However, thorough field evaluation and extension education on good agronomic practices for farmers, NGOs, and other stakeholders is vital to facilitate uptake and ensure the appropriate management of this new technology.

## 1.4 Background to the project

In 1996, the Kenya Agricultural Research Institute (KARI) requested ISAAA to facilitate a project that would introduce new technology to improve banana production in Kenya. In Kenya as in Africa as a whole, average yields of banana, like other major food staples, are significantly lower than in the rest of the world (Table 3). Worse still, in many cases they are still declining.

The KARI-ISAAA project was intended to realise the benefits of tissue culture for improving banana production on smallholder farms. All of the objectives of the project building and upgrading banana tc capacity, expanding the genetic base of banana and the varietal choice for growers, and developing a sustainable distribution system for tc materials—were subordinate to this aim.

**Table 3. Global and African yields of staple food crops.**

| Crop | Africa (Ave. yield in t/ha) | World (Ave. yield in t/ha) |
|---|---|---|
| Banana | 6.0 | 10.1 (Potential 60) |
| Maize | 1.7 | 4.1 |
| Cassava | 8.4 | 10.0 |
| Sorghum | 0.9 | 1.5 |
| Sweet potato | 4.8 | 14.7 |
| Potato | 11.3 | 16.1 |
| Wheat | 2.0 | 2.5 |
| Tomato | 21.2 | 27.4 |

*Source: FAO Year Data Book, 1996.*

Special attention was paid to the challenge of integrating tc technology with current farming practices in Kenya. By developing a successful model in Kenya, it was hoped that the project could later be extended to other countries, including Uganda and Tanzania.

## 1.5 Partnerships

From the project's inception, ISAAA had a clear vision of the direction and of the strategies that would ensure its success. As the lead institution, it assembled a multidisciplinary team that included biological scientists and socio-economists from several institutions. A major strength of the project was the formation of partnerships with both public- and private-sector institutions, which helped to promote a sustainable system of technology development and dissemination. Collaboration at a local level was greatly enhanced by Kenya's strong network of NGOs, such as church and women's groups. The Kenyan tradition of 'harambee' or pulling together helped farmers and researchers work together to evaluate the tc technology.

ISAAA identified KARI as a suitable collaborator to host the project, based on the following attributes:

- The comparative advantage of having a network of research centres throughout the country, including the banana-growing areas
- The human resource capacity to conduct on-station cultivar evaluations and agronomic studies for varieties that were not grown locally
- The necessary infrastructure to support extension and advisory services

At the start of the project, KARI and the Jomo Kenyatta University of Agriculture and Technology (JKUAT) had some experience with tissue culture techniques and were distributing small quantities of tc banana plantlets to farmers in an informal way, without any follow-up or evaluation. Since Kenya did not have sufficient capacity to mass produce plantlets, DuRoi laboratories, a private company in South Africa with long experience in tissue culture multiplication, was approached. This was important because the project needed to use high-quality materials to ensure favourable early reactions from farmers, whose attitudes would substantially affect subsequent adoption rates. A local counterpart private company in Kenya, Genetic Technologies Limited (GTL), was identified to handle the materials after they arrived from South Africa. GTL had experience with tissue culture work in other crops (pyrethrum and sugar cane), bringing valuable expertise to the project. Involving private companies right from the start meant that the project not only had a reliable supply of high-quality planting materials but was also able to confirm the feasibility of establishing the necessary commercial infrastructure to ensure the supply of plantlets in the longer term.

Technical backstopping was considered crucial to the success of the project, and the Institute of Tropical and Sub-Tropical Crops (ITSC), a public-sector institution in South Africa with the relevant experience and human resource capacity, was identified to perform this task. ITSC had conducted several studies which showed that the benefits of tc plantlets far outweigh the higher costs of production (Robinson, 1995), and this had provided the basis for successful commercialisation and the establishment of a healthy export trade in South Africa. Experience in South Africa and elsewhere also showed that strong links with farmers, including feedback and interaction between farmers and the tc laboratory, are essential for successful commercialisation. Additional technical support was provided by the UK's John Innes Centre, which investigated the incidence and diagnosis of viral diseases in Kenya.

ISAAA secured the agreement of the Rockefeller Foundation (RF) and the International Development Research Centre (IDRC) of Canada to fund the project. In addition, the African Technology Policy Studies (ATPS) network provided funds for banana technology diffusion research. This was important since past experiences have shown that if the needs of end-users are overlooked, then little adoption of new technology takes place. In addition, The Zentrum für Entwicklungsforschung (ZEF) of the University of Bonn, Germany, carried out an *ex-ante* impact assessment study. Table 4 summarizes the responsibilities of the main partners involved in the project.

The banana project has also benefited from lessons learned during the application of tissue culture techniques to other valuable crops in Kenya, including cut flowers, pyrethrum (a source of natural pesticide), and sugar cane. In all these commodities, the importance of integrating research, education and technology diffusion, and public-private partnerships had been demonstrated by the time the KARI-ISAAA project began.

**Table 4. Summary of the main institutions involved and their responsibilities.**

| Objective | Institutions | Main Output | Requirements |
|---|---|---|---|
| Tc Production | GTL, KARI, DuRoi Laboratories (S. Africa) | Selection of varieties, tc production, quality control and assurance, training in nursery management | Enhanced public-private collaboration, stringent quality control |
| Strategic/Adaptive Research | KARI, ATPS, ISAAA, farmer groups | On-station trials, varietal comparisons, spacing, agronomy, tc versus sucker comparisons, intercropping, training, demonstrations, and technology diffusion | Appropriate infrastructure and policy framework |
| Distribution | KARI, ISAAA, CBOs, farmer groups | Distribution mechanism channels – schools, churches, on-farm trials, markets, village leaders, and farmers | Well designed marketing plan, entrepreneurial skills, and willingness to participate |
| Links with farmers | KARI, STPS, ISAAA | Needs assessment through PRA, varietal choices, orchard management, access to tc plantlets, on-farm trials, training, large and small-scale farm demonstrations, and financing | Participatory approach geared towards meeting farmer expectations and aspirations |
| Marketing | KARI, ATPS, ISAAA, ZEF (Germany) and farmer groups | Socio-economics: pricing, quality control, distribution and training | Market structure establishment, post-harvest handling/packaging standards |
| Expansion | Micro-entrepreneurs, NGOs | Manure application, micro-irrigation, Banana Growers' Association, private investments (e.g., banana-related businesses and export markets) | Political and economic stability, entrepreneurial skills for identification of business opportunities |
| Technical backstopping | ITSC (S. Africa), John Innes Centre (UK) and DuRoi Laboratories (S. Africa) | Designing appropriate field management packages, commercialisation, strategy, virus disease diagnostics and training | Public-private collaboration, networking, and experience sharing |

**NB:** *Funding was mainly from the Rockefeller Foundation and the IDRC*

**Key:** *CBOs = Community-based organizations, NGOs = Non-governmental organizations, PRA = Participatory rural appraisals, ATPS = African Technology Policy Studies*

## 2. OBJECTIVES OF THE BANANA BIOTECHNOLOGY PROJECT

The overall goal of the project was to improve living standards for rural families, in particular those whose livelihoods depend on the production of banana. The following objectives were identified (KARI, 1997):

### 2.1 General objective

To make available to farmers in Kenya, particularly resource-poor and small-scale farmers, improved banana plantlets for increased production and productivity, leading to better nutrition and income generation.

