IITA
Transforming African Agriculture

CGIAR

Annual report 2019

Scaling up innovations

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IITA 2019 Annual Report
Published by the International Institute of Tropical Agriculture (IITA), 2020

PMB 5320, Oyo Road
Ibadan, Oyo State, Nigeria

ISSN 0331 4340

International mailing address
IITA, 7th floor, Grosvenor House, 125 High Street, Croydon CRO 9XP UK

Design, development, and production: IITA Communication Office

Correct citation: IITA. 2019. Scaling up innovations. IITA 2019 Annual Report. Ibadan, Nigeria. International Institute of Tropical Agriculture (IITA). Available online at www.iita.org/annual-reports

Cover photo: Farmers use a phone to check information about crops in Rwanda (foreground), with demo plots in Mozambique (background).
Photos by Olaoluwa Bode and Canon Engoke, IITA.

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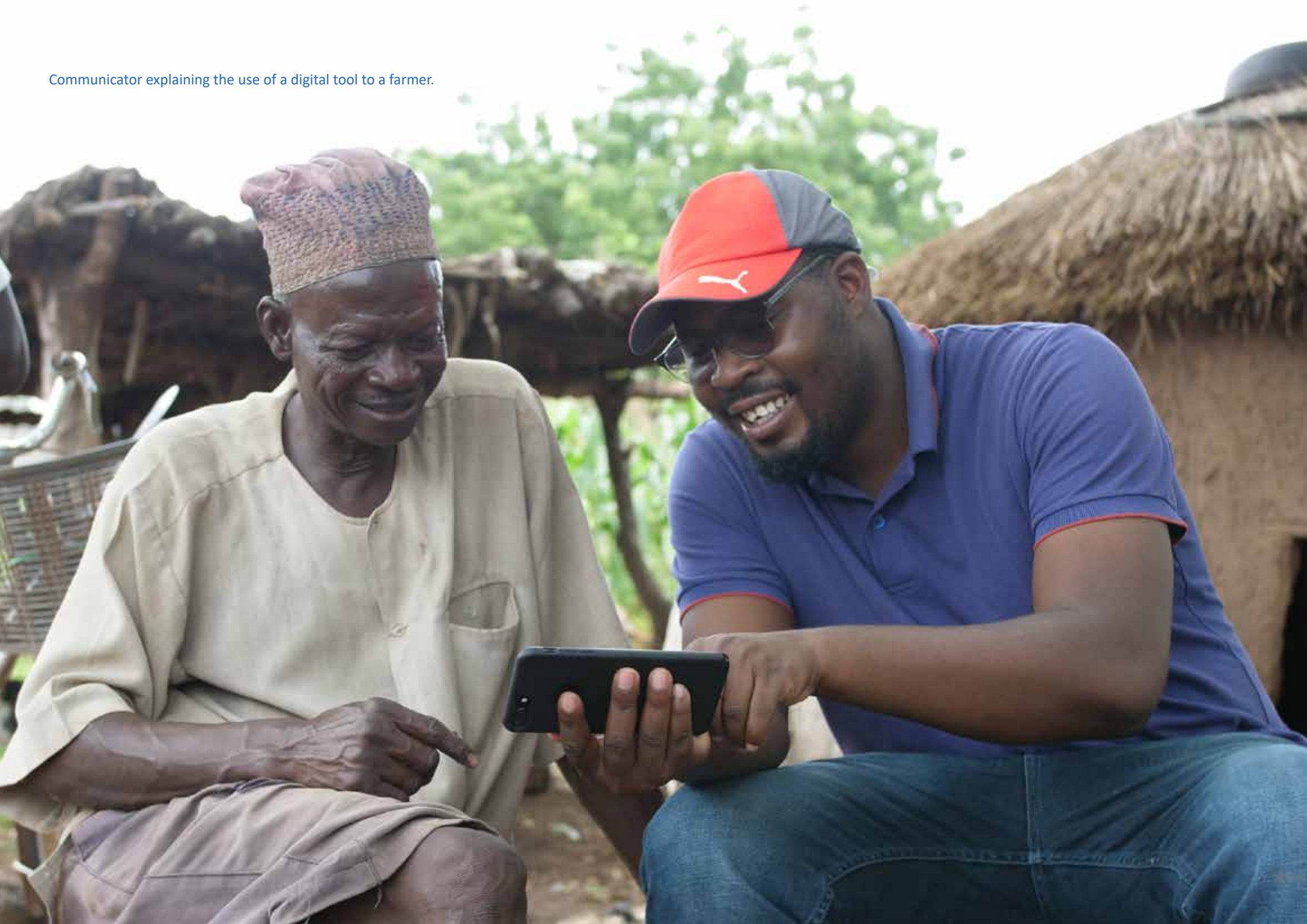

