Tissue culture banana (musa spp.) for smallholder farmers: Lessons learnt from East Africa

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Tissue Culture Banana (*Musa* spp.) for Smallholder Farmers: Lessons Learnt from East Africa

T. Dubois[1], Y. Dusabe[1], M. Lule[1], P. Van Asten[1], D. Coyne[2], J.-C. Hobayo[3], S. Nkurunziza[3], E. Ouma[3], N. Kabunga[4], M. Qaim[4], E. Kahangi[5], P. Mwirigi[5], P. Mwaura[5], D. Kisii[6], H. Kizito[6] and J. Mugisha[7]

[1] International Institute of Tropical Agriculture, PO Box 7878, Kampala, Uganda
[2] International Institute of Tropical Agriculture, PO Box 34441, Dar-Es-Salaam, Tanzania
[3] International Institute of Tropical Agriculture, Avenue Mwaro 3, Quartier INSS, B.P. 7180, Bujumbura, Burundi
[4] Georg-August-University of Göttingen, Department of Agricultural Economics and Rural Development, Platz der Göttinger Sieben 5, 37073 Göttingen, Germany
[5] Jomo Kenyatta University of Agriculture and Technology, Department of Horticulture, PO Box 62000-00200, Nairobi, Kenya
[6] Volunteer Efforts for Development Concern, PO Box 1224, Kampala, Uganda
[7] Makerere University, Department of Agribusiness and Natural Resource Economics, College of Agricultural and Environmental Sciences, PO Box 7062, Kampala, Uganda

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Abstract

The use of tissue culture (TC) banana (*Musa* spp.) planting material is an effective method of providing pest and disease-free plants. Although there are many added benefits to using TC plants, the adoption of TC technology remains relatively low in East Africa. Currently, adoption is increasing under impetus from the private sector. Adopting TC banana technology, however, is more expensive for the farmer than conventional suckers and may not be economically beneficial across all banana-producing areas in East Africa. One of the greatest potential dangers for sustainable commercial TC plant production is the limited use of certification for plant quality and health, which is especially important in order to avoid the spread of viruses. Additionally, TC plant nurseries are important components, as they provide essential distribution hubs connecting TC producers with farmers. However, TC nurseries in East Africa face an array of challenges. Organizing banana farmers into groups has long been considered advantageous, as they foster increased buying and selling power, reduce economic and social risk, increase economies of scale, and facilitate access to credit and inputs in the case of formally certified groups. Distribution of superior planting material alone, however, does not ensure improved productivity. Smallholder farmers are constrained by factors such as a lack of: land, capital, access to technology and effective marketing infrastructure. As such, efficient distribution systems need to deliver TC plants as part of a package, including training and access to micro-credit. Despite a booming commercial sector, there is only anecdotal evidence that farmers who have adopted TC bananas have benefitted substantially in terms of higher yields and household incomes. Sound socio-economic analyses are crucial to guide policy strategies, to learn from successes already achieved and to identify important constraints for a wider dissemination of TC banana in the region.

INTRODUCTION

In East Africa, banana (*Musa* spp.) is among the most important staple crops. In Uganda, per capita production of banana is the highest in the world, with an annual production approaching 10 million t/yr (Lescot and Ganry, 2010). Virtually all of this production are East African highland banana (EAHB, AAA genome), eaten cooked or brewed into beer (Gold et al., 2002; Biribwa et al., 2010; Lescot and Ganry, 2010). Annual production of banana in Burundi stands at ~1.5 million t/yr, also mainly of EAHB

(~1.1 million t/yr) (Lescot and Ganry, 2010). In Kenya, plantain (AAB genome) and EAHB account for 430,000 and 400,000 t/yr, respectively. In addition, significant volumes of dessert banana (370,000 t/yr), mostly 'Dwarf Cavendish' and 'Gros Michel' (AAA genome), are grown and used as a cash crop in Kenya (Lescot and Ganry, 2010). Additional dessert banana cultivars such as 'Williams' and 'Grande Naine' (AAA genome) are currently being introduced in Kenya through tissue culture (TC) technology (Muchui et al., 2010).

