Banana and Plantain
Technology Toolkit Catalogue

AFRICAN DEVELOPMENT BANK GROUP
GROUPE DE LA BANQUE AFRICAINE DE DÉVELOPPEMENT

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Transforming African Agriculture

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TAAT
Technologies for African Agricultural Transformation

Banana and Plantain Technology Toolkit Catalogue

The Technologies for African Agricultural Transformation (TAAT) is funded through a grant from the African Development Bank and is implemented by the International Institute of Tropical Agriculture (IITA) in close collaboration with other centers of the Consultative Group for International Agricultural Research (CGIAR) and specialized institutions such as the African Agricultural Technology Foundation (AATF), the Forum for Agricultural Research in Africa (FARA), the International Fertilizer Development Center (IFDC) and others. The DR Congo Agricultural Transformation Agenda (DRC-ATA) is a collaborative effort of the Government of the Democratic Republic of Congo and the International Institute of Tropical Agriculture that is designed to modernize that country's agricultural sector. It works closely with the African Agricultural Leadership Institute (AALI).

Front cover photographic credits: Tissue cultured banana plantlets (left) and a mature banana plantation with common bean understory (right). Credit: IITA

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A Report by the Technologies for African Agricultural Transformation Program and the African Agricultural Leadership Institute

Purpose and Introduction

This catalogue describes a series of proven technologies for banana and plantain management and agro-processing that promote increased productivity and profitability in Africa. It is developed through a collaborative effort from the Technologies for African Agricultural Transformation (TAAT) Program that seeks to increase stakeholder use of proven agricultural technologies, and the Agriculture Transformation Agenda of the Democratic Republic of Congo (ATA-DRC). The International Institute of Tropical Agriculture (IITA) is an active partner in both of these efforts. Together, these partners identified several proven technologies that advance banana and plantain production and processing as a means of achieving greater food self-sufficiency and adding economic value to agriculture. These technologies constitute a "technology toolkit" meant to promote understanding and stimulate adoption and investment into the modernization of farm enterprise.

About TAAT. Weaknesses in the production and supply of commodities are viewed as responsible for Africa's food insecurity, need for excessive importation of food, and unrealized expansion of Africa's food exports. The TAAT Program led by the International Institute of Tropical Agriculture (IITA) pioneers new approaches to the deployment of proven technologies to African farmers. TAAT arose as a common effort of IITA and the African Development Bank (AfDB); and is an important component of the latter's Feed Africa Strategy. Currently, TAAT is advancing 100 carefully selected technologies through 88 interventions in 31 countries organized around 15 "Compacts" that represent priorities in terms of achieving Africa's potential in achieving food security and advancing its role in global agricultural trade. Nine of these Compacts relate to specific priority value chains of small livestock (including poultry), fish, common bean, rice, wheat, maize, cassava, sweet potato, sorghum and millet. Together these Compacts design interventions in collaboration with national programs to introduce technologies and innovations intended to meet ambitious targets for agricultural development. In many cases, these targets are addressed through the implementation of projects resulting from sovereign country loans awarded by development banks, where TAAT's role in the design, planning and execution of these loan projects is a vital element of their success. Banana and plantain are commodities to become included within TAAT in 2023.

The Agricultural Transformation Agenda of the Democratic Republic of Congo (ATA-DRC) is a collaborative effort of the Government, the International Institute of Tropical Agriculture (IITA) and the African Agricultural Leadership Institute (AALI) designed to modernize that country's agricultural sector. It operates nationwide and focuses upon banana, cassava, rice, maize, soybeans, beans and aquaculture as key commodities and value chains. It seeks to double agricultural yields through greater use of improved crop varieties, fish breeds and production inputs. Its goal is to create wealth and jobs through modernized agriculture by consolidating and building upon several ongoing projects. It also seeks to better structure new projects being developed and financed by donors and development banks. It works closely with Bio Agronomic Business on behalf of the Ministry of Agriculture, welcomes a wide assortment of private sector actors and is intended to reach all 145 territories of the country and its example is expected to be replicated in other countries through the African Development Bank's Food and Agriculture Delivery Compact Program.

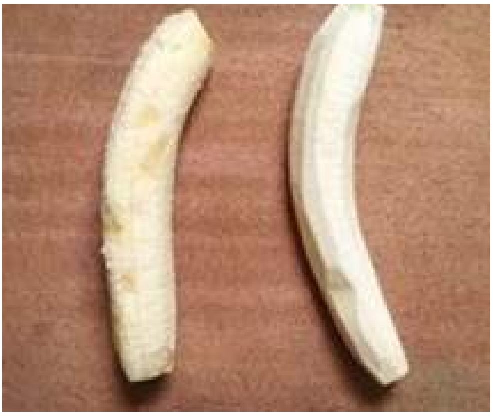
The Top Banana and Plantain Technologies. This catalogue describes banana and plantain as a modern and healthy commodity for the agri-food industry and then presents 11 technologies that serve to intensify production systems and promote value addition. These technologies include: 1) Improved varieties of banana for the African Highlands; 2) Improved varieties of plantain for tropical lowlands; 3) Propagation of disease-cleaned suckers; 4) In-vitro tissue culture propagation; 5) Specialty fertilizers and local blending; 6) Spacing and stand management; 7) Control of widespread pests and diseases; 8) Intercropping strategies for banana and plantain; 9) Peels as feed and organic resources; 10) Induced ripening of banana; and 11) Value added processing of bananas and plantain. The catalogue also describes successful efforts to overcome widespread production decline and the attraction of youth to the production and processing of banana and plantain.Details on these technologies and activities are included in the catalogue.

Banana and Plantain as a Modern Food Commodity

Bananas and plantains are popular plants and hugely important to food security, household livelihood, and sustainable agriculture. The perennial plant reproduces vegetatively and develops fruit without fertilization. Sweet varieties can be eaten raw when fully ripe while starchy varieties are cooked when green. Plantain resemble banana but fruits are longer, have a thicker peel, and contain more starch. They are usually cooked and not eaten raw unless very ripe. Plantains are more important in the humid lowlands of West and Central Africa. In 2018, about 12.4 million tons of plantains and 9.8 million tons of highland cooking bananas were produced in Africa. Uganda is the largest producer of banana and plantain, along with other major producing countries Rwanda, Ghana, Nigeria, and Cameroon. This crop offers an excellent energy source, with carbohydrate contents of 22% to 32% of fruit weight, and are rich in vitamins, minerals and dietary fiber. Unlike many other staple crops, banana and plantain provide food throughout the year, offering a staple food to more than 80 million people in Africa.

The main threats to banana and plantain production are pests and diseases such as weevils, nematodes, airborne fungal black leaf streak and soil borne wilts. Soil fertility degradation and low rates of nutrient replacement form another major limitation. A wide range of interventions exist for increasing banana yields, augmenting their value and reducing post-harvest loss. For decades, hybridization of bananas and plantains was considered impossible due to their vegetative reproduction and lengthy evaluation and selection cycles. Then, scientists at IITA developed a way to hybridize varieties that are resistant to black

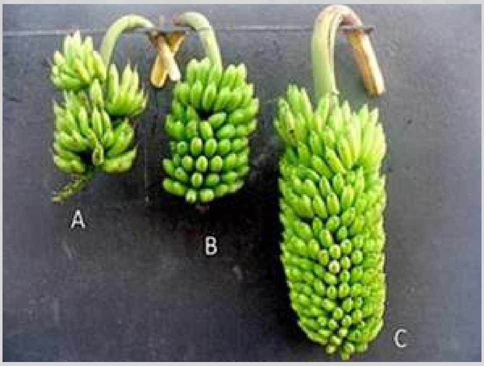
Bunches of cooking banana (left) and plantain (right)



Peeled matooke, left, and plantain, right (Credit: Leo Tunapika)

leaf streak using conventional crossing and novel molecular marker tools. Development of improved varieties is being finetuned by means of a digital application called the "banana breeding tracking tool". Now, advances in the production of clean planting material through simple macro-propagation systems and fully sterile and uniform micro-propagation make it possible to supply large quantities of improved varieties and increase earnings from seedling production. Site-specific advisory for agronomic practices such as planting density and weed management, as well as specialty formulated or blended fertilizer is now available as well. Banana and plantain can be processed into a variety of food products such as chips or ingredients like flour for baking and cooking relying upon a wide range of processes. Indeed, banana and plantain are now becoming an internationally recognized modern food commodity!

Technology 1. Improved Varieties of Banana for the African Highlands



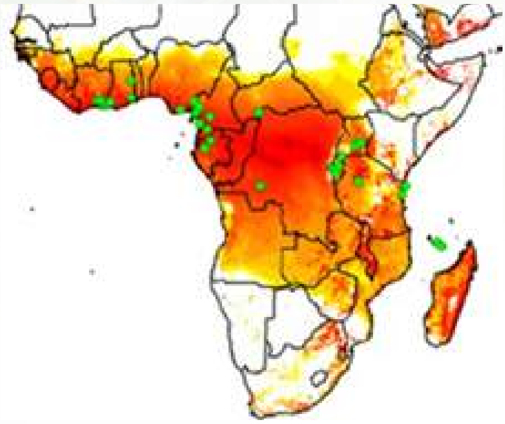
Progressive gain in bunch weight of cooking banana through selective breeding, A: grandparent, B: parent, and C: hybrid

Summary. Production of bananas in the Great Lakes region has stagnated. For example in Uganda, yields are as low as 5 30 t ha-1 year-1 compared to a potential 70 t. Banana bunch weights have dropped from 60 kg to 10 kg or even less. In large part this is because traditionally cultivated varieties of the East African Highland bananas are susceptible to several pests and diseases. Declining soil fertility and drought further undermine production. Low banana yields result in food shortages that place dependent communities at risk of hunger. Introduction of high-yielding, disease resistant hybrids forms an integral part of technology packages to improve productivity. Through conventionally breeding, a range of improved varieties were developed that are less susceptible to black leaf streak and resistant to nematodes and bunchy top disease. Cultivating improved varieties reduces the risk of die-off in plantations.