Communicator explaining the use of a digital tool to a farmer.

From the Director General and the Board Chair

Nteranya Sanginga
Director General

Amos Namanga Ngongi
Board Chair

The year 2019 was a transition year for IITA. For one, CGIAR started its journey in earnest as it transitions into One CGIAR. It looked at how the system can ensure the successful implementation of its research portfolio, how it can achieve improved and stable funding, and the development of an exciting new portfolio that would keep CGIAR's focus on big programmatic efforts to drive impact.

IITA strongly supports the One CGIAR system. This transition has allowed us to review and assess our internal capacities and resources. We believe that a better organized and more focused IITA can provide the food and agricultural research base and service and delivery partnerships necessary to ensure greater impact by complementing the ongoing efforts of African countries and their national undertakings.

Second, the ongoing CGIAR reforms necessitated that IITA position itself as a strong African center for delivery in support of agricultural transformation. As the first link in a network of international agricultural organizations in the region, IITA has been driving the agricultural transformation of Africa since its establishment in 1967.

IITA has therefore sought to better align its research-for-development, service, and delivery programs, and downstream institutional arrangements around strategies designed to have an impact on CGIAR's priority outcomes. To do this, IITA is working on transitioning into an institution that consolidates the efforts of CGIAR in Africa with programs that are efficient, relevant, and responsive to the needs of the Continent.

IITA's broad system-based agenda, its presence across the region, its focus on major mandate food crops of Africa, its improved framework on partnership and delivery of research innovations, its current successes, including the initiation of a delivery component of its research products through the Business Incubation Platform (BIP), fostering agribusiness opportunities and other agricultural development initiatives involving the African youth in agribusiness, and its good relations with various research and development partners—all these make IITA the CGIAR gateway for research and delivery in Africa.

We are also further expanding and strengthening our four hubs and establishing another one in the Sahelian region of West Africa, one of the most vulnerable regions of the world.

This year's annual report highlights some of our successes and impact stories on scaling out innovations, from establishing a gene-editing system for important African food crops such as banana and yam with resistance to major pests and diseases, to using digital delivery tools to ensure that our innovations reach farmers and other stakeholders, to commercializing a technology such as Aflasafe to minimize aflatoxin contamination and deliver safe food for Africans through creative partnerships with the private sector and youth groups, to further expanding the youth-in-agribusiness movement through a new program that introduces agribusiness to school children and changes their mindsets about agriculture.

The year 2019 was also a banner year for IITA. In recognition of its commitment to improving both agribusiness opportunities and the creditworthiness of youth across Africa, the IITA Youth Agripreneurs (IYA) program has been awarded the 2019 International Innovation Award for Sustainable Food and Agriculture. The award, the first of its kind, is funded by the Government of Switzerland and was presented, in conjunction with the Food and Agriculture Organization (FAO), during the 41st FAO Conference in Rome.

After garnering the 2018 Africa Food Prize, IITA established and launched another youth program focused on introducing agriculture to primary and secondary school children. The Start Them Early Program or STEP, which covers DR Congo, Kenya, and Nigeria, is now being expanded across sub-Saharan Africa.