In East African smallholder systems, new banana fields are traditionally planted with suckers. However, the use of TC plants is increasing, because they (a) are pest- and disease-free (with the exception of fastidious bacteria and viruses); (b) grow more vigorously, allowing for faster and bigger yields; (c) produce more uniform bunches, allowing for more efficient marketing; and (d) can be produced in large quantities in short periods of time, permitting faster distribution of planting material and new cultivars. As such, the use of TC can support farmers to make the transition from subsistence to small-scale commercial farming (Dubois, 2011). However, TC plantlets require the appropriate handling and management practices to optimize their benefits. Consequently, this additional effort and the cost of TC plantlets generate an extra cost for the farmer. The use of TC technology might therefore not be appropriate for all farmers or in all situations. Also, unsustainable production and distribution practices are threatening this relatively recent technology.

Since 2008, the Federal Ministry of Economic Cooperation and Development of Germany (BMZ) has supported efforts to assess and empower TC production chains in Burundi, Kenya and Uganda in East Africa. This overview paper provides some of its main findings.

THE TISSUE CULTURE INDUSTRY IN EAST AFRICA

The Importance of the Private Sector

In East Africa, the adoption of TC technology remains relatively low. In Kenya TC banana was recently estimated at 7% coverage of total banana acreage (AHBFI, 2008), while adoption rates in countries like Uganda, and Burundi are significantly lower. However, in East Africa, TC technology is fast increasing in popularity, primarily with the instigation from the private sector, which currently produces some 2-3 million plants/year. Despite the steep entry barrier, TC production appears highly lucrative for the entrepreneur, with profit margins that can reach up to 100% (T. Dubois, unpublished data). In some countries, universities and research organizations are also involved in commercial production of TC banana.

Within the TC production chain, there are principally three key players: (a) TC producers, who initiate, multiply and root plantlets in specialized laboratories; (b) TC nurseries, which wean plantlets in humidity chambers and subsequently harden them in screenhouses; and (c) farmers using TC. However, especially in Burundi and Uganda, TC producers have embraced and combined the first two levels of the production chain, from sourcing of the mother plants to hardening of the plantlets, instead of selling TC plantlets to nurseries.

The Importance of Location

TC plantlets come at a cost, which is greater than using sucker material, and the economic benefits of using them need to be assessed across banana-producing areas and situations in East Africa. Using a comprehensive quantitative questionnaire, we conducted a cost-benefit analysis of 240 farmers applying TC technology, across four districts in Uganda, and compared this to the use of conventional planting material (Fig. 1). Both production costs and revenues were consistently higher for TC than for sucker planting material. However, banana farm-gate prices varied greatly by district, and declined significantly with increasing distance from the main market. Also, production costs decreased significantly with distance from Kampala, due to better growing conditions, lower labor costs, and reduced pest and disease pressure (CIALCA, 2009). As a result, although both TC and suckers were profitable for the farmer, TC was increasingly more profitable than suckers with proximity to the main banana market. In districts further from the main banana market, farmers could receive similar gains by planting suckers than TC bananas. Consequently, in Uganda, it appears to make economical sense to only grow TC close to the main urban market (Dusabe, 2009). The same trend of diminishing returns for TC plantlets, compared to suckers, with greater distance from the main banana market was also observed in Burundi and Kenya, although no quantitative cost-benefit has been conducted. In Kenya, for example, the few TC nurseries that were established in Coastal Province have since ceased to exist (T. Dubois, pers. observation). These findings reflect those of Wairegi and Van Asten (2010), who determined that fertilizer, another banana input technology, was only profitable for farmers within a 160-km radius around Kampala. For Uganda, these data also imply that TC adoption rates may remain low for the foreseeable future, as just 20% of current banana production takes place in Central Uganda where TC is significantly more profitable than suckers (Ngambeki et al., 2010).

TC PRODUCERS

Certification for TC Plantlet Quality and Health

At present, commercial production of TC banana plantlets remains largely unregulated. Certification schemes are necessary to guarantee the quality and health of TC plantlets along the production process which would then need strict adherence by TC producers. Quality of TC plantlets is variable among TC producers, with at times inadvertent distribution of off-types and mixed cultivars, which becomes apparent only once planted in the farmers field. TC plantlet health is especially related to the absence of pests and diseases, which is guaranteed by high standards in the production process. Viruses, however, cannot be eliminated through the routine TC process and therefore schemes are required to include rigorous regulations regarding the source of the mother material. Currently, plant quality and health certification schemes are lacking or not implemented (Macharia et al., 2010). Commercial TC producers are expected to self-regulate the quality and health of their production systems, although implementation and enforcement of certification schemes, which regulate the operational processes in the TC industry, is essentially a governmental role. When implemented, it is important that schemes are adopted that are suitable and aligned appropriately to the specific situation, so that they do not themselves become an obstacle, but rather facilitate an otherwise vibrant industry.