### 2.2 Specific objectives

- To establish a pilot production facility, well linked with field evaluation, distribution, marketing, and feedback activities.
- To develop on-station and on-farm activities linked with farmers, extension services, NGOs, and other end-users to ensure tissue culture banana plantlets are evaluated, distributed, marketed, and utilised, primarily (but not exclusively) by small-scale farmers.
- To investigate the market opportunities and preferences for different banana cultivars in relation to the tissue culture production technology.
- To explore the possibility of using tissue culture plants to establish in situ nurseries from which clean suckers can be obtained as a preferred source of planting material over juvenile tissue culture plants and conventional suckers.
- To develop a regional training centre to oversee the production, evaluation, and placement of tc material with end-users.
- To create a model project to demonstrate the successful application of biotechnology to bananas in Kenya and to transfer this model to other countries, including Tanzania and Uganda.

## 3. METHODS AND STUDIES

### 3.1 Participatory rural appraisal

Participatory rural appraisal (PRA) was carried out to assess the needs of banana farmers in Kenya. PRA is a way of learning from and with farmers to investigate, analyse, and evaluate opportunities and constraints, making it possible to come to informed decisions about agricultural development projects. Four PRA focus groups were held, one in each study area, with over 150 farmers attending each meeting. The lack of clean banana suckers for planting was identified as the major factor preventing increased banana production, and the problem of severely degenerated orchards due to pests and diseases was also highlighted. These findings indicated that banana farmers urgently need improved, disease-free banana planting materials. Tissue culture was viewed as a viable solution to the problem. Additional factors of relevance to the long-term success of the project were also identified (e.g., information about the cultivars currently grown and the most frequently occurring pests and diseases). This information assisted in the selection of the improved varieties to be evaluated. The aim was to provide tc plantlets that would have appropriate resistance characteristics and would be acceptable to farmers.

### 3.2 Field Evaluation

Four regions were identified to represent the major agro-ecological zones (AEZs) of Kenya in which bananas are grown (Table 5). On-station evaluations were made at Thika in Central Province, Kisii in Nyanza Province, Embu in Eastern Province, and Mtwapa in Coast Province. On-farm trials were also carried out in the same areas, under the supervision of KARI. All trials were based on a randomised complete block design with three or four replications. Tc materials were imported from South Africa and several improved varieties were evaluated, including Gold finger, Valery, Grand nain, and Giant, Chinese, and Williams from the Cavendish group. These varieties were chosen because they represented a broad range of attributes and satisfied the criteria identified through the PRA studies. For example, Gold finger (bred in Honduras) is high yielding and tolerant to *Fusarium*, sigatoka, weevils, and burrowing nematode. The Cavendish group of dessert bananas is popular with farmers and consumers in Kenya as well as worldwide and is also tolerant to some races of *Fusarium*. Specific cultivars for the trial sites were chosen based on their suitability for each AEZ.

**Table 5. Tissue culture banana study locations.**

| Location | Province | AEZ | Altitude (m) | Rainfall (mm) | Participating farmers |
|---|---|---|---|---|---|
| NHRC-Thika | Central | $UM_3$ | 1500 | 900 | On-station |
| Murang'a/Maragua | Central | $UM_2$ | 1400 | 1750 | 250 |
| Gathiga-Kirinyaga | Central | $UM_4$ | 1300 | 600-950 | 135 |
| RRC-Kisii | Nyanza | $UM_1$ | 1750 | 1800 | On-station |
| Kenyenya | Nyanza | $UM_1$ | 1700 | 1800 | 20 |
| Suneka | Nyanza | $LM_2$ | 1500 | 1500 | 40 |
| RRC-Embu | Eastern | $UM_3$ | 1500 | 1000-1250 | On-station |
| Embu-Gatituri | Eastern | $UM_2$ | 1450 | 1000-2000 | 15 |
| RRC-Mtwapa | Coast | CL | 0-50 | >2000 | On-station |
| Mtwapa | Coast | CL | 0-50 | >2000 | 10 |

**Key:** *NHRC = National Horticultural Research Centre, RRC = Regional Research Centre, UM = Upper Midland, LM = Lower Midland, CL = Coastal Line*

The following performances were assessed:

- Tc banana plantlets versus conventional suckers
- Tc banana varieties in different AEZs
- Tc plants versus tc first-generation suckers
- Different planting densities

In addition, any advantage of tc plants in terms of yield and early maturity of the crop as well as farmer acceptability of different cultivars was noted. First-generation suckers were assessed to evaluate whether the superior vigour of the tc plantlets was carried over.

### 3.3 *Ex-ante* impact study

Matin Qaim, then a PhD student in agricultural economics at ZEF, University of Bonn, Germany, conducted an independent study on the probable socio-economic impact of tc technology on farmers. Having collected and analysed a wide range of data, he then made predictions of banana production, income generation, and the overall profitability of using tc planting material on different sized farms. ISAAA Brief no.10 (1999) describes his findings in detail.

### 3.4 Marketing and technology diffusion research

To successfully introduce tc technology, the new tc varieties must appeal to growers and comply with their production systems. Effective marketing and distribution channels for the anticipated increase in production must also be prepared. Accordingly, a thorough marketing study was included in the project. Technology diffusion research was needed to identify farmers' adoption constraints, and based on these strategies were formulated that would increase demand and ensure the effective management of tc banana plantlets.

At least 40-50 respondents were interviewed in each of the study regions. Data were collected on various topics including:

- Choice of variety to suit grower and consumer preferences
- Compatibility of tc banana with existing farming practices
- Potential impact of the cost of tc plantlets
- Gender issues
- Current status of marketing and distribution systems

Detailed research covering all stages of the tc technology process—from laboratory to consumer—was important to identify potential constraints that might affect the rate of uptake, as well as the best ways to disseminate the banana tc technology.

*Interviewing a Kisii banana trader in a local roadside market.*

## 4. RESULTS

### 4.1 Overview

In general, farmers were very enthusiastic about the potential of tc technology for banana production. They were particularly motivated by the capacity of the tc crop to generate additional income, especially where there was a need to compensate for lost revenue from other poorly performing commodities, such as coffee. Enormous interest was generated, especially in the trial areas, with a corresponding increase in the demand for tc planting materials. Factors contributing to the farmers' positive reaction were the fast growth rate, high yields, and uniform production of tc plants. Conventional suckers normally take over 18 months to produce a crop and tend to mature at different times. With tc plants, farmers are able to harvest all of the crop within a short period, providing a substantial lump sum of money. This helped to change their perception of banana from a mainly subsistence resource to a viable cash crop.