In 2019, we started consolidating efforts on using digital delivery tools and information and communication technologies (ICTs), including Internet radio (Radio IITA), in transforming agricultural systems in sub Saharan Africa. We are now looking more at optimizing the use of these digital and online tools for research management and knowledge sharing, including extension, scaling out, e-learning, collaboration, and agricultural value chain and service enhancement. We know that using digital platforms is critical to achieving research and development outcomes in terms of facilitating awareness creation, promoting behavioral change among knowledge users, and ensuring the adoption of technologies that could contribute to the success of delivery, especially under these challenging times.

Our work on partnerships and country alignment and advocacy all these years continues to strengthen IITA's work and its role as the lead research partner facilitating agricultural solutions to overcome hunger and poverty in the tropics. It is also helping us in our resource mobilization and advocacy efforts.

It is a pleasure to present the 2019 IITA Annual Report.

We would like to express our appreciation to our various funders, collaborators, and partners who have been with us throughout this continuing journey of hope, faith, trust, and learning.

Nteranya Sanginga
Director General

and

Amos Namanga Ngongi
Board Chair

Researchers in Tanzania inspecting banana leaves for Fusarium wilt.

Scaling up innovations

Two years ago, IITA celebrated 50 years of service to smallholder farmers in Africa. Since then, we have advanced even further in our mission to transform African agriculture through our work with farmers and farming communities, youth and women in agribusiness, and other partner-stakeholders.

IITA works across sub-Saharan Africa in ensuring the delivery of research innovations on five impact areas: Nutrition and food security; Poverty reduction, livelihoods, and jobs; Gender equality, youth, and social inclusion; Climate adaptation and greenhouse gas reduction; and Environmental health and biodiversity.

This is done through active participation in the following CGIAR Research Programs (CRP) and Platforms that are in line with the IITA strategy:

- CRP: Roots, Tubers and Bananas (RTB), Agriculture for Nutrition and Health (A4NH), Grain Legumes and Dryland Cereals (GLDC), Policies, Institutions and Markets (PIM), MAIZE, and Climate Change Agriculture and Food Security (CCAFS),
- Platforms: Genebank, Excellence in Breeding (EiB), Excellence in Agronomy (EiA), Gender, and Big Data

IITA also continues to focus on the following research for development areas that are aligned with the priorities of the One CGIAR portfolio:

1. *Harnessing genetic diversity to nourish future generations* through its work on genetic resources conservation and participation in the CGIAR Crops to End Hunger Initiative.
2. *Building sustainable systems for the future* with participation in the following: A CGIAR Plant and Soil Health initiative and Responding to biological threats; Excellence in Agronomy, and Strengthening policies, markets and services for food systems transformation in sub-Saharan Africa.
3. *Improving Nutrition and One Health* with a stronger CGIAR commitment to food systems research, Addressing Hidden Hunger.
4. *Reducing inequalities and vulnerability for women and youth.*
5. *Leveraging global responses to the climate crisis* with the Two Degree Initiative for Food and Agriculture (2DI).

IITA operates via its regional hubs and research stations across sub-Saharan Africa on Partnerships for Delivery to make the delivery of research innovations more efficient. In 2019, IITA added the Sahelian region of West Africa—one of the most vulnerable regions of the world—as a priority impact zone, where the agriculture sector is under strain due to the many risks that are likely to deteriorate in the face of climate change. Hence, IITA and partners are making contributions in the Sahel through collaborative projects to improve livelihoods, enhance food and nutrition security, increase employment, and ensure the preservation of natural resource integrity.

Researcher talking with women vendors selling grains and legumes, Bodija market, Nigeria.

Improving crops

Superior hybrid: a new high yielding resistant matooke hybrid.

Genome editing: A powerful tool for crop improvement

The biggest challenge in agriculture is to feed the growing human population, which is projected to reach 9.7 billion in 2050 compared to 7.7 billion in 2019. There is a critical need to close the yield gap in staple crops and enhance food production to feed the world. In Africa, the emphasis should be on roots, tubers, and bananas which are the main crops used for staple food and income generation.