Virus certification is of paramount importance in any certification scheme for planting material quality and health. Implementation of virus certification schemes are urgent, especially as TC plantlets are being increasingly distributed internationally within Africa. Similarly, international movement of uncertified mother material is a concern which needs to be regulated. Uncertified international movement of TC plantlets from, and mother material into, TC laboratories is potentially hazardous for the spread of viruses, such as *Banana bunchy top virus* (BBTV), which is listed among the top 100 worst invasive diseases globally (Lowe et al., 2000). BBTV currently occurs in Burundi and Rwanda, but has, to date, not been recorded in Kenya and Uganda (Lava Kumar and Hanna, 2009; Lava Kumar et al., 2011).

Several elements are essential for correct virus certification: (a) accredited governmental or independent virus indexing laboratories as a commercial service to TC operators; (b) TC producers’ access to virus-free and true-to-type mother plants through the establishment of certified mother plant gardens; (c) international harmonization of certification schemes, especially in view of the international movement of TC plantlets and mother material.

Contrary to a general perception among donors and organizations focusing on capacity building, it is not merely the virus indexing protocols themselves that are the bottleneck. Virus indexing protocols themselves are well established for the known banana viruses, the equipment for virus indexing has become relatively inexpensive and technical skills are relatively available. A key obstacle is the limited knowledge on how and when virus indexing is implemented along the value chain, through certification schemes. In East Africa, virus certification schemes from other regions or from other clonally propagated crops should be readily transferrable and adopted for banana.

A further hurdle for virus certification schemes is quarantine procedures. These procedures are currently unavailable, partly in relation to the limited information in sub-Saharan Africa regarding quarantine pests, such as BBTV and other viruses, on which these procedures are built.

DISTRIBUTION SYSTEMS

TC Buyers

A major consideration for a healthy, commercial TC sector is a sustainable market pathway to deliver TC plantlets to the farmer. The sustainability of the banana TC industry is especially compromised in countries where the distribution chain of TC plantlets is heavily subsidized. For example, countries where TC plantlets are purchased and distributed for aid programs, which have good intentions but lack the technical support for management of TC material. Provision of TC material to farmers unaware of the handling needs and time requirements can be damaging in the long run to the perception of the value of TC material. The transfer of TC material to subsistence farmers needs to be undertaken in comprehensive training program or input package. Also in Uganda, for example, TC plantlets have been offered to smallholder farmers at subsidized prices. TC technology can only benefit the farmers when sustainable distribution systems are in place, such as through the use of nurseries (Kahangi, 2010).

TC Nurseries

All TC producers operate their own nurseries at the production facility from where they sell ready-to-plant plants. However, TC satellite nurseries, in strategic locations at distance from TC production facilities are essential, as they act as (a) distribution hubs connecting TC producers to farmers and (b) intervention centers for TC farmers and farmer groups (e.g., training, supply of inputs). Nurseries face an array of challenges, however.

We conducted a survey of all 40 TC nurseries in Burundi, Kenya and Uganda, using a semi-quantitative questionnaire. In Kenya, sub-optimal relationships between TC producers and nurseries are especially related to bad timing, poor quality and insufficient quantity of plantlet supply. At the nursery level, there are three main operational issues: water access, credit and transport of plantlets. Location of the nurseries is also crucial. Nurseries need to be close to the TC producer and to the market, otherwise their success is compromised. Clear drivers for success of a nursery are good agricultural practice (e.g., provision of enough moisture to sensitive TC plantlets at weaning stage) and, interestingly, diversification into crops other than banana (Burkhart, 2009).