### 4.2 Field evaluation

#### *Tc banana plantlets versus conventional suckers*

Field trials of tc banana plantlets were extremely encouraging, with a considerable overall increase in yields compared to conventional suckers. On-station trials showed a 19% increase (Table 6), while small-scale farmers were harvesting bananas with a bunch weight averaging 40kg, compared to their previous (non-tc) average of only 15-30kg (MOA, 1994), an increase of at least 30%. In addition, the growth rate of tc plants was generally higher than that of conventional suckers.

**Table 6. Comparison of tc plants versus conventional suckers at NHRC Thika.**

| | Days to harvest | Yield (t/ha/year) |
|---|---|---|
| Tissue culture | 341 | 49.9 |
| Conventional suckers | 414 | 41.9 |

#### *Different cultivars and AEZs*

The banana varieties chosen for Phase I of the project were generally well received. Two of the introduced cultivars—Grand nain and Chinese Cavendish—were accepted as viable alternatives to one of the most popular local varieties, Gros michel, which has been devastated by *Fusarium* wilt. In addition, the new Gold finger variety, which has good resistance to *Fusarium* wilt and black and yellow sigatoka, has gained popularity as a cooking type.

Table 7 shows the performance of some of the improved tc cultivars across different trial sites. The results illustrate several important points:

1. Growth rate was highest at Mtwapa in Coastal Province, probably due to the hot and humid climate, together with the use of irrigation. Tc cultivars with fast cycles are especially productive in warmer areas, but farmers need to ensure adequate rainfall or irrigation in order to maximise yields.
2. The lowest average yields were

**Table 7. Tc banana yields in different trial locations.**

| Cultivars | Yield per annum (t/ha) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Central Province | | | East Province | Nyanza Province | | | Coast Province | | |
| | Thika | Mura ng'a | Kerin yaga | Embu | Kisii Suneka | Kisii Kenyenya | Kisii RRC | Mtwapa (Khosla farm) | Average | Suscepti-bility to diseases |
| Chinese Cavendish | 56.2 | 66.0 | 79.7 | 59.6 | 35.6 | 20.0 | 22.9 | 28.3 | 46.0 | BS+ FOC- |
| Dwarf Cavendish | 60.4 | 54.5 | 77.8 | 34.0 | 37.5 | 22.1 | 29.1 | 31.0 | 43.3 | BS+ FOC- |
| Grand nain | 66.5 | N/A | N/A | 71.0 | N/A | N/A | 29.6 | 33.3 | 50.1 | BS+ FOC- |
| Gold finger | 55.6 | N/A | 75.5 | 37.1 | 33.0 | 20.3 | 20.8 | 36.2 | 39.8 | BS+ FOC- |
| Average | 59.7 | 60.3 | 77.7 | 50.4 | 35.4 | 20.8 | 25.6 | 32.2 | 44.8 | |
| Maturity period (months) | 10.0 | 9.1 | 9.6 | 15.7 | 13.9 | 16.8 | 15.5 | 8.6 | 11.0 | |

**Key:** *N/A = Data not available; BS = Black sigatoka; FOC = Fusarium wilt; + = susceptible; – = not susceptible*

obtained in Kisii (Nyanza Province), which has historically been the best yielding province in the country (MALDM, 1996 and 1997). Lower than expected yields were due to a prolonged drought that lasted for three months after planting. The farmers used some irrigation, but this was clearly not sufficient. Although yields in the region of 20 tons/hectare were achieved, the results illustrate the vulnerability to drought of young tc plantlets and underscore the need for adequate irrigation, at least during the first five months after planting.

3. Comparison of different cultivars reveals that different varieties appear to be best suited to different regions. For example, Gold finger had the highest yields in the Coastal Province, but the lowest in Nyanza. Gold finger has good resistance to black sigatoka and its introduction is therefore expected to have a marked effect on yields–in the Coastal region. The presence of black sigatoka in the Coastal region reduced-yields of the Cavendish group, but this did not occur in Nyanza.
4. Dwarf Cavendish was found to be unsuitable in the highlands due to its high susceptibility to cigar-end rot, although it is doing well along the coast. This demonstrates the importance of selecting cultivars for a given location not only for their acceptability to farmers but also for their capacity to tolerate local pests and diseases.

### *Tc plantlets versus tc first-generation suckers*

Under on-station conditions, early results indicate that there is little difference between tc plantlets and first-generation suckers in the growth parameters measured (e.g., plant height, girth, and days from planting to flowering), indicating that the increased vigour of tc plants may be carried over. However, at farm level, farmers have reported comparative advantages of tc plantlets over first-generation suckers and have decided to buy tc plantlets to expand their orchards instead of using suckers. (The issues surrounding the use of first-generation suckers as new planting material are discussed further in Section 6.5.)

### *Optimum planting density*

On-station trials at Thika showed that plant growth was enhanced when planting was at a relatively high density (2,222 plants per hectare). This is probably due to the microclimate created in closer spacing, which allows just enough light into the orchard. Too much sunlight dries the soil and may interfere with microbe activities, resulting in poor plant growth. In addition, the plants compete for light and grow faster at a higher plant density. These findings are in agreement with other data from the tropics that indicate yield per hectare is increased at higher plant densities (Robinson, 1996; Robinson and Nel, 1988). However, high-density planting will induce a longer crop cycle, smaller bunches, and smaller fruit, although total yield per hectare will increase due to the greater number of bunches. Robinson *et al* (1994) found that production costs per hectare increased drastically at a high density of planting. The optimum density is defined as that at which gross margin per hectare per annum is maximised over the entire plantation life. This definition integrates input


*Field trials with tc banana plantlets in Western Region.*

costs, prices received, and marketable yield over the long term.

Plant density is therefore an important factor in the establishment of a new tc banana orchard. Farmers should be advised to plant their tc seedlings at the optimum planting density in order to maximise yields. This may allow farmers to reduce the area planted with banana, while actually increasing the total yield. Income generation is then likely to be improved, both from the banana orchard itself and from the extra land made available for growing additional crops on the same farm.

### *Banana tc plantlet distributors*

The success of the field evaluations has increased the demand for tc plantlets. As a

**Table 8. Tc banana distributors.**

| | |
|---|---|
| **Embu Catholic Diocese** | Church-based organisation with a potential outreach of 30,000 farmers in Easter and Central Provinces |
| **Wangu Investment Ltd.** | Community-based NGO and cooperative, serving over 3,000 farmers in the central region |
| **Individual entrepreneurs** | Several entrepreneurs have set up nurseries and distribution for tc materials, with sales of up to 1,000 plantlets per week during the planting season. |
| **Public institutions** | KARI, JKUAT, and Kenyatta University continue to provide limited quantitites of tc materials for distribution, mainly to medium- and large-scale farmers. |
| **Private companies** | GTL and Kalimoni Tissue Culture Services Laboratory are the leading private companies. |

result, several tc banana distributors now exist in the different banana growing areas (Table 8).