To fulfill the increasing demand for food with limited resources, better and efficient ways to produce food are required. Modern biotechnological tools such as genome-editing (GE) offer cost-effective strategies for developing improved varieties. Researchers at IITA have established the GE system for banana and yam.

Banana production is severely constrained by many pathogens and pests, particularly where a number of them are co-existing. Using disease and pest-resistant banana varieties is one of the most effective options to improve banana, which is important in enhancing food security. Recent advances in GE have the potential to accelerate breeding of banana for disease and pest resistance.

IITA researchers inspecting the performance of genome-edited banana under glasshouse conditions.

The availability of a well-annotated, whole-genome sequence of banana and well-established genetic transformation protocols makes the banana a strong candidate for GE.

Banana/plantain Recently, a robust CRISPR/Cas9-based GE system was developed for banana and plantain. This system could open up avenues for efficient and targeted genome manipulations for disease resistance in banana. IITA uses GE as a tool for improving banana for disease resistance.

Once the efficient protocol for GE was established at IITA, this technology was used to inactivate the endogenous banana streak virus (eBSV) integrated into the B genome of plantain, overcoming a significant challenge in breeding and the dissemination of hybrids. BSV is a prevalent virus pathogen showing symptoms such as chlorotic streaks on leaves. Advancement of the disease leads to death of the plant. When the banana plants are stressed, the eBSV recombines to produce a functional episomal viral genome and infectious viral particles that result in disease symptom development.

The GE plantain was generated using a multiplex CRISPR/Cas9 construct targeting the editing of integrated eBSV sequences in the host genome. Sequencing and phenotyping of the edited events showed targeted mutations and confirmed the inactivation of eBSV for its ability to be converted into infectious viral particles. This strategy can be applied to improve breeding lines for use in developing plantain hybrids with no risk of activation of the functional virus.

IITA is developing genome-edited banana varieties by disrupting the function of disease-causing susceptibility ('S') genes, the negative regulators of plant defense, and sugar transporters as a strategy to develop resistance against bacterial and fungal pathogens.

Bacterial wilt The target genes in a banana for resistance to bacterial disease have been identified through the comparative transcriptomics of the resistant wild type banana *Musa balbisiana* and susceptible banana Pisang Awak.

Yam Yam production is severely limited by pests and diseases. The genetic improvement of yam by conventional breeding is very challenging and can be complemented using the GE tool. Therefore, an efficient CRISPR-Cas9 based GE system has been developed for *Dioscorea rotundata* using *PDS* gene in Amola, a farmer-preferred variety (Fig. 1). The establishment of CRISPR/Cas9 system will facilitate the improvement of yam for economically important traits.

Regulation GE has shown immense potential for crop improvement, but its regulation is still in the early stages. There are differences among the countries regarding the regulation of genome-edited crop varieties (Fig. 2).

Gene editing (GE) is a type of genetic engineering in which a DNA is inserted, knocked out, modified, or replaced in the genome (set of genes or genetic materials) of a living organism. Unlike genetic engineering that randomly inserts genetic material into the host genome, GE targets the gene modification to site-specific locations.

In recent years, GE using sequence-specific nucleases (enzymes that split nucleic acids) has emerged as a powerful technique to generate targeted mutation in the genome organisms and applied plant gene function studies and crop improvement. Of these nucleases, clustered regularly interspaced short palindromic repeats/Cas9 (CRISPR/Cas9) was widely adopted as the most robust GE tool in plants because of its simplicity, design flexibility, high efficiency, and its ability to edit multiple genes simultaneously.

GE technology uses "molecular scissors" that create precise double-strand breaks at the desired target site in the genome. These double-stranded breaks are then repaired by the cell's natural repair mechanism and produce a user-desired mutation or genetic outcome.