Technical Description. Breeding pipelines for cooking banana is enhanced as more high yielding and pest and disease resistant hybrids become available. Early field evaluation processes are accelerated by improving pollination and increasing the number of crosses made. A major breakthrough is the 'NARITA' hybrid line obtained by crossing the East African Highland Banana (EAHB, AAA group) with a wild variety (Calcutta 4, AA group). Hybrids are then selected for culinary quality, color, aroma, taste, mouthfeel, and texture. Building upon the NARITA success, the Tanzania Official Seed Certification Institute has registered four Tariban cooking banana hybrids.

Uses. The recommended hybrid varieties in Tanzania are TARIBAN1 through 4. Clean swords of these varieties are available from the Tanzania Agriculture Research Institute. Tissue culture plantlets are available from designated

private laboratories in Tanzania. In Uganda, the National Banana



Potential occurrence of black leaf streak disease; highest in red areas, lowest in yellow areas (Credit: Yonow et al. 2019)

Research Program of NARO in Kawanda maintains hybrid cooking banana varieties at on-station fields. They are accessible through NARO and domestic private enterprises. In Rwanda, evaluations show that NARITA hybrid and Mpologoma perform well at sites with varying altitude, soil fertility and rainfall. In DR Congo, traditional cultivars of cooking banana dominate but Hybrid lines derived from NARITA are undergoing field evaluation.

Composition. Improved hybrid varieties have a compact bunch with more fruit, as well as heavier and larger fruit than traditional cultivars. Tall banana plants are normally vulnerable to wind damage but TARIBAN2 is particularly sturdy. The TARIBAN cultivars produce pronounced swords and few suckers except for TARIBAN3.

Application. Conventional breeding of banana involves the crossing of edible varieties with wild seeded bananas. New molecular techniques assist in this approach. Resistance against nematodes is acquired by inserting foreign genes through a bacterial vector. Early field evaluation consists of monitoring single plants among large populations of hybrids, while preliminary yield trials assess entire rows of clonal hybrids. Climate and soil conditions have strong influences on the suitability of varieties so performance evaluation of banana hybrids must be done at multiple contrasting locations to ascertain performance, adaptability, and stability. This way specific or broadly adapted cultivars can be selected and commercially multiplied (see Technologies 3 and 4). Trials conducted over two production cycles provide reliable information at reduced costs. For example, TARIBAN varieties have been developed by testing of 27 hybrids in three sites over four. The final selection of prospective "Matooke" hybrids is guided by a product profile that includes host plant resistance to BLS, culinary acceptability, and bunch weight significantly higher than the standard local check. For obtaining satisfactory production, clean planting materials must be used (see Technologies 3 and 4) alongside with balanced nutrient inputs and optimal spacing and stand management (see Technologies 5 and 6).

Commercialization and Start-up Requirements. International breeding centers and national programs offer access to improved banana cultivars for cooking and desert purpose. Starter materials of disease resistant high-yielding varieties have been successfully distributed via farmer associations and NGOs in many countries for widespread nursery propagation of plantlets. Promoting hybrid banana among small-scale farmers requires

Bunches of new Matooke cooking banana cultivars, A to D = TARIBAN 1 to 4 (Credit: Madalla et al. 2022)

information campaign about its nutritional benefits and easy access to quality planting material. This involves: 1) Identifying appropriate cultivars for specific climatic conditions, stand management, production targets, and market demands, 2) Awareness raising with multipliers, farmers and food processors about the benefits of new disease resistant high-yielding varieties, 3) Establishing local hubs for training on macro-propagation of healthy plantlets and good agronomic practices, and 4) Distributing clean material for multiplication.

Production Cost. Breeding of improved banana varieties in the laboratory and greenhouse and testing their performance under field conditions requires significant long-term investment that must be funded by the public sector and donors. A switch to resistant varieties involves the purchase of new planting material which ranges between US $290 and $1,000 per hectare. Recommended inputs of animal manure and synthetic fertilizer for increasing yield and plant health cost US $670 to $3,300 per hectare. Labour costs to plant, manage and harvest plantations amount between US $700 and $1,300 per hectare.

Customer Segmentation and Potential Profitability. Subsistence and commercial banana producers can benefit from disease resistant varieties, especially in disease infested areas including. Scaling this technology also involves national research and extension systems, private companies, traders, and food processors. Improved cultivars have greater bunch weigh and annual yield than common cultivars which results in higher food security and income for farmers.

By example, the average bunch weight of TARIBAN varieties across different regions in Tanzania ranges from 26.5 to 34.2 kg, with total yields ranging from 16.0 to 20.3 t ha-1 per year, which is 68% - 117% higher than the traditional variety. Depending on the variety, management and yield, net annual profits from improved bananas will amount between US $1,200 and $9,500 per hectare in the first cycle and are between US $1,900 and $15,000 per hectare in ratoon cycles.

Licensing Requirements. Farmers, NGOs, and private enterprises have the right to multiply hybrid banana varieties without royalty since these cultivars are a Regional Public Good. Compliance with regulations on seed systems and plant health policies is required in many cases.

Technology 2. Improved Varieties of Plantain for Tropical Lowlands

Summary. Plantain is the third most important food crop after yam and cassava in much of Central and West Africa. The major producing countries are Cameroon (4.5 million t), Ghana (4 million t), Nigeria (3.2 million t), and Ivory Coast (1.6 million t). Black leaf streak disease is the greatest production constraint with yield losses ranging from 33% to 50% or more. Weevils and nematodes undermine yields by destroying the corm and root system. Population growth reduces fallow intervals and soil fertility. The devastating effects of diseases and pests on plantain production spurred development of resistant hybrids. Improvement of plantains also focused on high productivity, drought resilience and preferred cooking traits. Varieties of improved plantain now exist that are adapted to diverse climatic and production conditions

Effect of black leaf streak on plantain; susceptible variety, left and resistant variety, right (Credit: Alvarez et al. 2015

Technical Description. Breeding for host plant resistance to diseases and pests is the most appropriate control strategy since chemical control is expensive and environmentally hazardous. Most of varieties of the hybrid line "PITA" were produced by crossing a female with increased fertility (AAA group) and the wild banana (Calcutta 4). On-farm research in Cameroon, Ivory Coast and Nigeria shows that mixing disease resistant plantain hybrids with local cultivars reduces black leaf streak pressure on the susceptible local cultivars, raising the number of functional leaves at flowering and increasing fruit yield. This strategy preserves genetic diversity while providing farmers access to high-yielding resistant hybrids. It must be noted that while plantain hybrids offer prospective for enhancing yield and resistance, they do not have the same cooking properties of preferred landraces and therefore can only be used for specific preparations.

Uses and Composition. Specific varieties of the high-yielding and black leaf streak resistant hybrid PITA line have been selected for different countries. PITA 4, PITA 14, PITA 17, and PITA 18 perform best growing areas in Nigeria, while PITA 23 and 27 are suitable for Cameroon. Another plantain hybrid, called PITA 3, is popular among growers in Ivory Coast and has also been adopted in Mali and Burkina Faso. The variety FHIA 21, bred from a Honduran high-yielding and black leaf streak resistant line, is massively propagated, and distributed to farmers in Benin, Burkina Faso, Ivory Coast and Togo by the West Africa Agricultural Productivity (WAAAP) program. The PITA hybrids have moderate resistance to nematodes so must be cultivated on plot with low infestation. Traditional varieties of plantain in West Africa include Big Ebanga, Orishele, Afoto and Agnirin which are resistant to nematodes but susceptible to black leaf streak. Farmer preferences are also guided by height, with shorter statured (<3m) varieties requiring no staking, being less vulnerable wind and allowing easier harvest. Taller statured plantains (4-5m), on the other hand, prevent theft of bunches which can account for substantial preharvest losses. All varieties can be boiled, mashed, or fried for use in local dishes.

Sika Plantain (Credit: B. Dhed'a)

Application. Plantains are typically grown in smaller gardens with application of manure and household refuse that ensures continuous high productivity for many years. They are also produced in fields under shifting cultivation and bush fallow with low or no input of organic fertilizer causing bunch yields to decline rapidly after the first production cycle due to disease pressure and poor management practices. The major harvest in West-Africa occurs in the dry season spanning the months of

December through March, when most other starchy staples are in short supply, but bunches of fruit are produced throughout the year.

Start-up Requirements, Production Cost and Potential Profitability. These costs are similar to banana (see Technology 1) where new planting material requires US $290 to $1,000 per hectare with a minimum $1400 needed for production inputs and labor. Improved varieties typically provide 3 to 4 kg greater bunch weights than traditional ones. Nematode and weevil damage is about 25% to 34% less in hybrids, resulting in extended stands. Benefit to cist advantages in varietal investment are about 5:1.

Licensing Requirements. Once improved varieties are purchased, there are no further licensing requirements from plantation improvement.

Technology 3. Propagation of Disease-Cleaned Suckers

Complete decapitation with excised meristem (top) and sprouting suckers (botto ready for transplanting

Summary. Farmers in Africa depend on natural vegetative regeneration mechanisms of banana and plantain for the supply of planting materials but these are often contaminated by pests and diseases than undermine productivity and lifespan. Suckers are traded on local markets which forms an important source of income for farmers. Sword suckers are lateral shoots with thin leaves and a pseudostem length of 80 to 120 cm, which naturally develop at the flowering stage. Their macro-propagation is based upon the removal of the apical dominance to stimulate additional sprouting of suckers. It involves simple techniques that can supply large quantities of disease- and pest-free seedlings at affordable prices, including planting material from earlier released high-yielding hybrid varieties.

Technical Description. Macro-propagation of suckers can be classified into two categories: field-based techniques relying, based on decapitation, and detached corm techniques conducted in beds. The complete and false decapitation techniques involve stimulating lateral production of sucker buds by destroying the meristematic corm and triggering

accelerated sprouting. Using partial decapitation, a small hole is made in the pseudostem through which the meristem is destroyed. The foliage remains physiologically active for about three months thereafter. Using complete decapitation, the pseudostem is cut down, destroying the meristem. Detached corm techniques involve excised buds or plants resulting from stem fragments. A higher number of seedlings and greater growth uniformity is achieved by the detached corm technique than from pseudostem decapitation, and plantlets obtained from corms are less prone to stress once established in the field. It is very important that the starting material for macro-propagation is free of pests and diseases.