The project deliberately sought to involve the private sector in the propagation and distribution of tc materials. Results to date indicate that it will be possible to promote an efficient, sustainable distribution system with the private sector supplying the quantity and quality of material that is required. However, the issue of high and variable pricing within the various private tc labs still needs addressing.

### 4.3 *Ex-ante* impact study

This independent socio-economic study was based on farm-level data as currently observed (i.e. without the widespread use of tc plants), and on banana experts' projections of adoption rates and yields. The resulting predictions indicate that there is potential for substantial growth in average yields, especially on small-scale farms, where yields could rise by up to 150% (Qaim, 1999). This finding was in complete contrast to the widespread belief that small-scale farmers cannot benefit from modern biotechnological applications. The study also demonstrated the potential for high profitability, since tc technology considerably increases the net return on labour costs. However, a high level of investment is required, with production costs for small-scale farmers rising by up to 130%. Qaim suggested several initiatives that could lower the smallholder's perceived risk and speed up diffusion of the technology:

- Reduce the cost of the plantlets (for example by using first-generation

suckers as a source of new planting material)
- Create awareness and improve information flow amongst the farmers
- Form farmers' groups, for example a Banana Growers' Association for collective bargaining in the production-marketing chain
- Provide a source of micro-credit, for example in the form of a revolving fund
- Extend the range of varieties for which tc plantlets are available

The study concluded that tc banana technology is likely to produce important welfare gains for Kenya's producers and consumers, with the possibility of access to export markets. In addition, it opens the way for more rapid dissemination of biotechnology innovations in the future. An example of such an innovation is genetic modification for sigatoka resistance, which may soon become available as a result of research by organisations such as the International Network for the Improvement of Banana and Plantain (INIBAP) and the International Institute of Tropical Agriculture (IITA).

### 4.4 Marketing research

Results from the marketing research indicated that farmers generally prefer to eat banana varieties that are familiar to them. Farmers from Kisii expressed some reluctance to change from their local banana types to improved tc cultivars during the early stages of the project. However, they were highly impressed by the improved yields and better resistance to pests and diseases achieved with the new varieties. In several cases, farmers who had initially refused to try tc plantlets changed their minds when they saw the performance of their neighbours' new tc orchards.

The criteria used to assess consumer acceptance included taste, colour, size, and finger holding capacity. The tc bananas met with excellent consumer acceptance, generally having all the qualities that consumers are looking for, and there have been no problems reported in the markets regarding palatability. However, results from consumer studies showed marked differences in regional preferences. For example, in Kisii (Western Province), Kisii Sweet was the favourite, especially with the women, but Chinese Cavendish is gaining in popularity. In Maragua (Central Province), Grand nain has become a popular alternative to Gros michel, which is very susceptible to *Fusarium* wilt. The cooking banana Gold finger is also in demand, especially in areas affected by sigatoka. Dwarf Cavendish was favoured as a fruit, but found to be susceptible to cigar-end rot in the highlands. However, this variety does well at the coast where the small fruits are quite popular with tourists. Dwarf Cavendish is unfortunately highly susceptible to black sigatoka, and this is prevalent at the coast, so the introduction of Goldfinger (which is tolerant to black sigatoka) is an ideal choice. In urban areas, the most popular traditional variety is Gros michel, which has been severely affected by *Fusarium*. Alternative varieties to replace Gros michel include Grand nain and Chinese Cavendish, and these have been well accepted in urban markets.

### 4.5 Technology diffusion studies

Demonstration farmers played a significant role in 'spreading the word' about tc banana technology. The selection criteria were their ownership and availability of clean land, their commitment to provide labour and inputs, and their willingness to allow neighbouring farmers to visit their banana orchards. In return, they received their plantlets free of charge, were taught how to manage their plantlets, and participated in visits to other farms and research stations. By demonstrating the potential benefits of tc bananas, they created interest and awareness amongst other farmers, and provided data about how to manage the crop so as to maximise returns. The resulting interest and demand for tc plantlets has led some of the demonstration farms to start nursery units that are providing local sources of planting material.

Farmer groups (often formed through their applications for credit) have also benefited from education workshops organised at the research stations. These groups have in turn been encouraged to start their own nurseries, thus extending the areas where planting materials are available.

The diffusion research (Karembu 1999) identified several possible constraints to widespread adoption of the technology:

- Relatively high cost of tc plantlets compared to conventional suckers
- The need for more choice of varieties - both local and commercial
- Gender issues
- Higher requirement of tc banana plantlets for labour and inputs
- Limited availability of clean land
- Poorly established marketing and distribution systems
- Lack of irrigation facilities and inadequate water (drought)

### *Choice of varieties*

Generally, farmers prefer to eat what is familiar to them. However, in the Central and Eastern Regions, where banana is starting to become a cash crop, the demonstrated potential of the introduced tc cultivars and high consumer acceptance has led to increased demand for a wider choice of tc varieties. There are also marked regional differences in environmental suitability and consumer preferences between those who consume the fruit as a staple (e.g., Kisii) and those in the Central Province who view it as an alternative cash crop to coffee. For both these reasons, expanding the varietal choices would likely increase uptake of the technology.

### *Gender issues*

Banana is still considered a woman's crop, since women traditionally take responsibility for feeding the family while men look after the cash crops. Because men make the decisions regarding land use, it was feared that women would lack land on which to plant improved tc banana plantlets. And in some areas, such as Kisii in Nyanza Province, women tend to market the traditional small varieties of apple banana, which do not fetch good prices, while men market the more lucrative larger-growing varieties. Watering the crop is also considered to be a woman's job, so the higher water requirements of tc plantlets could put excessive demands on women's labour resources. The results so far have shown that the technology has the potential to narrow the gender gap in the choice and division of labor as far as growing banana is concerned. More men are now participating in the banana business, while the women have opportunities to market better quality bananas.

### *Input requirements*

Tissue culture plantlets require more care and management than farmers currently give to their banana orchards. When they are transplanted, they have no nutrient reserves. External stress is particularly harmful to them during the first five months after planting out. Without sufficient nutrients, weeding, and water, the performance of tc plantlets can be worse than that of conventional suckers. Although climatic stress factors are usually less severe in Kenya than in many other locations (planting can take place during the rainy season), it is obvious that tc technology can only be successful when farmers alter their traditional practices and increase the allocation of inputs to their banana crop. To avert the problem of manure availability, farmers are being sensitized to the need to extend the manure available from kitchen compost, chicken, and livestock to bananas as well. The Kenya Institute of Organic Farming has also been approached to train farmers on composting. In addition, since irrigation is expensive, in terms of both labor requirements and set-up costs, farmers are being encouraged to harvest rain water and use bucket irrigation to maintain the orchards.

### *Clean planting land*

Transplanting *in vitro* plantlets into pathogen-infected soils can be more damaging to growth performance than planting conventional material. Ideally, tc plantlets need to be planted on land where bananas have not previously been grown. Due to extensive infestation by pests and diseases, it is becoming increasingly difficult for farmers to find suitable land for a new tc orchard. This is especially difficult for small-scale farms.