A recent development in GE can accelerate breeding by making efficient and precise changes in the plant genome to develop new traits such as resistance to various biotic and abiotic stresses. The advantage of targeted gene editing is that it can be used for 'trait stacking,' whereby several desired traits are physically linked to ensure their co-segregation during the breeding processes. This precise GE has the potential to revolutionize crop improvement in sub-Saharan Africa.

Figure 2. Establishment of genome-editing system for yam. (A) Genome-edited yam targeting the *phytoene desaturase* (*PDS*) gene as a marker as mutations disrupting PDS causing albinism of plants. (B) IITA PhD student looking at the experimental plates.

GE technologies are capable of creating genotypic and phenotypic variations in plants that are indistinguishable from those produced through natural means or conventional mutagenesis methods.

The genome-edited varieties with no foreign gene integration are not regulated in countries like Argentina, Australia, Brazil, Chile, Canada, Japan, and the USA. Several other countries like Kenya, Nigeria, and India are in the process of developing the regulatory guidelines for the application of genome editing. Science-based regulatory guidelines will enhance the adoption of disease-resistant GE varieties that would contribute to food security.

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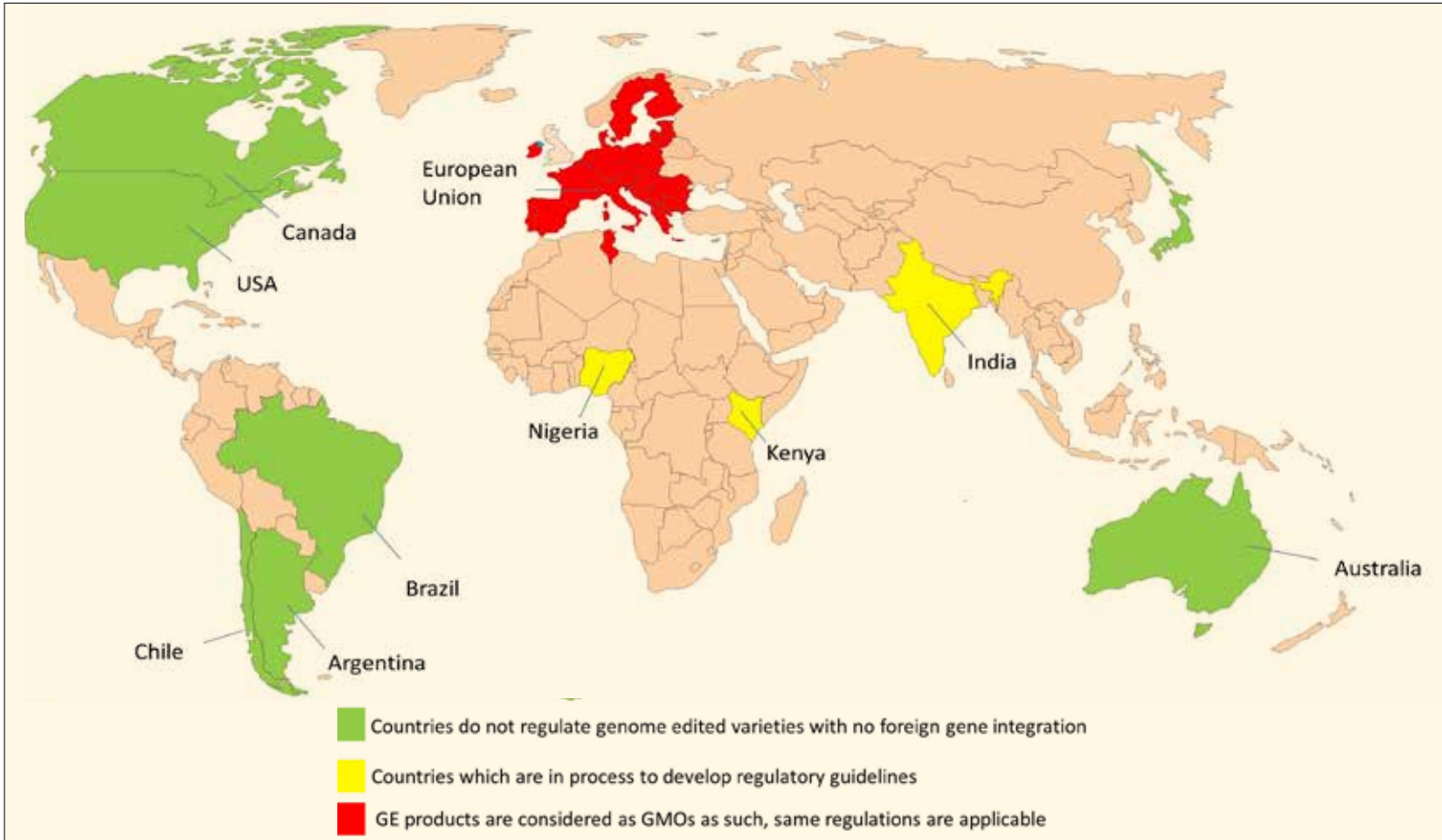