The distribution of TC plantlets through satellite nurseries differs with country. In Uganda, satellite nurseries are conducted as independent businesses by TC operators and farmers. In Burundi, satellite nurseries are wholly managed by TC producers. However, in both countries, few satellite nurseries are successful as TC producers prefer to sell ready-to-plant TC plants directly to governmental organizations (GOs) and non-governmental organizations (NGOs), where economies of scale help create faster economic returns. In Kenya, a successful TC satellite nursery model has been developed. Nurseries are run independently from TC producers, and most of them are owned by formalized farmer groups that equally act as customers for these nurseries. The business model in Kenya seems to hold the secret for a sustainable and vigorous link between TC producers and farmers.

TRAINING OF TC NURSERY OPERATORS AND TC FARMERS

Sustainable distribution systems need to deliver TC plantlets as part of a training package. We conducted a comprehensive training of prospective TC nursery operators and farmers. Prospective TC nursery operators and farmers were trained separately in Burundi and Uganda, while in Kenya, they were trained together. Trainees were recruited in locations where use of TC is more economically justifiable (e.g., close to the main banana markets) and using leaflets that emphasized the profit-making aspect of selling or growing TC banana as a business enterprise. The training program differed in two ways from other TC-related training in the region. (a) Training modules included marketing, business and financing, and, for TC farmers in Burundi and Uganda, group formation and group dynamics. This commercial focus was additional to the normal practice focusing only on technical and agronomic aspects (e.g., humidity chamber or screenhouse construction and maintenance for prospective TC nursery operators; e.g., water management shortly after field transplantation for prospective TC farmers); (b) Participants were trained over a period of ~1.5 years, as opposed to short intensive periods. Each prospective TC farmer received 41-45 training days, whereas each of the prospective TC nursery operators received 12-23 training days.

Throughout the three countries, as a result of the trainings, 12 new nursery businesses were established. Cost-benefit analysis after 12 months (comprising two TC plantlet selling seasons) for three nurseries in Uganda demonstrated profits of Ugandan Shillings 478-641/plant, with higher profits obtained with increasing number of plants sold (Table 1).

Throughout the three countries, 11 new farmer groups were formally established. Some of these farmer groups were able to secure micro-credit and expanded into activities beyond banana (e.g., rental of event equipment, outside catering). To measure the training impact, we monitored agronomic and economic data from 1,350 individual banana plants in 87 farmer fields over two crop cycles in Burundi and Uganda. Farmers were randomly divided into three groups: (a) non-TC farmers, (b) untrained TC farmers, and (c) TC farmers that were trained during the current project. In the first crop cycle, there was no difference in yield between farmers that grew suckers versus farmers that grew TC material (Fig. 2). However, because of lower plant loss and bigger bunches (data not shown), farmers who grew TC banana and received training harvested twice the yield compared to the other two groups. In addition, as a consequence of receiving training and formal group formation, trained TC farmers marketed their produce better and obtained a higher price/kg, resulting in a threefold increase in revenue compared to untrained TC farmers.

In our training, we found that organizing farmers into groups has major advantages, because of increased buying and selling power, reduction in economic and social risk, increased economies of scale, and access to credit and inputs in the case of formally certified groups. Especially in Uganda, where extended market pathways with numerous middlemen result in low returns to farmers, formation of farmer groups who engage in collective marketing also increased farmers' revenues in similar studies (Ngambeki et al., 2010).

SOCIO-ECONOMIC IMPACT ASSESSMENT

Ex Post Impact Studies

Although TC banana technology has been promoted with farmers for over a decade in East Africa, a rigorous ex post socio-economic assessment of its impacts is, surprisingly, lacking in East Africa. Despite a flourishing commercial sector, there is only anecdotal evidence that farmers that have adopted TC bananas benefit substantially in terms of higher yields and household incomes, partly because of a large body of subjective 'grey' literature, sometimes unconditionally and unilaterally promoting the benefits of TC bananas. Sound socio-economic analyses are crucial to guide policy strategies, learn from successes and identify important constraints for a wider dissemination of TC banana in the region. Studies on the impacts of TC in the region have either employed ex ante methods before any meaningful adoption was observable (e.g., Qaim, 1999), or they have used relatively simple and ad hoc qualitative methodological tools (e.g., Muyanga, 2009), which may result in misleading conclusions. By measuring the impact of a technology, one cannot simply average out adopters and non-adopters, and compare, because adoption is not random. TC banana adoption is liable to selection bias, as adoption is influenced by several exogenous factors that need to be accounted for using sound mathematical models. In Kenya, we conducted a socio-economic impact assessment composed of 223 adopters and 162 non-adopters, using a quantitative structured questionnaire. Data were analysed using average treatment effect modeling (Kabunga et al., 2011).