### *Marketing the crop*

Poorly established marketing systems and inefficient channels of distribution to urban markets are likely to affect the profitability of the crop, especially as supplies increase. At present, farmers have little access to information about market prices and are consequently open to exploitation by middle-men. Due to a lack of organisation, surpluses are often sold by individual growers and there is no co-operation to increase profitability. There is also no official channel such as a Growers' Association through which the farmers' collective voice can be heard.

### *Cost of tissue culture planting material*

The cost of tc plantlets is considerably higher than that of conventional suckers, which can sometimes be obtained free of charge or by barter. The current price of a tc plantlet ranges from KSh 60 to KSh 150 (US$ 0.8-2.0). Most resource-poor farmers are willing in principle to pay this price once they have seen the benefits, but without credit facilities few are actually able to do so. Typically, participating farmers could only afford between 10 and 20 plantlets, too few to have an impact on poverty alleviation. Field trials have established that the minimum scale of a commercial tc banana plantation would be about 50-80 plants (taking into consideration inputs, management, cost of plantlets, and land preparation) with the plants covering about 0.05 ha, which is a feasible amount of land for most small-scale farmers. However, this scale of planting requires an initial investment of about US$ 200, a sum beyond the reach of most resource-poor farmers.

Currently, only very limited sources of credit are available to the small-scale farmer because local, lenders perceive such loans as high risk. Introducing a credit scheme was therefore essential for the project to make a significant difference to livelihoods.

Adoption constraints and possible solutions are explored further in Section 6.5.

## 5. The Pilot Micro-credit/Revolving Fund Model

### 5.1 Background

Once it became apparent that the cost of plantlets could drastically limit diffusion of the tc technology, ISAAA took the responsibility of establishing a credit scheme to ensure the success of the project. Following discussion with farmers, it was clear that a form of micro-credit would be essential. To demonstrate the feasibility of the scheme to microfinance and development-orientated organisations, a pilot model was launched with a donation from the ISAAA Board of US$ 10,000 and an additional US$ 5,000 from an anonymous donor in the USA. KARI donated US$ 8,000 in the form of planting materials.

The micro-credit scheme is based on the Grameen Group Approach, which was successfully developed in Bangladesh in the 1980s and is now widely used elsewhere. The Grameen model relies on peer group monitoring to reduce lending risks. It also overcomes the three major constraints that prevent formal financial institutions from offering credit to the poor, since the functions of screening, monitoring, and enforcement of repayment are transferred from the bank agents to the group members themselves. Replacing many small loans to individuals with one larger group loan also reduces the cost of lending.

The micro-credit scheme involves banana farmers joining together in groups of 30-50 members and managing the loan process themselves through elected leaders. Members contribute a minimum agreed sum on a monthly basis, but the group is ultimately responsible for repayment in case of individual defaults. The scheme is based on a revolving fund, whereby money given out is repaid, then lent to new farmers.

### 5.2 Benefits

The micro-credit scheme has so far covered three districts, Kirinyaga, Maragua, and Murang'a. Initial results have been overwhelming, with a planting material demand of more than 100,000 plants from both within and beyond the project area in just one season. Although the recommendation was for 80 plantlets per farm, this has not been widely achieved due to the limited availability of clean land and the small size of many farms. However, an average of 41 plantlets per farmer has been achieved, which is considerably greater than the 10 or so being bought without the availability of credit. Moreover, farmers who originally bought a small number of plantlets on credit have been coming back for more.

The average income per farm in the areas studied was US$ 40 per month. The projected additional income following adoption of tc banana is US$ 25 per month, representing a 38% increase in disposable income per family per month. This is enough to make a substantial difference to a family's standard of living. The repayment rate currently stands at 95%, which is comparable to the best repayment rates achieved by Grameen projects in Asia and is highly encouraging for the future sustainability of the scheme.

Beyond the provision of credit, forming micro-credit groups brings many additional benefits to individuals and the wider community. The broader participation of resource-poor farmers greatly increases the equity impact of the project, providing some of Kenya's poorest people with opportunities to grow more food and increase their incomes. These benefits will spread from farmers along the distribution and marketing chain to traders and consumers. Another important advantage of the groups is the information, education, and monitoring services to which members get access. These services are not available when individual contracts between a bank and a borrower are made. The formation of groups strengthens the social-economic fabric of communities and can encourage other activities. For example, a group can rent additional land and gain the knowledge required to grow other horticultural crops to supplement the diet and provide additional income. Economies of scale also come into play, for example better purchasing power in buying tc materials from the laboratories and the ability to organise group distribution of surpluses to market.

*Mrs. Esther Gachugu, demonstration farmer and women's group organiser with her crop of tc bananas.*

## 6. DISCUSSION

### 6.1 Benefits to farmers

Before this project was implemented, critics contended that biotechnological advances would not benefit the rural poor in developing countries. Such a view is undercut, however, by the results of the *ex-ante* impact assessment study, which indicated that tc technology is likely to bring about considerable aggregate welfare growth in the Kenyan banana sector. Most significantly the study concluded that potential yield and income gains would be greater for poorer small-scale farmers (Qaim, 1999). These findings should encourage the introduction of other promising biotechnologies to resource-poor farmers across the developing world.

In the areas where it has been adopted, tc technology has brought many significant benefits to banana farmers. The most important is the availability of improved, disease-free planting materials. Farmers can now replace their ageing and diseased orchards with superior early- maturing material, which will lead to higher bunch weights and a higher annual yield per unit of land—a significant achievement considering the very small farm sizes of the majority of the farmers. The uniform development of tc plants will permit the coordination of production, harvesting, and marketing, leading to higher incomes and changing the perception of banana from a subsistence crop to a cash commodity. Furthermore, biodiversity will be maintained and even increased by cleaning and reinstating local germplasm and by providing improved varieties that are high yielding and resistant to pests and diseases.

The introduction of tc plantlets has also stimulated improved orchard management practices, leading to further increases in productivity. Likewise, the novel practice of applying inputs is improving soil fertility in orchards and raising the yields of additional food crops grown between the banana plants. The availability of credit has enabled farmers to invest in irrigation solutions (e.g., digging new water holes, buying pumps and donkeys to carry water), which benefit the entire farm by increasing the value of land and improving the productivity of other crops. Better health and enhanced welfare of the whole family is the ultimate result.

The data and information gathered in this project can be used to help farmers decide if they want to commit the land, time, and other resources required for tc banana cultivation. It can also help them determine which varieties are best suited to their location and production objective (e.g., for local consumption or urban marketing). Farmers can see the benefits for themselves by visiting the demonstration farms and research stations, and the formation of micro-credit groups can provide essential financial support to farmers launching their improved orchards. Such groups can also disseminate information and promote economies of scale in purchasing plantlets and marketing the crop. From a broader viewpoint, channelling the products of 'upstream' research at international networks or institutes such as INIBAP or IITA to poor farmers will include them in the development process instead of marginalizing them, which has too often been the case in the past.