Uses and Composition. To increase banana production, farmers should have access to affordable, high-quality vegetative seedlings that are free of pests and diseases. For all methods of macro-propagation, knives must be cleaned with boiled water to avoid disease transmission. The detached corm technique requires that hardened sprouts are used. Convenient dimensions of a propagation chamber are 1.5 m wide, 5 m long and 1 m high. It should be covered by transparent polyethylene and be at least 50% shaded. Plastic covers must be fitted to ensure high humidity and temperature. These chambers are filled with a mixture of soil; composted manure; and sawdust, coffee husk, rice husks, oil palm fiber or cocoa fiber at a ratio of 6:3:1. The substrate must be steam-sterilized by placing it on top of a metal drum containing boiling water.

Detached corm propagation: a) Scarified corm, b) weaning chamber, c) secondary shoots, and d) acclimatization shed

Application. The technique of false decapitation starts by making a square incision of 5 cm wide at 20 cm from the ground level up to the middle of the pseudostem using a 6-month- old plant, killing the active meristem. Angle the bottom side of the hole slightly downwards so water and plant sap collect in the hole to further kill the meristem. Decapitated plants are left for at least one month to allow sprouting. For complete decapitation the apical dominance is removed by cutting down a 6-month-old plant to the ground level and excising the middle 5 cm of the softer meristem leaving the harder corm intact. The cut stem should be covered with soil to promote sprouting. Within three weeks, four to seven suckers will emerge. Suckers with three to four leaves are detached by pulling them from the pseudostem and transplanted to the field.

For macro-propagation using the detached corm technique, the source material are healthy suckers collected between flowering and harvest. Roots are cut from suckers and washed before peeling leaf sheaths. The whole corm is then sanitized by submerging it in boiling water for 30-40 minutes (or fungicide for 20 minutes. Corms are scarified by making a shallow incision at the top and then left to air dry for 24 hours. Whole corms are planted in the weaning chamber at 30 cm distance, or the corm is split into 2 or 3 fragments or buds are excised in pieces of 50-100 g that are planted at 10 cm distance, and are covered with 2 cm of sawdust. Upon planting the chamber is well watered. Three to seven shoots will sprout from one piece of planting material within three weeks. After about 10 weeks, 10 to 50 secondary shoots will emerge with two to three small leaves each. Plantlets are detached and those that have roots are directly transplanted into a potting mixture one plant per container. Plantlets are acclimatized and hardened in a shaded area for 3 to 6 weeks.

Production Cost and Potential Provitability. Macro-propagation via pseudostem decapitation and detached corm techniques are easy to learn and inexpensive to establish. Propagation through decapitation costs about US $0.30 per 100 plantlets every four months. Building chambers that can hold 8,000 plantlets costs about US $2,300. The cost of constructing a shade house that can hold 2,500 plantlets is about $340. Plantlets propagated via the decapitation method are sold at US $ 0.5 whereas larger ones from detached corm method are sold at US $ 1. A study in South-Kivu DR Congo shows that macro-propagation of plantain using semi-cylindrical tunnels with manure in the substrate that produces 850 to 1,100 plantlets per cycle can achieve a net profit between US $725 and $1,050 per cycle.

Licensing Requirements. Multiplication of banana and plantain through macro-propagation methods is not subject to regulatory approval in most countries but voluntary certification of nurseries for adherence to plant health standards may be in place.

Technology 4. In-Vitro Tissue Culture Propagation

Steps of in-vitro tissue culture micro propagation: a) Removal of sheaths, b) Separated corm, c) Desinfection and segmentation of corm, d) Transferal to sterile tubes with growth media tubes, e) Culturing in climatized chamber, f and g) Transferal of propagules for proliferation of shoots by subculturing in jar, and h) Nursing of plantlets in screenhouse (Credit: B. Dhed'a)

Summary. Banana and plantain is propagated in the laboratory through tissue culture (TC). In vitro micro-propagation eliminates all pests and diseases except for viruses. TC consists of five important steps: Initiation, Multiplication, Shooting and rooting, Primary Hardening in green houses and Secondary Hardening in shade houses. TC plants have the benefits of uniformity and fast propagation of large numbers of plantlets. These advantages enable marketing and more rapid recovery from broad-scale damage such as disease outbreak and extreme weather.

Technical Description. In-vitro micro-propagation relies upon a liquid, semi-solid, or solid growth medium such as broth or agar multiplied under sterile growing conditions. The most common tissue culture techniques is meristem culture but other techniques such as callus culture, somatic embryogenesis, cell suspension, and protoplast culture are poissible. TC plantlets tend to be less robust than suckers and require greater care due to their initial sterile production devoid of beneficial microorganisms. They are nevertheless regularly planted into fields with high pest and disease burdens and abiotic constraints. Inoculation of TC plantlets with beneficial microorganisms such as *Fusarium oxysporum* and *Trichoderma spp.* helps to reintroduce immunity (see Technology 9).

Micro-propagation through tissue culture techniques is an efficient method of producing large quantities and good quality plantlets but requires high capital investment and skills. Strict adherence to aseptic standards and micro-

climatic conditions and care during the hardening is important. Careful examination of the stock is required to avoid culturing the infected plants. Farmers should be aware that planting TC culture plantlets from a single banana or plantain species causes low genetic diversity and variability that poses a risk if disease or pest outbreak occurs.

Uses and Composition. Tissue-cultured banana seedlings are not always conveniently available. Larger-scale banana farmers may wish to establish their own banana tissue-culture facility to ensure availability of disease-free seedlings. To make TC plantlets readily accessible to farmers in remote areas, there is need for linkages with macro-propagation nurseries (see Technology 3). Water purified system for producing double distilled water to prepare the stock solutions and media, autoclave for sterilizing tools and media, pH meter and refrigerator to store the stock solutions and hormones. Laminar airflow cabinets to perform culturing and subculturing plants, these can be high-end models for specialized laboratories with large output capacity but may also be fabricated with plastic boxes and a small air filter. Other materials required include a pH meter, hot plate/stirrer, glasswares and beakers, forceps, bunsen burner, wash bottles, brushes, culture vessels and tubes, Erlenmeyer flasks, graduated cylinders, glass pipettes, scalpel handles, and blades, spatulas, stir bars, roll tape, gloves, parafilm, lab markers, paper towels, detergents, isopropyl alcohol, chlorine bleach, and brushes. Growth media for the preculture are made with Murashige & Skoog basal medium supplemented with 5.0 mg/l BAP, and subculture media are half of those concentrations. An air-conditioned room fitted with two 40-watt fluorescent tubes and a 16-hour photoperiod.

Application. The first step is to collect suckers 40–100 cm tall from strong mother plants that are free of disease symptoms, making sure to separate the sucker without cracking the corm. It is advised to collect at least two suckers from each plant source, one for micropropagation and the other for a nursery farm for future propagation. Approximately 10 cm of inner tissue containing the meristematic corm is excised from the stem by removing

Effect of endophyte inoculation on TC seedling, with left and without right (Credit: T. Dubois)

Effect of endophyte inoculation on TC seedling, with left and without right (Credit: T. Dubois)

the leaf sheaths in a clean laboratory and rinsed with water to wash of soil. The second part of the process happens in a laminary flow hood using autoclaved scalpels, forceps, cutting plates and solutions. The entire corm is disinfected by submerging it in series of disinfectant solutions. Next, the surface-sterilized corm is trimmed until it measures 1 × 1 cm, with the corm tissue as thin as possible. On a fresh cutting plate, the corm is cut longitudinally into propagules of 0.5 cm. Propagules are placed in tubes with xx milliliter growth media and closed with an open cap. Over one month the propagules are kept in the room during which bulging and browning of the corm, greening of leaf tissue and shoot emergence is monitored. Contaminated or off-growth precultures must be discarded. When the propagules are 2 cm tall, they are transferred from tubes into jars with growth media to proliferate more shoots. Larger propagules can be cut in two. These subcultures must be kept in the growth chamber for 3-4 weeks to obtain desired numbers of shoots. Separating propagules from one subculture to get more shoots can be repeated 5 times. Before selling TC plantlets or planting them in shade houses to produce suckers, the seedlings need to exposed them to partial sunlight under greenhouse conditions for a few days.

Start-up Requirements, Production Costs and Potential Profitability. In Africa, a number of commercial tissue culture laboratory enterprises are operating that supply farmers with clean high quality material for planting and macro-propagation. These include, Agrobiotec and Phytolabu in Burundi, Mimea International and Jomo Kenyatta University of Agriculture and Technology in Kenya, and Agro-Genetic Technologies and Makerere University Plant Tissue Culture Laboratory in Uganda. Steps needed for starting a TC production plant involve: 1) Business planning and proper market analysis, 2) Obtaining a loan from a bank or other financing institution to acquire equipment, 3) Training of operating staff on handling and quality control procedures, and 4) Awareness raising of nearby farmers about planting and macro-propagation of TC plantlets. The efficiency of in-vitro propagation systems is mainly influence by the rate of multiplication which is dependent on genotype as well as operating procedures. Plantlets are sold for about US $1.3 to $1.5 by large commercial retailers. A nursery business can produce more than 3,000 TC plantlets per cycle and earn a gross revenue of US $1,600, achieving a return on investment of 1.4. Where TC material is used, farmers shorten production cycles allowing earlier harvest and allowing more than 90% of plants bear bunches.

Licensing Requirements. In some cases, micro-propagation techniques are licensed but mostly they are protected by trade secrets. Once purchased, producers are generally free to multiply their stock using macro-propagation techniques.