Knowledge Awareness

Among farmers in the study in Kenya, a substantial share of the population was aware of TC banana and is therefore generally sensitized to the technology's existence, while just a few have had a chance to fully understand its performance and requirements, which we labelled knowledge awareness. Farmer group membership facilitates knowledge gathering and sharing, which points to the important role of social networks for knowledge dissemination. Increased distance to the closest farm input shop reduces knowledge exposure. This is plausible, because input suppliers are important sources of information for smallholder farmers. Female-headed households are also less likely to be aware of TC banana, which may be due to gender bias in extension efforts and informal information flows (Kabunga et al., 2011).

Drivers of TC Adoption

We subsequently looked at the drivers of TC adoption while adjusting for knowledge exposure bias. One of the most interesting observations is that the percentage of banana TC adopters in the farmer's social network has a negative impact on adoption. In other words, the more banana TC adopters there are in the personal network, the less likely it is that the farmer also adopts TC banana. This indicates that TC adopters have a negative experience with the technology, and consequently encourage other farmers to avoid it. Farmers in high-potential banana areas are less likely to adopt TC, which highlights a strong negative selection bias. In high-potential areas, bananas grow relatively well, even under poor management conditions, so that there is less need for TC bananas. Farm size and ownership of other productive assets do not influence adoption, indicating that the technology is scale-neutral. Female-headed households are more likely to adopt TC banana, which is particularly important from a policy perspective, as bananas are predominantly managed by women in Kenya (Kabunga et al., 2011).

CONCLUSION

The lack of implementation of certification for plant quality and health is a major threat to sustainable commercial TC production. TC nurseries are essential in the production chain but neglected by the private sector and donors. Nevertheless, they can be highly profitable, provided a full training package is delivered. TC technology is especially important for areas with high banana production constraints and areas close to large banana markets. To maximize the economic benefit of TC technology for smallholder farmers, implementation of the technology needs to be combined with a comprehensive training package to enable its full benefits, including business, marketing and farmer group formation.

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Tables

Table 1. Cost-benefit analysis (in Ugandan Shillings[1]) of three tissue culture banana (*Musa* spp.) nurseries in Central Uganda during the first year of operation (representing two plantlet seasons) and following extensive training.

	Nursery 1	Nursery 2	Nursery 3
Investment cost[2]	65,200	270,000	138,616
Operational cost	18,147,000	4,475,000	12,011,000
Revenue	24,500,000	6,173,900	19,520,000
Profit	6,287,800	1,428,900	7,370,384
Plants sold	9,800	2,988	12,200
Profit/plant	641	478	604

[1] Ugandan Shillings 2,297 = $ 1 (1 January 2011).
[2] Training costs are not included.