### 6.2 Benefits to the wider community

It is not just farmers who will benefit from tc banana technology. Increasing yields are likely to lower market prices, making bananas more affordable for the consumer. Reducing the cost

*Delivering tc plantlets to farmers in Maragua District.*

of basic foods will also increase the demand for other goods and services, exerting a positive effect on the whole economy.

The banana project has already created new business and employment opportunities for tc laboratories, traders, and retailers. Further expansion in the labour market surrounding the banana industry is likely, as more private companies become involved and the potential for processing the crop is exploited. New markets are likely to be opened, including the opportunity for exports. Gender inequalities may also narrow as increased business opportunities become available for women.

There are environmental benefits too. Well-managed banana orchards can improve local soil conditions, helping to reverse the degradation that has resulted from increased population pressure on the land. In addition, tc technology can help save traditional varieties threatened with genetic erosion and increase biodiversity on farmers' fields.

Knowledge gained during the project has enhanced Kenya's national biotechnology capacity and the level of training in biotechnology. Tissue culture has also opened the way to a more rapid dissemination of future biotechnology innovations such as genetically modified materials with better disease resistance that are expected to become available within the next 10 years from international public sources such as INIBAP and IITA.

The overall success of this project means that it can be used as a model for introducing tissue culture in other communities and with different commodities.

### 6.3 Role of the private sector

Prior to the KARI-ISAAA project, only JKUAT was applying tc technology to banana. Now an additional public-sector research institute (KARI) and two private companies have become involved. And as take-up of the technology increases, a substantial business opportunity for increased plantlet production at existing sites as well as new laboratories has become apparent. Distributing banana planting materials is another rapidly growing business, with NGOs, community-based organisations, and banana farmers themselves (including some of the project demonstration farmers) becoming involved. Additional marketing opportunities will be created as the quality, quantity, and regularity of the supply of tc bananas improves, providing extra employment and a more steady income for fruit distributors and retailers.

Involvement of the private sector was encouraged from the start of the project in order to create a self-sustaining system. Once Phase II is completed, it is hoped that sufficient capacity will be in place to ensure that the benefits of tc banana technology will continue to be reaped by a widening group of stakeholders.

## 6.4 Market development opportunities

Banana processing has previously been extremely limited in Kenya due to a low or fluctuating supply of good-quality fruit. The more regular harvests and greater quantity of fruit promised by tc technology will allow for market development into processing, with economic gains to all stakeholders in the industry. Banana is already used to make beer and baby food in Kenya, but not on a commercial scale. Other banana products such as crisps, wine, and jam are not widely consumed in Kenya, although they represent additional market opportunities within the country and for export.

## 6.5 Strategies to counter adoption constraints

### *Reducing the cost of plantlets*

Prices for *in vitro* plantlets are likely to fall as supply increases, especially when competition occurs as other providers enter the market. For example, plantlets are available in South Africa for the equivalent of KSh 35 (US$ 0.42), whereas the cost from commercial laboratories in Kenya is around KSh 100 (US$1.20). Due to the higher costs of production (electricity and imported chemicals), the low South African figure is unlikely to be achieved in Kenya, but it does illustrate the scope for price reduction in the future. Another option is to import small *in vitro* plantlets from South Africa, or to use split corm techniques (taking slices of the corm of available suckers to multiply scarce planting material) as a cheaper alternative to tissue culture. However, while split corm techniques prevent the spread of weevils and nematodes, they do not remove fungal and bacterial diseases, which severely constrain banana production in Kenya.

Establishing in situ nurseries is another way to reduce the cost of 'clean' planting material. Farmers could propagate suckers from their own tc banana plants, thus considerably reducing the cost of the technology. Initially, the project had assumed that tc plants might be good sources of suckers for farmers seeking to expand their improved orchards, as in the traditional practice. This hypothesis, however, has now been rejected due to results from the on-farm trials, which indicated that tc plantlets had better growth characteristics than first-generation suckers. In addition, there are disadvantages to using first-generation suckers as a source of planting material. Although the original tc plantlets are clean, there is a risk of infection once they are planted in farmers' fields. Using suckers from such plants would result in increased infection and a corresponding general decline in vigour. Thus the practice would contradict the very purpose of using tc technology—to guarantee the farmer clean, vigorous planting material. Furthermore, the loss of vigour and increased infection rates would accelerate through succeeding generations. Consequently, while farmers may perceive the use of suckers as a short-term gain because they do not have to pay for the initial materials, they are less likely to benefit from higher yields and incomes in the longer term. In addition, the yields from healthy tc plants have been shown to be high enough to justify the cost of buying new plantlets. These findings underscore the need for a source of credit for smallholders.

There is, however, a need for price regulation of tc planting materials. At present, the private laboratories are providing large quantities but charging high prices because they need to make a profit, while the government-funded public institutions charge commercially unsustainable rates. Additional studies are required to establish the cost-effectiveness of running subsidised nurseries to increase competition and force the laboratories to lower their prices. The formation of a farmer-based NGO such as a Banana Growers' Association may also help to put pressure on prices.

At present there are poor links and distribution chains between farmers and tissue culture laboratories. One benefit of forming micro-credit groups is that farmers can take advantage of economies of scale to buy in bulk from the laboratories, thereby obtaining a lower purchase price.

Further research is needed to identify the optimum time to re-plant orchards to maintain productivity. It is thought that the enhanced productivity of tc banana plants will decline after about 4-6 years. Traditionally, banana plants are believed to be productive for 10-15 years, and many of Kenya's existing orchards are much older than this. Further education of farmers will therefore be required to emphasise the benefits of early re-planting, an activity that is likely to need additional financial support.

### *Applying sufficient inputs*

There will be an ongoing need to change farmers' perceptions of banana and to educate them in proper agronomic practices, including the need to apply sufficient inputs to their plants. Farmers are being advised to plan for planting at the onset of the rainy season (April and October) and to maintain proper de-suckering. KARI is currently investigating alternative methods of providing the necessary inputs of water and nutrients. For example, the drip-irrigation system under research at the institute just needs a bucket and a hose pipe to water plants by gravity. This method has low investment costs, reduces labour and results in a more efficient use of water. Group training in alternative sources of nutrients, such as green manure and composting, is also being explored in conjunction with the Kenya Institute of Organic Farming (KIOF) and Wangu Investments. Another NGO, FPEAK (Fresh Produce Exporters Association of Kenya), has been approached to offer field management training in bananas, in line with its experience in other horticultural crops.

### *Improving the availability of clean planting land*

*In vitro* plantlets are more delicate than conventional suckers and require pathogen-free soils for optimum performance. Farmers who have no clean planting land are being encouraged to disinfect their soils before planting or to follow a crop rotation (i.e., they must first uproot their old banana orchard and grow a different crop for one or two seasons). Phase II will provide an integrated pest management (IPM) component and a disease diagnostic facility, which the farmers will be able to use for soil-pest analysis before planting tc materials. It is very important that farmers are advised against planting clean material in infested soils, as the results are very poor and their investment will be wasted.