Technology 5. Specialty Fertilizers and Local Blending

Example of a fertilizer blend for banana

Summary. The production of banana in Sub-Saharan Africa suffers widely from low nutrient availabilities in soils. To counter this limitation, fertilizers must be applied that provide a balanced supply of nutrients. Specially designed fertilizer blends can be used that contain nutrients like nitrogen, phosphorus, potassium, sulfur, and others in proportions that are aligned with soil fertility status and crop requirements. Readily accessible single nutrient fertilizers and existing infrastructure in Sub-Saharan Africa can be used to mix these specialized blends for farmers. Note that banana and plantain have a particularly high requirement for potassium, and that blends for root crops are also suitable for this crop as well. Applying the right fertilizer at the right time and place to banana and plantain greatly enhances productivity and nutritional value and strengthens resilience to drought and pests. Specialty fertilizer blends allows farmers to obtain greater returns on input investments.

Technical Description. Formulations of blended or compounded fertilizers balance and replenish nutrient stocks in soils, which ensures that the added inputs are utilized more efficiently for increasing banana and plantain production. Blending technology offers a very large degree of flexibility to adapt fertilizer formulations in line with general soil characteristics and production objectives, as is prescribed by the guiding principles of integrated soil fertility management. The various elements that are mixed have specific benefits. For example nitrogen, phosphate and potassium promote stem growth, flowering and bunch filling, sulfate reinforces photosynthesis and transpiration, and calcium, magnesium and zinc enhance the uptake of nutrients and water from soils. Use of specialty fertilizers for banana and plantain has very strong synergies with improved varieties (see Technology 1 and 2) as larger bunches necessitate greater nutrient demand. Applying micronutrients results in fruit with greater nutritional and energetic value that help overcome deficiencies in rural communities. The right nutrient balance promotes uniform ripening and prevents splitting of immature and early ripened fruit.

Uses and Composition. Fertilizer blending technology is suitable for all major growing areas and especially important in low fertility soils. Split

A simple rotary fertilizer mixer

applications of specially blended fertilizers greatly improve the health of plantations and their yields and nutritive value. This approach is particularly important when farming highly weathered soils characterized by low fertility and pH imbalance. Note that fertilizer mixes designed for banana can be suitable on root, tuber and flower crops; and this versatility is advantageous for input manufacturers, distributers and farmers alike.

Specific nutrient formulas result from blending a wide range of solid granular fertilizers like urea (46% N), potassium chloride (52% K), single superphosphate (16 to 20% P_2O_5, 11

RFC Root manufactured by MEA Fertilizers in Kenya

to 21% Ca and 11 to 12% S) or triple superphosphate (46% P_2O_5). Micro-nutrients like zinc, boron, amongst others can be added in solid form or impregnated as liquid. An example of a mixed top-dressing fertilizer is "Banana blend" from Zambian with 12% N, 3% P_2O_5, 22% K_2O, and 35% organic matter which should be applied at 100 g per plant every month. Examples of specialty compound fertilizers for banana and plantain are Java®, Power®, Nitrabor® and Winner® from Yara which contain N, P, K, S, Zn, Ca, Mg, Fe, and B that serve different stages of the production cycle. Another useful blend for topdressing root, tuber and fruit crops (5:13:21 + MgO 5.8% + CaO 4% + S 3% + Zn 0.4%) manufactured by MEA Fertilizers in Kenya. These fertilizers are typically sold in bag sizes ranging from 5 to 50 kg.

Application. Information about the nutrient deficiency and imbalance in specific growing areas is contained within soil maps and past agronomic trials and is often sufficient for developing blending formulations. The production of the specialty fertilizer blends is also subject to the availability of different single fertilizers. Manufacturing of blends is done using a dry rotary system available at medium to large scales and is best packaged into sizes needed by farmers. Banana and plantain require NPK at rates of 200-40-200 kg ha^{-1} month intervals is advised. Some of these inputs may be substituted with organic inputs, particularly for ratoon crops.

Commercialization and Start-up Requirements. Several commercial input suppliers in Africa distribute fertilizer blends designed specifically for banana. Their specific composition, formulation and means of combination are often protected by trade secrets. To produce a new blended fertilizer, the following steps are required: 1) Derive the formula of blended fertilizers based upon nutrient demands and the soil fertility conditions requirements across a large production area, 2) Establish manufacturing protocols for mixing different sources of fertilizer and packaging the blend, 3) Sensitize agro-dealers about the benefits and profitability of specialty fertilizer blends and provide customer information about them, 4) Provide these branded fertilizers at affordable prices on local markets and monitor their sales, and 5) Conduct demonstrations and trials to assess the efficacy of a blend compared to other management options, and refine the formulation and branding campaigns over time as necessary.

Production Costs. Designing a new fertilizer blend needs not be expensive as it can be based upon desk study from a wealth of secondary information, including the composition of similar products. Refining that blend over time based upon agronomic trials and plant and soil analysis is considerably more expensive. Manufacturing specialty blended fertilizers bears a considerable start-up cost based upon capital investment for on multi-channel dry rotary systems and automated packaging. There is also the cost of assembling the primary fertilizers to be blended. These costs are considerably reduced for fertilizer companies with existing blending capacity that is seeking to expand their product lines. Smaller, more labor-intensive blending systems may be developed for localized operations, and even operated as a community-based operation once specific formulations are known.

Customer Segmentation and Potential Profitability. Blended fertilizers are intended for use by soybean producers through distribution via agro-dealer networks. The profitability of fertilizer blending is not based upon crop response to individual component fertilizers, but rather their improved response to strategic combinations of those ingredients, a feature that well informed farmers are willing to buy. Basically, blended fertilizers should offer returns that are greater than the

sum of the ingredient parts. Combining two or more needed fertilizers offers more efficient labor operations as well. Research in Cameroon has shown that fertilizing plantain with NPK at 200-40-200 kg ha^{-1} can increase yields by about 6.0 t ha^{-1}.

Licensing Requirements. The formulations of fertilizer blends may be subject to licensing but are more often protected as trade secrets. Those with knowledge of fertilizer composition may easily calculate desired blend proportions from different primary fertilizer materials. Responses to fertilizer application and combinations are available as Regional Public Goods when published by research institutions.

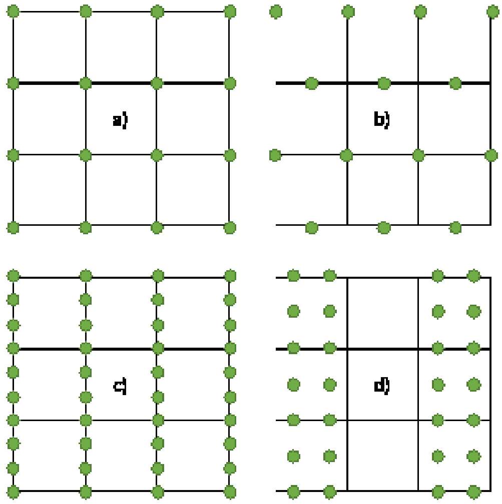
Technology 6. Spacing and Stand Management

Differences in plant spacing; low density (left) and high density (right) (Credit: T. Ndabamenye)

Summary. Spacing of banana and plantain is based upon the stature of the variety and expectations of the farmer. Most varieties are spaced 3 m x 3 m apart, or 1,111 plants per ha. Dwarf vatieties are planted at densities of 2 m x 2 m (2,500 plants per ha) or less. Very large varieties are planted at 4 m x 4 m. Note that the fibrous roots of even dwarf varieties can extend for 6 m. Spacing can also depend upon soil fertility level, and rainfall. Bananas are best planted in square blocks because the plant is adversely affected by wind. When planted in blocks, the plants provide protection to one another. Another consideration is the practice of establishing young plants in excavated holes of at least 30 cm x 30 cm x 30 cm that is fortified with organic materials. Establishing a large number of new plants thus requires considerable compost or manure, particularly if the soil is less fertile. Banana and plantain require abundant moisture with good drainage. Rows should be straight in flat fields to give plants the maximum amount of sunlight. On slopes, rows should follow the contour lines to decrease soil erosion.

Technical Description. Careful attention must be paid to planting arrangement and density when establishing banana and plantain as stand management affects labor requirements as well as bunch size and yields. Higher densities lead to excess competition for light, nutrients and water and result in taller, weaker stands with delayed maturity. Lower densities may lead to excess weed competition but provide scope intercropping (see Technology 8). Another consideration is the need to rotate plantation areas over time due to the accumulation of a host of pests and diseases, with a typical stand area of 8 to 10 years before rotation is needed.

Dwarf varieties require less space. Dwarf Cavendish, a widespread dessert variety, is planted at densities of 2500



Planting layouts: a) square, b) triangular, c) single row, and d) paired row

to 4400 plants per ha and can provide as much as 100 t/ha/year qith smaller bunches and fruits produced at higher planting densities. Plants arranged within blocks result in stands with desirable humidity and temperature levels. Most cooking bananas and plantains are larger and must be planted at wider spacing such as 3 m x 3 m forming 1,111 mats per ha. Some banana and plantain varieties are particularly large statured, growing to heights of 8 m and producing large mats with many shoots. These varieties should be planted at spacing of 4 m x 4 m or more. It is important to note that spacing greatly influences the expression of weeds, and that with proper spacing and residue management it is possible to establish plantation understories that are virtually weed free.

Uses. The optimal density is a function of cultivar type, climatic conditions that influence water availability, soil fertility levels, and interactions among these factors. Farmers must learn which varieties perform best for them and what spacing they require. For example, research in Rwanda found that under lower rainfall (<1,000 mm), yields attained a maximum at 3,333 plants ha^{-1} for cooking cultivars "Injagi" and at 4,444 plants ha^{-1} for "Ingaju". Under higher rainfall (>1,000 mm), the yields of these cooking cultivars increase beyond stand densities 5,000 plants ha^{-1}.