Figures

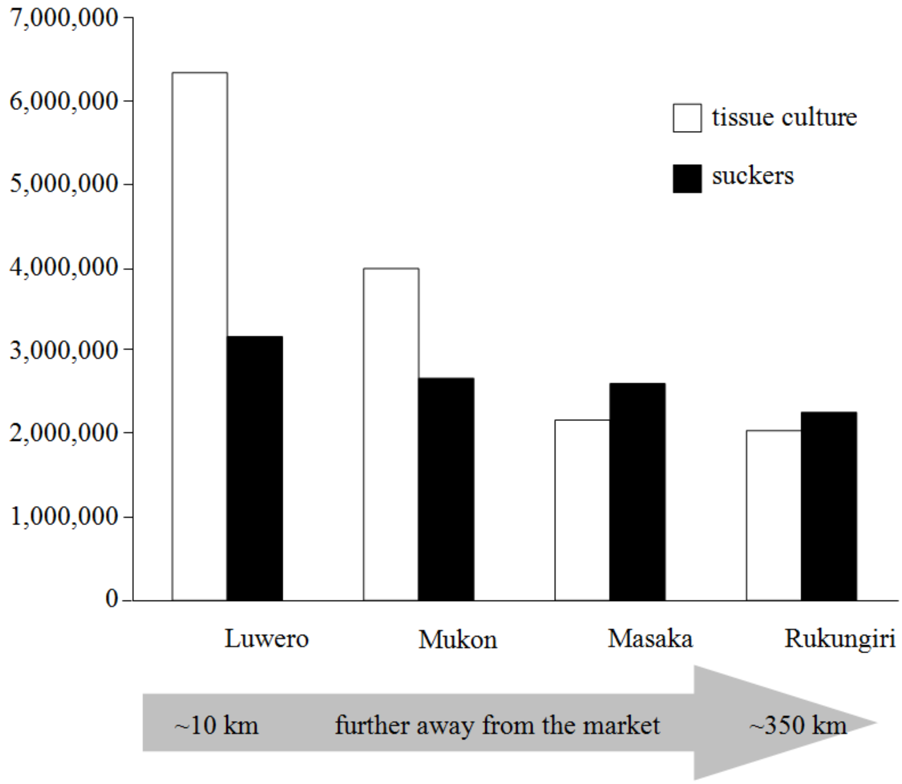

Fig. 1. Gross margins (in Ugandan shillings)/ha/yr of banana plantations derived from tissue culture compared to conventional planting material in Uganda, as a function of distance from the main banana market (Kampala). Ugandan Shillings 1,957 = $ 1 (1 January 2009).

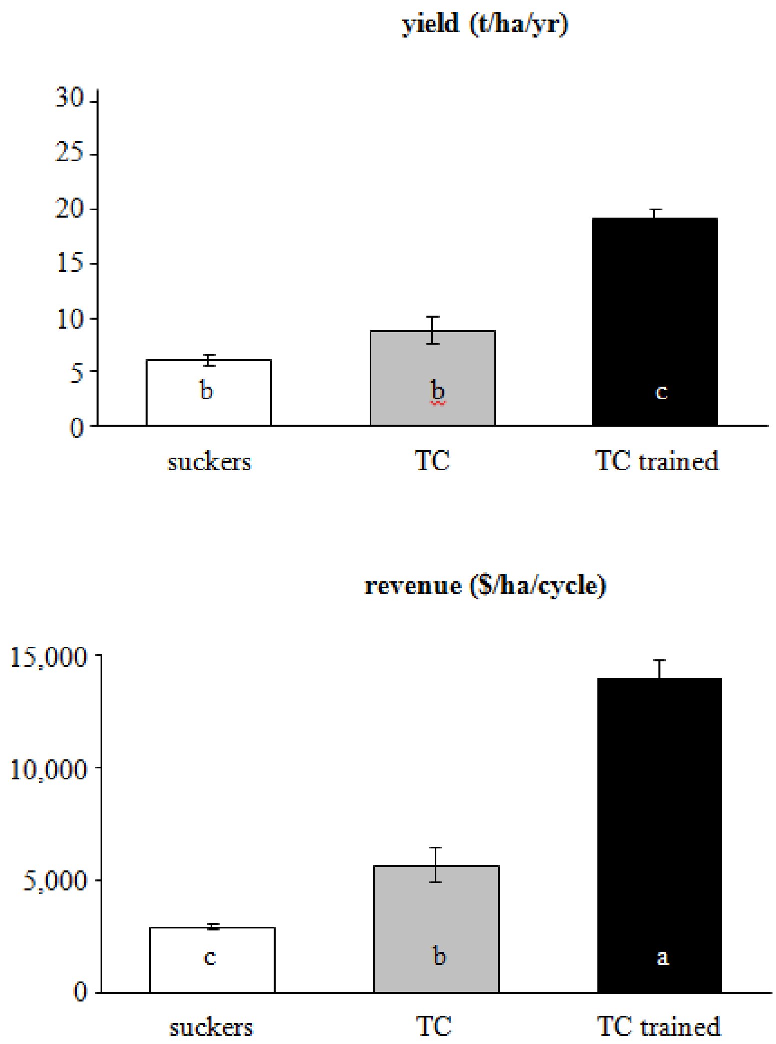

Fig. 2. Yield (t/ha/yr) and revenue ($/ha/yr) of banana plantations from three types of farmers: (a) growing conventional planting material (suckers), (b) growing tissue culture bananas (TC), and (c) growing tissue culture bananas and trained following a comprehensive training package (TC trained).