### *Establishing formal marketing systems*

Lack of information about market prices has allowed middlemen to exploit small-scale farmers. An option being explored in Phase II is to link farmers through a Banana Growers' Association to existing institutions that are helping rural communities to set up commodity information centres. ACDI/VOCA, an international development NGO based in Kampala, Uganda, is one such institution. In Kenya, this NGO works with the Kenya Agricultural Commodity Exchange (KACE), a private-sector firm. Access to up-to-date information via rural telecentres would help to keep farmers informed about markets, especially those more distant from production areas, where prices tend to be higher.

Forming a Banana Growers' Association will also help to ensure the sustainability of the project by strengthening the links between existing farmer groups. These can co-operate to organise their own marketing by hiring transport and cutting out the middlemen. In addition, studies of post-harvest handling techniques will aim to improve profitability by reducing losses during transport and storage.

### *Expanding the choice of varieties*

In order to complement the availability of improved foreign cultivars, efforts are being made to develop clean planting materials from local varieties. This has the added advantage of maintaining biodiversity and ensuring the survival of banana types that might otherwise be lost to pests and diseases.

### *Gender issues*

Results from the project's socio-economic research indicate that traditional production systems are evolving towards a more egalitarian distribution of power as they become more market-orientated. As men realise that bananas are earning more money than their traditional cash crops, they are releasing more land for bananas to the women or starting to plant bananas themselves. Gender issues were therefore a less important influence on uptake of the tc technology than had been anticipated. Additionally, improved varietal choice will give women the opportunity to market bananas with a better profit margin if they choose to do so. Ongoing research will continue to assess the interrelationships between traditional gender roles and uptake of the new technology, which has the potential to deliver considerable improvements to the welfare of the whole family unit.

### *Providing virus indexing*

The East and Central Africa region lacks facilities for virus indexing, which is needed to ensure that both local and improved germplasm is free of viral diseases. At present, Kenya appears to be generally free from banana viruses, but the banana streak and bunchy top viruses are known to exist in Uganda. With increasing cross-border use of materials it will be important to develop a virus diagnostic kit for use in tc laboratories and in the banana-producing areas.

In addition, a system of quality control needs to be implemented to ensure that all materials going through local laboratories meet minimum quality standards and that the incidence of somaclonal variants is controlled. Sustainability will be threatened if the quality of the planting material sold to farmers is allowed to decline. Government regulatory agencies, such as the Kenya Plants Health Inspectorate Service (KEPHIS) and the Horticultural Crops Development Authority (HCDA) will be needed to regulate imports and exports and to ensure that the quality control system works as it should.

### 6.6 Why the project succeeded

The success of the KARI-ISAAA banana project has been quite remarkable. After only three years, participating small-scale farmers have reaped considerable benefits from a biotechnology application hitherto little used in Kenya. A substantial number of farmers can now access tc banana planting materials within 5 km of their farms—a significant achievement considering that three years before the start of the project there were no supply facilities anywhere in the country. The project's multidisciplinary approach and collaboration between its various participating organisations contributed significantly to its success. Laboratory-based R&D was firmly tied to the needs identified through participatory on-farm research, with requests from farmers being fed back to the tc laboratories to ensure that they were propagating the varieties farmers wanted. Public-private partnerships—a relatively new concept in Kenya—allowed the commercial potential of the project to be confirmed and exploited. Additionally, international links between public research institutions and private laboratories permitted the introduction of new varieties of banana with enhanced performance.

Trials of the technology on farmers' fields as well as research stations meant that the farmers themselves had the opportunity to test this innovation and learn together with the scientists. Collaboration between scientists and NGOs or extension services created further partnerships and opportunities for many individuals to be involved throughout the integrated R&D process. At all times, close attention was paid to the needs and interests of the farmers. Technology diffusion studies identified early on the likely constraints to adoption of the technology, and appropriate strategies were devised and introduced to counter these. The crucial innovation that ensured effective technology transfer to resource-poor farmers was the successful introduction of a pilot micro-credit scheme. This has created a model that other micro-credit providers could use.

## 7. FUTURE PLANS - PHASE II STUDIES

### 7.1 Establishing a sustainable system

Funding has now been secured from IDRC and the Rockefeller Foundation for a second phase of the KARI-ISAAA banana project, to run from 2000 to 2003. The aim is to establish a self-sustaining system for the production, distribution, and utilisation of tc banana plantlets, providing long-term benefits for farmers and further entrepreneurial opportunities for the private sector. The growth in production facilities and the high demand for tc planting material during Phase I of the project illustrates the opportunities for private enterprise throughout the system, from tc laboratories through plantlet distributors and farmers, to traders and market stall-holders. The potential for adding value to the crop through processing is also likely to create additional employment.

Improving the links between stakeholders will be a vital factor in creating sustainability within the system. To this end, the formation of a Banana Growers' Association will be encouraged, and links with organisations such as the Sustainable Agriculture Community Development Program (SACDEP) will be formed. SACDEP focuses on developing self-reliance in small-scale farming communities. It offers extension services to farmer groups in agriculture and has the potential to use its network of farmers to expand the uptake of tc banana technology and encourage correct management practices.

Future research by KARI and ISAAA will concentrate on 'downstream' issues to support farmers and promote widespread adoption of tc technology. Further use will be made of participatory approaches, including the 'farmer-field-school' model developed by the Food and Agriculture Organisation of the United Nations (FAO), whereby farmer groups meet regularly for practical training (FAO, 1994). The outcome is a team of trained farmers, each of whom can then train other farmer groups, creating a network of knowledge and empowering farmers to influence their own development.

### 7.2 Increasing choice of varieties

In order to increase the choice of varieties available to farmers and to maintain biodiversity, Phase II will investigate the use of tc material derived from local varieties. Increased knowledge and skill levels within the tc laboratories mean that local germplasm can now be cleaned and reinstated in the farming system. Research into the optimum tissue culture media and growth conditions for different local banana cultivars is also planned.

### 7.3 Extending the project

Phase II will concentrate on establishing a truly sustainable system in at least one region (Maragua), where Phase I has already identified the issues to be addressed. These include the need to establish marketing channels, increase orchard size and establish sustainable distribution systems. The project will then provide a model that can be used to expand the NGO/private-sector network and encourage scaling up and commercialisation of tc technology in the rest of the banana-growing areas of Kenya, as well as expansion into Tanzania and Uganda.