Composition. Different types of planting systems exist that align with specific farm conditions and production objectives. Small-scale farmers mostly adopt the square system where plants are positioned at each corner with a spacing of 2 x 2 m or 3 x 3 m. In a triangular system, the plants in alternate rows are positioned in the middle of the square instead of the corner. In a single row system, plants are closely spaced within the line (0.5 - 0.8 m), whereas the distance between the row is wide (1.8 - 2 m). In a paired or double row system, two lines of bananas are planted at 0.9 to 1.2 m with plants located at equal level, and paired rows are spaced at 2 to 2.5 m. On fields with very steep slopes a contour system is best used where plants are grown in lines of equal height using pits and plants in alternating lines should be staggered to minimize soil erosion. During early establishment the use of herbicides may be required to control weeds, with systemic contact herbicides such as glyphosate performing best.

Application. Plant density is often expressed as the number of mats per hectare, with a mat consisting of a mother plant and its suckers of younger generations. To determine the average spacing between mats, the distance of the mother plant in one mat and that of four closest mats is measured. "Earthing-up" of the stem base and additional support of mature bunches is required in areas prone to strong winds. Herbicide must be applied before the weeds start producing seeds and should not be sprayed on the banana plants themselves, intercrop, or naked soil. Contact herbicides can be used at the beginning of a production cycle and may need to be reapplied for controlling perennial grass. Systemic herbicides are recommended for established plantations. Operators can target which plants to remove and which to maintain favoring the establishment of a natural plant cover. Mechanical weeding is possible in double row plantations with larger alleys that allow rotavators to pass without damaging stems. Under such management it is important to use lighter attachments to avoid soil compaction. Using optimal plant density, increased water use efficiency and can reduce irrigation requirements by 30-40%, and result in 25% higher nutrient uptake from fertilizers. High density planting makes stands less vulnerable to damage from wind but can result in accelerated pest and disease accumulation.

Licensing Requirements. No licensing fees are associated with adjusting spacing to meet farmer's own conditions and individuals are encouraged to consult experienced peers and extension experts when preparing a new plantation area.

Technology 7. Control of Widespread Pests and Diseases

Summary. Banana and plantain are susceptible to a wide range of pests and diseases, many of which are very aggressive and contagious. Once established they are difficult to eradicate. The occurrence of outbreaks and damage depend on part on

Toppled banana plants due to root necrosis by parasitic nematodes (Credit: D. Coyne) environmental conditions as moisture favors fungal diseases and dry weather promotes insect outbreaks and their associated virus diseases. There are many pests and diseases and often they work in conjunction in ways that exploit the soft and sappy tissues of banana and plantain. Serious pests and diseases occur in all parts of banana and plantain including roots, corms and rhizomes, pseudostems, leaves and fruits. Furthermore, some pests transmit serious diseases. While integrated pest and disease management can offer useful guidelines in avoiding and limiting these outbreaks, the tools necessary are seldom on hand and in most cases farmers must resort to treating the most severe expressions as a means to extend the lifetimes of less productive and declining plantations. Managing these syndromes is very complex, and beyond the scope of this toolkit catalog, but instead we offer guidance on how to best recognize and manage some of the most common constraints.

Technical Description. Several pests and diseases pose a serious threat to the productivity and longevity of banana and plantain plantations. A wide range of managements are available to counter those threats. Weevils may be baited and poisoned. Virus vectors such as aphids and mealy bugs are susceptible to insecticides and natural predators. Infestations by nematodes can be managed with the use of clean planting material, fallowing and mulching with antagonistic plants, endophyte inoculation of plantlets, boiling water sanitation, and synthetic nematicides. Application of fungicides, leaf pruning and improved soil fertility counter foliar fungi. Resistant varieties (see Technology 1 and 2) offer a solid foundation for preventing airborne fungi. Virus diseases are controlled through reliance upon clean planting materials and control of insect vectors. Farmers must recognize that their exchange of planting material results in the spread of pests and disease, and that simple practices such as hot water treatment of suckers and corms reduces this threat. Left uncontrolled, complexes of pests and disease greatly curtail plantation productivity, and this problem may be curtailed or delayed.

Major insect pests. Banana weevil (*Cosmopolites sordidus*) larvae bore into corms, suckers, and roots causing extensive damage and diminished

Seedling tray dipped in endophyte spore suspension (Credit: A. zum Felde)

plant growth. With time, premature toppling of plants occurs. Adults are trapped at night by baiting with slices of banana pseudostem. When planting, care must be taken to select rhizomes free of lesions and immerse them in hot water for 10 to 15 minutes. Practice sanitation by minimizing debris around infested mats and remove their stumps after harvest. Insecticides are only partly effective because the larvae remain protected within a labyrinth of tunnels. Another insect pest worthy of mention are thrips that scar and deform banana fruits by feeding on the skin. Aphids attack young green tissues and spread virus disease. Both of these insects are readily controlled by insecticides, but also by natural predators, so a judicious balance in management is advised.

Major nematode pests. Nematodes are microscopic worms that live as soil-borne parasites. The root-knot nematodes (***Meloidogyne*** spp.) and the burrowing nematode (***Radopholus similis***) can significantly weaken root systems, reduce yields, topple stems and considerably reduce plantation longevity. These nematodes are managed through use of nematode-free and heat treatment of planting material, pre-plant soil fumigation, chemical nematicides, plant support and varietal resistance. Tissue cultured plantlets are protected by an enhanced fungal endophyte (*Fusarium oxysporum*) by drenching plantlet roots with a spore suspension. Other parasitic nematodes include ***Helicotylenchus*** spp., ***Rotylenchulus reniformis***, ***Rotylenchulus*** sp. and *Pratylenchus* sp.

Major fungal diseases. Fungi are prevalent pathogens of banana and plantain. All organs are attacked by various fungi and achieving control of fungi can represent a large share of plantation management expenses. Sigatoka (*Mycospharella musicola*) is a debilitating and contagious leaf disease that is globally distributed. Symptoms develop as small brown areas on the undersides of younger leaves that develop into necrotic streaks with black margins. This damage grows into large, blighted areas that cause entire leaves to wither to the point where few of no green leaves remain on the plant. Bunch yield loss can be massive. A combination of cultural and chemical control practices is recommended that include field sanitation, application of fungicides, and rigorous pruning of affected leaves. A closely related disease is Black Streak caused by *M. fifiensis*. Fusarium wilt (*Fusarium oxysporum*) is a soil borne disease where infection starts in the roots and moves into the pseudostem. Symptoms include reddish stem necrosis, rotten roots, and overall wilting. Once established, the fungus persists in soils but fortunately, some resistant varieties are available.

Major virus diseases. Banana and plantain viruses are transmitted through planting infected plant materials and insect vectors. Two particularly lethal viruses are Banana Bunchy Top and Banana Streak. Banana Bunchy Top is first expressed as dark green streaks on the veins of banana leaves, progressing into small, erect, brittle leaves with a bunching rosette appearance. Affected plants often do not bear bunches. disease is spread by planting infected material or by insect transmission. Management of aphids is the key to reducing the spread and severity of this disease. Banana Streak was first described in Africa in 1974 and is now widespread. This virus is transmitted by mealybugs and vegetative propagation. Symptoms consist of chlorotic streaks on leaves progressing into narrow, continuous lesions that turn necrotic. Affected plants are stunted and have small bunches. Control the disease through the use of virus-free planting material and eradication of diseased plants.

Licensing Requirements. Distribution of pesticides demands certification and multiplication of resistant varieties must comply with national regulations on seed systems.

Technology 8. Intercropping Strategies for Banana and Plantain

Summary. There are several advantages and disadvantages from intercropping bananas or plantains with other crops. Intercropping with annual field crops allows for early harvests months before banana yields, and in the process suppress weeds within the plantation. Intercrop canopies and roots protected against soil erosion. Legume intercrops provide nitrogen through biological fixation. Biomass from the intercrops may be applied as mulches and sources of organic nutrients. The disadvantages of intercropping include below- and aboveground competition for nutrients and water, the potential introduction and spread of diseases, and damage to banana roots from soil disturbance during planting and harvest of companion crops. A common practice is to intercrop with annuals during the first year of plantation establishment; another is to grow bananas with shade tolerant perennial crops such as coffee or cacao. A third option is to grow bananas with agroforestry trees that provide poles that support banana stalks and fruit.

Banana with a common bean understory (Credit: B. Dhed'a)

Technical Description. Intercropping involves the production of two or more crops simultaneously on the same land. It serves as insurance against crop failure due to abnormal weather conditions. In the case of banana and plantain, it is possible to establish a multi-story system where crops with different canopy heights are established. Intercropping of bananas with other crops is common soil fertility improvement practice. Trees such as mangos and papaya may be established within banana plantations as sources of fruit and to serve as windbreaks. Root systems of banana and plantain are delicate and require fertile soil to allow sufficient water and nutrient uptake and guarantee anchorage and sucker production. The residues of companion crops may provide this need.

Understory intercropping make it possible to achieve a high level of land, nutrient and water use efficiency due to synergistic effects between the two different crops. Mixing of crops also reduces the infestation rate of weeds, pests and diseases on farmer fields which benefits the productivity of both and slows down the spread of organisms that are harmful to agriculture. The cultivation of banana and plantain that is high in carbohydrates with grain legumes banana rich in protein provide more nutritious diets within smaller parcels of land. Yield decline in banana and plantain is avoided or reduced by protecting the soil with mulch from intercrops. Inorganic fertilizers are used very efficiently in mixed cropping systems greater diversity in root structure results in greater capture. Banana regulates temperature through shading. Intercropping typically generates larger returns to investment and labor. One difficulty with intercropping however is that some field operations become more complicated, confounding mechanization and herbicide application.

Uses. Integration of other crops is suitable for banana and plantain growing areas in Sub-Saharan Africa, and is particularly advantageous under lower soil fertility and moisture availability. Intercropping legumes contributes to strengthening the climate resilience of food systems and the communities that draw income from them. Understories pf younger plantations may be intercropped with food crops such as groundnut, sweet potato or bush bean. Choice of the understory depends agro-ecological conditions, marketing opportunity, and food preferences. Maize intercrops are often considered harmful because of competition. It is best that young plantations be intercropped with plants that cover the soil quickly to protect soils.

A banana-vanilla intercrop in Uganda (Credit: UGP-Uganda Vanilla Guide)

A banana-coffee intercrop established in Uganda (Credit: IITA archive)

Complex banana intercropping systems where banana is the understory of coconut (left); banana is grown beneath oil palm with a cacao understory (center); and a multi-story garden that includes palms, spices and banana (right)

Older plantations with more complete canopies benefit from shade tolerant intercrops. Vanilla vines grow well in the shade of mature plantations but requires additional support for its heavy vines. Vanilla cultivation is complex but potentially rewarding. Vanilla and banana climatic requirements pair well but the vanilla flower must be hand pollinated to insure fertilization and pod development. Vanilla beans may be harvested twice a year. This is high value intercrop. In 2023, the price range for Uganda Vanilla as much as US $370 per kg.

Growing banana and coffee together increases crop revenue by more than 50% compared to monocrops of both. Banana and coffee systems are more diverse, reduce risk and provide food throughout the year. Bananas mature first, providing harvest and income before coffee becomes productive. Bananas provide shade to coffee and compete less than other crops for water during drought. Together these perennials mitigate greenhouse gas emissions by increasing standing above- and below-ground carbon stocks.

Commercialization and Start-up Requirements. Understory intercropping of banana and plantain is a traditional practice in Africa that has been improved by researchers and extension agencies. Different mechanisms contributed to this, including awareness creation about its nutritional and income benefits, farmer collective action, and the development of more effective marketing mechanisms and value-added cottage industries. Successfully promoting the integration of banana and plantain with other crops relies on 1) Education of farmers about its benefits for agricultural intensification and diversification, and savings on fertilizer use; 2) Extension support on varietal selection and good agronomic practices under local contexts; 3) Multiplication of high quality seed by community or private enterprises; and 4) Access to low-cost plant propagules (see Technologies 3 and 4), fertilizers (see Technology 5) and other needed production inputs from local suppliers.

Production Cost. Intercropping systems have greater start-up costs for seed and fertilizers than monocrop cultures. Their yields, however, are greater as is input use and organic recycling efficiency.

Customer Segmentation and Potential Profitability. Intercropping with banana and plantain is attractive to small-scale and commercial farmers alike. Small-scale farmers are attracted to this practice because it allows households to grow more and a greater variety of food within their smallholds. Studies in DR

Innovative use of banana within complex cropping systems: banana fence line grown as a hedgerow between field crops (left) and banana pseudostems from harvested pants used a mulch for annual intercrops (right)

Congo suggest that understory intercropping provides about 2.2 tons of additional food harvest per year. In many cases the advantages to smallholders diminishes with time because the canopy development of banana increasing shades their desired companion field crops. Commercial farmers are less attracted to intercropping because of the increased complexity and labor requirement of complex intercropping although banana-coffee and banana-coconut intercropping at a large scale has shown to offer economic advantages.

Licensing Requirements. No commercial or environmental licenses are needed to practice intercropping. Knowhow for intercropping banana and plantain plantations is regarded as a Regional Public Good disseminated by IITA, ICRAF and many local extension agencies.

Technology 9. Peels as Feed and Organic Resources

Summary. Banana and plantain peels are the outer cover of the fruit that in itself has many uses. In bulk it is used as both an animal feed and an organic input to soil but there are concerns about its chemical composition and nutrient ratios. Techniques are available that allow for treatment such as silage and composting). Dried peels contain about 2% protein, 6% fat and 12% carbohydrates as well as substantial potassium, phosphorus, iron, calcium, magnesium, and sodium. Zinc, copper, and manganese occur in low concentrations. As a result, proper handling and supplementation of peels used as feeds are required but dried composts may be applied directly to soils without concern. In smaller quantities, peels are used

as an ingredient in cooking, water purification, and manufacture

Conversion of banana and plantain peels onto silage for feed and dried compost

of beauty and health products. Ironically, lack of understanding about the different values and processes surrounding peels results in their wasteful accumulation in some urban areas.

Technical Description. Huge quantities of the peels are produced where plantain or cooking banana are staples. The peel constitutes approximately 40 percent of the fruit, resulting in massive wastes. There are several methods to remove a peel from a banana. The peel from ripe fruit is easily shed and discarded as a single unit, whereas the peel from green fruit must be stripped away. Once the peel is removed, the fruit can be consumed fresh or cooked while the peel is too often discarded. The peels of green bananas and plantains are difficult to remove but machinery is available for this purpose. A single belt 0.37 kw peeler able to handle 600 units per hour costs about $3500 in China. Larger multi-channel 2.0 kw machines peel and slice 7200 pieces per hour and cost $16,000. Many of these machines also peel root crops.

Use as an animal feed. The greatest potential for use of banana and plantain peels is as an animal feed. Peels have numerous attributes that make them suitable as a component of combined diets. Fresh peels have

An industrial green banana peeler able to processes 600 units per hour

a high moisture content (about 85%), allowing animals to remain hydrated. Dried peels are rich in starch, contain less fiber than forage grasses (about 30%), and offer several vitamins. These peels are high in tannin that can result in feed refusal and result in meat with a lighter color, but sugars in the peel result in increased rumen activity. In many cases, it is more advantageous to prepare silage from peels and other banana wastes. Peels are chopped and packed into airtight storage to encourage lactic acid fermentation. This allows conversion of sugars into lactic acid, lowering pH and inhibiting microorganisms that would otherwise spoil the material. Better silage results from adding additional energy-rich materials such as molasses, and ensuring that containers remain airtight. The ensiling period for raw banana peels without any additives is about 28 days, but addition of sugar reduces that to 24 days. Note that the crude protein content of banana peels is quite low and this feed must be supplemented for optimal animal performance.

When considering peels as feed, the relationship between nutrient composition, stage of maturity and cultivar must be considered. For example, peels of dessert banana contain more fiber than plantain peel, and their lignin content increases with ripening. Green plantain peel contains mostly starch while green banana peel contains more free sugars. In general, ripe peel has higher moisture, crude protein, crude fiber, and ash contents than unripe peel. The protein content of banana peel is low but that protein is rich in key essential amino acids, including leucine, valine and phenylalanine. Carbohydrate contents are greater than 50% and allow unripe banana peel to serve as an energy source in many animal diets. Potassium is particularly abundant in unripe plantain peels (e.g. 750 mg/kg) and increases further during ripening process. Unripe peel contains higher calcium and iron than the ripe peel.

Reliance upon peels as feed is often limited because of the presence of tannins and oxalate. These compounds that are present in the skin to protect the fruit cause a bitter taste to the peel. Moreover, these are anti-nutritional and can result depressed growth and reduced feed efficiency; but these peels may be processed to detoxify unwanted effects. Most common is sun drying for four or five days. Sun drying binds tannins into insoluble forms and greatly reduces the moisture content (e.g. to 10%). This effect is also achieved through oven drying or treatment with alkali. Fermentation by silage also de-toxifies peels in part through microbial assisted oxidation.

Use of raw peels in poultry feed is restricted because of the deleterious effects of tannins, and sun drying reduces it to safe levels. As a result, ripe plantain peel can replace maize by between 25 to 75% ration, depending upon the bird's growth stage. In contrast, banana peels may be fed directly to swine without any form of processing, even at up to 50% ration, but diets of 100% peels should be avoided. Farmers feed peels to animals because they are inexpensive and readily available, but anti-nutritional factors affect stock in different ways, so this organic resource must be used wisely.

Use as organic fertilizer and soil amendment. Composting banana peels requires only 3 to 4 weeks under ideal conditions. Peels are best mixed with other compost ingredients to achieve the best results. Peels need not be chopped before composting. Banana peels are particularly well suited to vermicomposting (with earthworms) but not in combination with poultry manure. Composts prepared from peels are best dried before use and are suitable as mulch as well.

Other uses of banana and plantain peel. Cooking banana peel is common in Asian cuisine where the peel is roasted with other ingredients. In vegan recipes, banana peel is suggested as a meat substitute but this never gained popularity. Television chefs occasionally include it within stews but again with little impact. A list of several domestic uses of banana peels is offered, but with little explanation: as a shoe and leather polish; a moisturizer and face cream; a home remedy for insect bites; a treatment for acne; a wart and splinter remover; and a teeth whitener. These uses were not tested in the course of this review. When using fresh banana peels for domestic uses, it is important to rely upon fresher peels and to store away from heat, sunlight and refrigeration. Banana peels are processed industrially as a substrate for biogas and mushroom production, and its ash combined as alkaline for soap making.

Technology 10. Induced Ripening of Banana

Summary. Banana ripening is a combination of physiological and biochemical processes resulting in changed color, sugar content, texture and aroma. Dessert bananas are most often harvested

Industrial ripening chamber with refrigeration and gas control (Credit: Nilkamal)

prematurely to reduce injury during transportation. Bananas may be artificially ripened using different chemical agents, most often ethylene gas. Commercial ripening chambers control temperature, humidity, and ethylene gas concentration. Catalytic generators are used to produce ethylene for induced ripening, with concentrations of 100 ppm for 12 hours having immediate effect. Acetylene serves as an ethylene analogue. Ethephon is a widely used compound that releases ethylene. Fruits artificially ripened have a similar yellow color and taste to those naturally ripened. This is not the case for bananas ripened by more traditional methods such as burning leaves or kerosene

Technical Description. Plantain and banana suffer major post-harvest losses due to poor damage during transportation. This is particularly the case for dessert banana that are generally purchased in a ripened state. Traditionally, bunches are ripened by wrapping green leaves around them, requiring up to two weeks and resulting in non-uniform results. Ripening chambers are available to more rapidly and uniformly ripen bananas based upon timed exposure to ethylene gas. This induced ripening reduces the protein content and increase sugar in most banana varieties.