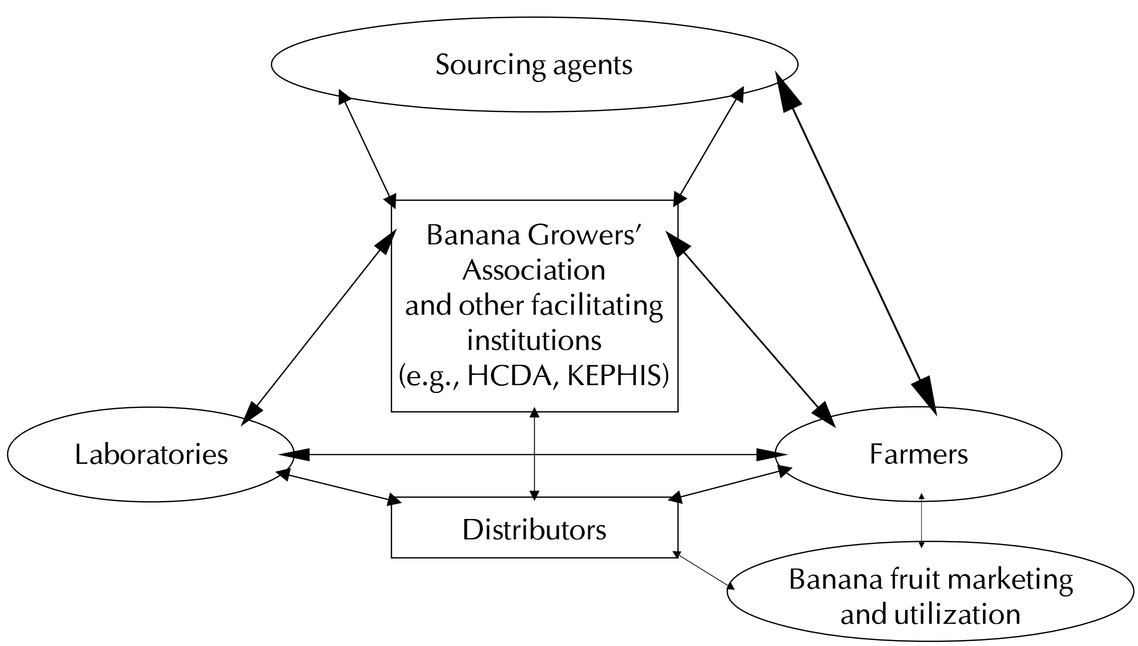
Twelve on-farm trials of tc banana have already started in Tanzania. Here, banana production is also declining due to infestation by pests and diseases, with similar implications for welfare as in Kenya. During Phase II, KARI will collaborate further with HORTI-Tengeru, the Horticultural Research Training Institute at Tengeru, Tanzania, to carry out further evaluation trials and build the capacity for technology transfer, using the farmer-field-school model. In Uganda, research has been undertaken on some local banana genotypes of the East African Highland cooking types, which was shared in Phase I by having KARI and private laboratory scientists trained by Ugandan national scientists. In Phase II, further links and sharing of research results are likely to bring major benefits to all the collaborating partners and countries.

The micro-credit scheme has helped many farmers during Phase I and will now be extended further. ISAAA is approaching further micro-credit donors so as to increase the revolving fund to US$ 520,000, enough to cover 5,000 families. An additional US$ 30,000 has already been allocated by RF. This will be used not only for the purchase of planting material but also to improve marketing, for example through improved handling facilities to reduce post-harvest losses. Additional credit providers will also be sought to allow the extension of credit facilities to stakeholders other than farmers, such as small-scale entrepreneurs who wish to become involved in tc production and distribution as well as fruit marketing. Once credit becomes widely available, higher rates of adoption and wider impacts are anticipated. Sustainability of the project, without donor support, will be promoted through the extension of horizontal networks, involving organisations such as ACDI/VOCA, Winrock, and other NGOs, including church and women's groups.

### 7.4 Expected benefits

Phase II will build on the benefits achieved by Phase I. As already indicated, it will address identified adoption constraints to make the

**Figure 3. Conceptual model of a self-sustaining tc-based banana production and marketing system.**



application of tissue culture technology in bananas a commercially viable venture and a replicable self-sustaining system. The focus will be on making the different components of the system—sourcing, production, distribution and utilisation—operate sustainably (Figure 3).

In the system, the tc laboratories receive 'unclean' materials from the farmers. These materials are then cleaned using tissue culture and passed back to the farmers, either directly or through agents at a fee. Two issues are important here: farmer/consumer preferences and the quality of the plantlets produced by the laboratories. Certain checks and balances will be required on a continuous basis to take care of these issues. Farmer management practices then determine the output from the tc plantlets. Once the crop is ready, marketing and utilisation become the issues affecting sustainability. Efforts will be made to devise and evaluate appropriate measures for making this system, and its inherent business and development opportunities, viable and appreciated by all stakeholders in the industry.

Phase II will have a number of benefits in addition to increasing the sustainability of the project as developed under Phase I (KARI, 2000). This phase will enhance institutional and human capacity. It will also increase banana production and thereby increase banana yields and improve food security. Employment opportunities will arise from the new banana businesses that are developed under this project. Further, the creation of novel agri-business in the area of biotechnology will stimulate adoption of biotechnological applications in other crops. Phase II will also reduce gender inequality by providing opportunities for women. The second phase of the banana project will suggest the breadth of the impact that biotechnology can have upon society and the economy.

Because of its unprecedented success, the tc banana project provides real hope for a better future, not only for the Kenyan banana sector but also for additional crops and different regions—wherever there is a need to move from subsistence to market-oriented production. Creating an agricultural surplus through tc technology grows the whole economy. This project demonstrates biotechnology's potential to be one of the most powerful tools available for reducing poverty and hunger in developing countries around the world.

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## LIST OF ACRONYMS

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| **AEZ** | Agro-ecological zone |
| **ATPS** | African Technology Policy Studies |
| **CGIAR** | Consultative Group on International Agricultural Research |
| **FAO** | Food and Agriculture Organisation of the United Nations |
| **FPEAK** | Fresh Produce Exporters Association of Kenya |
| **GDN** | Global Development Network |
| **GTL** | Genetic Technologies Limited |
| **HCDA** | Horticultural Crops Development Authority |
| **HORTI** | Horticultural Research Training Institute |
| **IDRC** | International Development Research Centre |
| **INIBAP** | International Network for the Improvement of Banana and Plantain |
| **IITA** | International Institute of Tropical Agriculture |
| **ISAAA** | International Service for the Acquisition of Agri-biotech Applications |
| **ITSC** | Institute of Tropical and Sub-tropical Crops |
| **JKUAT** | Jomo Kenyatta University of Agriculture and Technology |
| **KACE** | Kenya Agricultural Commodity Exchange |
| **KARI** | Kenya Agricultural Research Institute |
| **KEPHIS** | Kenya Plants Health Inspectorate Service |
| **KIOF** | Kenya Institute of Organic Farming |
| **MALDM** | Ministry of Agriculture, Livestock Development and Marketing |
| **MOA** | Ministry of Agriculture |
| **NGO** | Non-governmental organisation |
| **PRA** | Participatory rural appraisal |
| **RF** | Rockefeller Foundation |
| **SACDEP** | Sustainable Agriculture Community Development Program |
| **tc** | tissue culture |
| **ZEF** | Zentrum für Entwicklungsforschung (Centre for Development Research) |

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