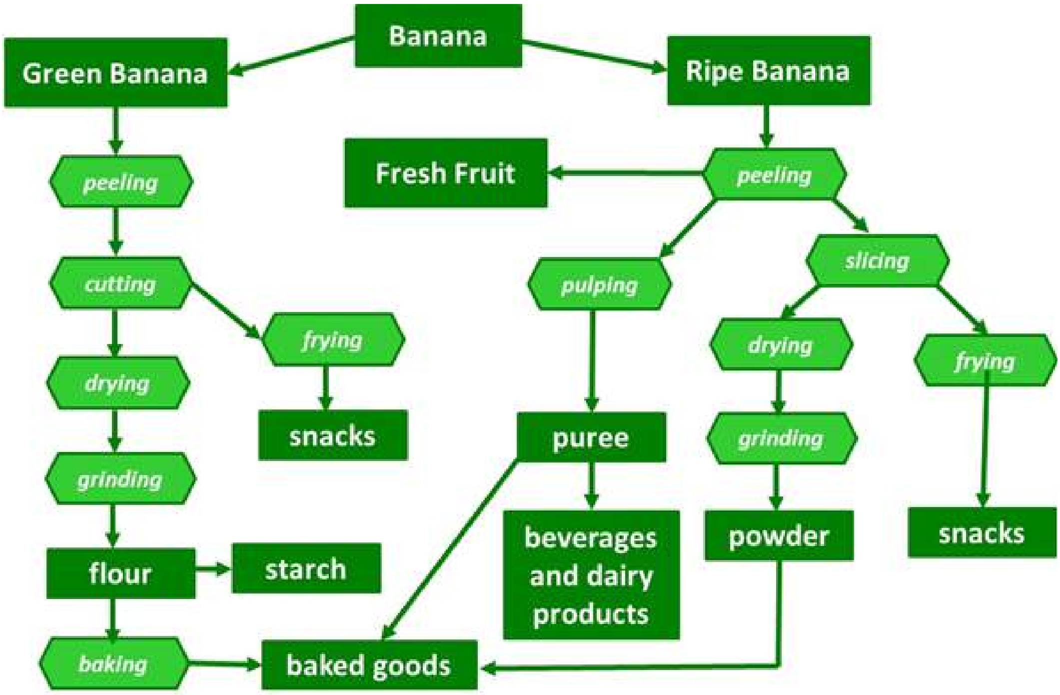
Application. Low-cost ripening chambers are constructed with metal or wooden frames and covered with airtight plastic sheeting. Simpler systems rely upon avocados and passion fruit as catalysts because these fruits release lots plentiful ethylene. More advanced industrial ripening chambers include insulated chambers, refrigeration system, humidifier, ethylene generators, gas analyzer and a control panel. Ethylene is introduced by generating chemicals such as Ethephon (Trade name Ethrel, 2000 ppm dip for 3 minutes). For best ripening results, humidity should be 90% to 95% to prevent moisture loss. In simple passive closed chambers, this is achieved using basins of water, and in industrial-scale rooms this is achieved using humidifiers. Quick ripening is requires temperatures of 18-20°C within 4 days, slower ripening lower happens at lower temperature (14-16°C) takes 8-10 days.

Commercialization and Potential Profitability. Low-cost techniques for hastened ripening are applicable for small-scale local resellers. High-end industrial cooling and gassing chambers serve large cooperative and commercial producers with a constant supply of fruit and market demand throughout the year. Timed ripening can hugely increase profits but is a sensitive process requiring technical expertise. Sold green, a plantain or banana bunch of 80 kg sells for US $9 to $12 whereas ripened its retail commercial value increases to $27.

Licensing Requirements. Commercial-scale ripening requires regulation because of the compounds in use. Ethylene exposure by adults is limited to 1 ppm over an 8-hour average and must not 5 ppm over any 15-minute interval.

Technology 11. Value-added Processing of Bananas and Plantain

Processing and products prepared from banana Banana flour has a growing demand as a wheat substitute



and in many cases plantain

Summary. Plantains and banana offer multipurpose processing options and are a great source of starch and energy. A wide range of products can be made from the unripe and ripe fruits, particularly puree for beverages and syrups, flour for baking and fried and dried slices for chips. Both ripe and unripe bananas and plantains are typically peeled and sliced before processing. Sun drying is the most widespread technique where climate conditions permit, but oven drying is also practices. Banana and plantain products are increasingly manufactured at an industrial scale. Most production is made from green bananas and plantains because ripe bananas are often damaged during transport. Banana flour is produced from unripe fruit, and banana powder from ripe fruit, and both products have rapidly expanding markets due to their nutritional and medicinal benefits.

Technical Description. A wide variety of food products may be processed from both ripe and unripe fruits of banana and plantain. Green banana and plantain are peeled, cut or chopped, dried and ground to produce a useful baking flour. This flour contains up to 80% starch that may be extracted into purer forms used in cosmetics. Cut green banana are fried into savory snacks. Ripe bananas are peeled for fresh fruit consumption and industrial processing. Pulped banana produces a puree for use in drinking beverages and dairy products such as ice cream and yoghurt. Sliced banana is dried and ground into banana powder or fried into sweet snacks. Banana and plantain is rich in dietary fiber, potassium, phosphorus, calcium, vitamins A

Steps of industrial flour production from plantain (Credit: Kaifeng Sida)

and C, crude fat, carotenoids and other nutritious compounds. Traditional flour processing results in a brownish color that is unattractive for baking, but blanching or soaking in sodium metabisulfite or organic acids counteracts this problem.

Applications. Traditionally, the flour of unripe plantain and banana is prepared by cutting the peeled fruit into slices and air drying for 1-3 days before milling. Before peeling, it is critical that the bunch or fingers are thoroughly washed to remove the sand and impurities. Peeling can be done by hand or with an industrial scale automated machine. At industrial scale the fruit is usually made into a smooth mash by wet milling that is dewatered using a press filter and flash dryer. Dried chips or press cake is then milled and sieved to obtain a fine high-quality flour.

Banana flour is a powder traditionally made of green bananas and offers a gluten-free alternative to wheat flour. It has a very mild banana flavor that is nearly indistinguishable when blended at 25% with wheat flour. It is produced from green bananas that are peeled, chopped, dried, and then ground. This process requires 8–10 kg of raw green bananas to produce 1 kg of dried banana flour. In contrast, banana powder is made from ripe banana that are dried and ground and has a stronger taste of banana. Both banana flour and powder are internationally marketed as gluten-free alternatives to wheat-based flours. Banana flour has excellent cooking characteristics that allow it to replace wheat even in cooked products such as pasta. The banana powder market rapidly expanding owing to its recognized medicinal and nutritional characteristics. This market is segmented into food, pharmaceutical, animal feed, and cosmetics applications. Flour from unripe plantain and banana can be incorporated into pasta, infant foods, and in milk replacement for calves.

Banana puree is prepared from ripe bananas after washing and peeling. Bananas are blanched with steam or boiling water to a temperature of 93°C, requiring about 15 minutes. Blanched bananas are then cooled and passed through a blender. The puree as an attractive color, fine texture and fruity flavor and may be frozen or canned. This puree is used for fermented and non-fermented beverages, baby foods, snack foods, and in a variety of jams and sauces. Banana beverages are produced by peeled ripe fruit and cuting into pieces, blanched for two minutes in steam, pulping and then adding pectolytic enzyme at a concentration of 2 g enzyme per 1 kg pulp. This moxture is heated to 65° C for 30 min. Another method relies upon lime to eliminate the pectin. In yet another approach, banana pulp is

acidified and steam-blanched in a partial vaccuum to deactivate the enzyme. The pulp is then diluted 1:3 with water.

There are two different methods for making banana chips. One of these is to deep fry thin slices of banana in hot oil, in the same way as potato chips or crisps. The other is to dry slices of banana, either in the sun or

Different foods prepared from plantain in Nigeria

using a solar or artificial dryer. The products made by the two methods are quite different. In general, 4 kg of plantain without yields 1 kg of chips. An assembly line to produce fried chips involves the following: 1) slice the unripened fruit, 2) fry the slices at 180°C until golden brown with either gas or electric heating, being careful that the slices do not stick together, 3) de-oil the fried chips, and 4) add flavoring as required and package into plastic bags to retain chrispiness.

Commercialization and Start-up Requirements. Banana flour production machinery able to process 100 kg per hour is available in Clina for as little as $15,000, producing an adjustible mesh size. It operates through a combination of hot air and vaccuum drying, placing product into either plastic bags or bottles. This machine not only processes banana, but also vegetables and spices such as garlic, ginger and chili powder. Larger processing equipment able to process 5 tons per hour cost about $300,000.

Equipment for the automatic production of fried banana chips costs netween $10,000 and $60,000 depending upon throughput capacity. This equipment processes between 100 to 500 kg per hour and include a banana peeler, banana slicer, a gas powered continuous fryer, a vibrating de-oiler, a flavoring station and automatic weighing and packing. The same equipment is suitable for the production of potato, sweet potato and cassava chips.

Commercial presses for producing banana pulp are available in a variety of capacities. Spiral juicers operate on the principle of filtered screw-push extrusion with adjustable mesh sizes. These machines are able to pulp banana as well as pineapple, oranges and other fruit. These machines cost about US $1,500, are made of stainless steel and have a pulping capacity of 0.5 ton per hour. Slightly larger machines able to pulp 2.5 tons per hour cost about $4,000 in China. Fully automatic juice mixing and bottling production lines cost upward of US $50,000. These machines combine washing, blending, mixing, filling and capping of about 2000 bottles (330 ml) per hour.

A banana macro-propagation chambered operated by an Agripreneur youth

Licensing Requirements. The establishment of commercially operated processing agribusinesses involves the acquision of several businesses licenses and is subject to regulatory health inspection.

Youth-led Agribusinesses involving banana and plantain production and processing

Youth have much interest in building agribusiness enterprises around banana and plantain, in large part because of the versatility and high productivity of this crop. In a recent survey of youth-led businesses resulting from IITA Agripreneur Movement enterprise, banana and plantain ranked fifth in popularity among 19 different commodity categories following poultry rearing (17%), cassava production and processing (15%), aquaculture (13%) and maize production (11%). Banana and plantain attracted 6% of young entrepreneurs, and was closely followed by Orange Fleshed Sweet Potato, a crop with similar products and processing opportunities. Of these young businesspersons, 67% were engaged in production, 25% in processing and 8% in propagation, although it is likely that youth producing elite varieties of

Youth-led plantain processing in Nigeria: milling the dried plantain into flour (left), bagged product ready for sale (center) and business partners pleased with their progress (right)

banana and plantain were also selling swords as propagative material to other farmers.

The average income generated from banana and plantain enterprise was US $2,863 per year, with little difference (4%) between producers and processors. It is likely that bananas and plantains are one of several mixed crops produced, and multiple commodities are being processed, so these income figures are likely an underestimate, but they indicate that banana- and plantain-based enterprises position youth well above the absolute poverty level of less than $2 per day. The highest reported income was $12,500 per year (or $17 per day).

Agripreneur training in banana and plantain enterprise focuses upon three areas: modernized production, macro-propagation and processing. IITA advances banana and plantain as one of its mandate commodities. Youth attached to training programs have opportunity to learn about best varieties (Technologies 1 and 2), optimal fertilization (Technology 5), stand management (Technology 6) and pest and disease control (Technology 7). Hopefully, the contents of this booklet can further improve their agronomic management.

Agripreneur training also includes macro-propagation as described in Technology 3. Following a proven macro-propagation technique, chambers are constructed in a cost effective manner; providing youth an opportunity to produce and sell planting materials year-round. Emphasis is placed upon obtaining and multiplying elite varieties. Once in full production, each 2.5 m2 chamber can produce over 80 propagules per month, each worth about $0.50 depending on their size and variety. Farmers rely on this technology to access disease-free planting material and a young person who is skilled in propagation can generate an average income of $250 per month on very little land by operating several of these chambers in a way that requires only a few hours work per week..

Several trained youths in West Africa have also ventured into value addition to plantain by producing plantain flour, plantain chips and banana puree as baby food (see Technology 11). For the most part these are lower technology approaches where fruits are peeled by hand and then mashed or dried using simple machinery, but these businesses are nonetheless profitable. Of six businesses studies in Benin and Nigeria, all were operating at a profit, earning an average $2,933 per capita per year. Most of these businesses produce plantain flour made from unripe fruit that is air or oven dried and then milled into flour. Their products are generally packaged in five and ten kg bags and sold locally.

A particularly successful venture is Gracevine Venture, a Nigerian limited liability company initiated by Ms. Idowu Abosede, a former intern of the IITA Youth Agripreneur Movement. The business conducts value addition to plantain, cowpea, and yam by milling these commodities into flour. This business was started in 2015 using personal savings of only US $3,000 and was assisted with additional funds for expansion in 2018 after presenting a business plan to EKIMIKS Limited, an agribusiness consulting firm. Gracevine Ventures is presently located in a suburb of Ibadan, Oyo State, Nigeria and operates a milling factory with a 120-ton batch capacity that permanently employs five persons as well as several other casual workers. After expansion, this factory has the ability to generate monthly revenue of US $140,000 and operates at about 20% profit. Indeed, Gracevine serves as a best case example of a youth-led agribusiness that adds value to multiple commodities by milling them into flour, and their example should be emulated across Africa.

Youth may also be mobilized as effective reporters on the spread of banana diseases using electronic tools. A few years ago in Uganda, UNICEF launched a campaign to track the spread of Banana Bacterial Wilt as a growing threat to food security by launching a simple survey. Within one day, over 35,000 "U-reporters" responded, allowing the disease to be tracked and problem areas identified. Within five days, about 190,000 SMS messages were sent to inform key stakeholders about wilt and how to control it. The interest of youth in banana, and their role in electronic extension mechanisms are clearly illustrated through this example.

Conclusions

This catalogue describes a series of proven technologies for banana and plantain management and agro-processing that promote increased productivity and profitability in Africa. These are popular plants and hugely important to food security, household livelihood, and sustainable agriculture. Unlike many other staple crops, banana and plantain provide food throughout the year, offering a staple food to more than 80 million people in Africa. Banana and plantain are also important to agro-processors. They can be processed into a variety of food products such as flour, puree, beverages and snacks, relying upon a wide range of scalable processes. Banana flour and powder are gluten-free and partial substitutes for wheat flour in baking. Indeed, banana and plantain are now becoming an internationally recognized modern food commodity!

This catalogue provides a wide variety of options for modernizing banana and plantain production in Africa. It recognizes that many improved banana and plantain hybrid varieties are available and provides guidance on how to access them (Technologies 1 and 2). It identifies hybrid varieties resistant major diseases such as black leaf streak and wilt. These high yielding varieties are adapted to different growing areas and have fruit characteristics that meet specific consumer preferences and market opportunities. Sweet dessert bananas are quite different from starchy cooking bananas and plantains, and producers must know their target markets. The importance of establishing disease-free plantings is emphasized. This is achieved either by cleaning the vegetative suckers produced by the banana mat (Technology 3) or through in-vitro tissue culture (Technology 4). The latter technique (tissue culture) is most useful when scaling up the availability of new and improved lines. Either technique offers a specialized business opportunity when a sufficient number of commercial banana and plantain producers are organized.

Bananas and Plantains require moist, well-drained soils and a large supply of nutrtients to be fully productive. The requirement for Potassium is particularly high. Fertilizer blends that specifically recommended for banana and plantain are described in Technology 5. Spacing and stand management is also very important, in part because different banana varieties vary in stature (Technology 6). In general, stands vary between 625 plants per ha (= 4 m x 4 m) and 1,111 plants per ha (= 3 m x 3 m). Holes receiving both organic and mineral fertilizers are prepared for each plant. Stand management also considers the number of stems permitted to grow per mat with insufficient pruning resulting in small and poorly formed bunches. Banana and plantain are susceptible to a wide range of pests and diseases with a wide range of control options available to producers (Technology 7). Field sanitation and early identification and response are particularly important components of integrated management strategies. Foliar diseases of large statured plants in dense canopies poses a serious problem. Many options exist for intercropping within banana and plantain stands (Technology 8). Annual crops are grown in younger stands, providing weed control and early revenue generation. Shade tolerant perennials such as vanilla, coffee and cacao are intercropped in mature stands. Banana is an important component of complex, multi-story agroforestry intercrops as well.

Bananas and plantain are important components of household diets in the humid tropics, but these crops also offer many market and processing opportunities as well. Banana peels are nearly 40% of bunch biomass and offer a potentially valuable byproduct from fruit processing (Technology 9). Banana peels may be used as feed, compost ingredients or industrially processed into a variety of products. Machinery that peel and chop green bananas and plantains are commercially available. Bananas must be harvested while green to prevent extensive damage during transport, and technologies are available that permit uniform ripening upon delivery (Technology 10). Ripening is induced using ethylene within a few days without a loss of quality. Banana and plantain are processed into a wide range of food products including flours, snacks and purees (Technology 11). Flours may be used to partially substitute for wheat in baked products. Machinery suited to different scales of production are commercially available.

The proven solutions featured in this catalogue provide means to greatly improve yields and add value to banana and plantain in Africa. It was prepared with a variety of users in mind whether they be producers, agents of agricultural development or private sector investors. Farmers can use many of these technologies as production guidelines. Those from the public sector can utilize the catalogue as a whole and design agricultural projects involving banana and plantain as a means of achieving agricultural transformation. Members of the private sector, including propagators, input manufacturers, processors and investors also benefit from the contents of this catalogue in terms of formulating and prioritizing investments.

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Contemporary banana art: famous banana by Andy Warhol (left), commercially available banana wallpaper (center), and an example of banana "tattooing" by Jason P. Smith

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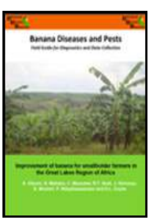

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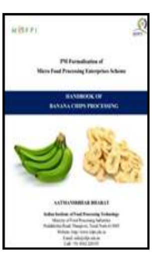

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Technologies for African Agricultural Transformation (TAAT)

The development objective of TAAT is to rapidly expand access of smallholder farmers to high yielding agricultural technologies that improve their food production, assure food security and raise rural incomes. This goal is achieved by delivering regional public goods for rapidly scaling up agricultural technologies across similar agro-ecological zones. This result is achieved through three principal mechanisms: 1) creating an enabling environment for technology adoption by farmers, 2) facilitating effective delivery of these technologies to farmers through a structured Regional Technology Delivery Infrastructure, and 3) raising agricultural production and productivity through strategic interventions that include improved crop varieties and animal breeds, accompanying good management practices and vigorous farmer outreach campaigns at the Regional Member Country level. The important roles of sound policies, empowering women, and youth, strengthening extension systems and engaging with the private sector is implicit within this strategy. The Clearinghouse serves as an agricultural transformation incubation platform, aimed at facilitating partnerships and strengthening national agricultural development programs.

Back cover photographs: A large banana bunch produced by IITA (left), local transportation of banana bunches using a bicycle, common sight across Africa (center), and processed plantain flour ready to use as a gluten-free baking ingredient.

African Agricultural Leadership Institute (AALI)

The African Agricultural Leadership Institute offers a unique approach to advancing agricultural transformation in Africa. AALI envisions a vibrant and bold African leadership, supported by experienced African agricultural professionals, to catalyze public and private investments and accelerate and sustain Africa's needed agricultural transformation. This vision demands that agriculture be viewed as a business that attracts the private sector and investment from governments and development banks to stimulate and modernize its advancement. For this transformation to occur, the mindset of the current SSA leadership at all levels must change to acknowledge that modernized and more resilient agriculture must drive Africa's future economic growth. AALI's value proposition includes 1) identifying and mentoring a critical mass of young African leaders and build their capacity to provide advice and planning for agricultural development on the continent; 2) mobilizing a critical mass of experienced African professionals within the continent accomplished in designing and delivering successful programs and projects with proven impacts; and 3) supporting current and future African political leaders and their governments in countries with the most critical needs to establish innovative delivery mechanisms. Identifying and promoting key modernizing agricultural technologies, such as those presented in this catalogue is critical to transforming African agriculture. Overall, AALI´s actions aim to reinforce rural infrastructural development, rehabilitation of learning facilities, and acceleration of small-scale mechanization, higher value enterprise and digital agriculture.

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