Figure 2. Regulation of genome-edited crop varieties among different countries.

Authors: Leena Tripathi, Valentine Otang Ntui, and Jaindra Nath Tripathi, IITA-Kenya (Nairobi).

Modernizing IITA breeding programs: soybean for enhanced genetic gains

IITA's Soybean Improvement Program (ISBP) remains the primary source of improved germplasm for both private and public organizations with over 100 varieties already released by partners. The ISBP activities are mainly supported by the US Agency for International Development (USAID) (about 75%) and partly by the Soybean Innovation Laboratory (SIL) and CGIAR Research Program on Grain, Legumes, and Dryland Cereals (GLDC). Increasing the rate of genetic gain through a consistent rate of variety turnover to avoid genetic dilution is the cornerstone of the breeding program.

High-yielding soybean varieties in the breeding pipeline.

As part of the modernization process, the program focused on:

- Operationalizing the stage-gate breeding process
- Refining product profiles and market segments
- Expanding network testing through the Pan African variety trials, and
- Upgrading and implementing modern technologies, mechanization, and digitization of data collection and transfer

Operationalizing the stage-gate breeding process To clearly define the roles, responsibilities, expertise, and criteria of making decisions as well as engage collaborators at various stages of the breeding program, the stage-gate approach has been operationalized in the IITA soybean breeding program. The stage-gate approach permits advancements, process, and resource allocation based on defined breeding metrics. These metrics allow quantifying genetic gain, which is crucial in measuring the impact of the breeding programs. Stage-gate also allows leverage of germplasm in gene pools and breeding populations to increase and preserve genetic diversity for long-term improvements as well as avoid dilution of genetic gain by managing the product life cycle. (Fig. 1).

The program aims to develop products suited for market needs aligned with the value

chain based on product profiles. Product profiles, trait prioritization, and market segmentation are refined in consultation with public and private sector partners. The four main market segments which the breeding program focuses on include early maturing soybean for the lowland savanna, early maturing soybean for the mid-altitude savanna, medium to late maturing soybean for the lowland savanna, and medium to late maturing soybean for the mid-altitude savanna. A portfolio of deliverables within the market segments included soybean varieties with resistance to the Asian soybean rust **(***Phakopsora pachyrhizi***),** large-seeded varieties, tolerance to lodging and shattering. Breeding pipelines are based on the market segments to ensure that varieties developed to meet specific demands as per the product profiles have also been initiated. On average more than 20,000 lines at different breeding stages are evaluated annually to identify lines that fit within the product profiles determined by the market segments.

Expanding network testing through Pan African Variety Trials The Pan-African Soybean Variety Trial (PAT) network is an initiative by SIL, IITA, Syngenta Foundation for Sustainable Agriculture (SFSA), and the African Agricultural Technology Foundation (AATF). The PAT network fast-tracks testing, release, and registration of soybean varieties through a transparent process. Over 21 countries are participating in the PAT, with evaluated lines coming from Australia, Colombia, USA, and national and private

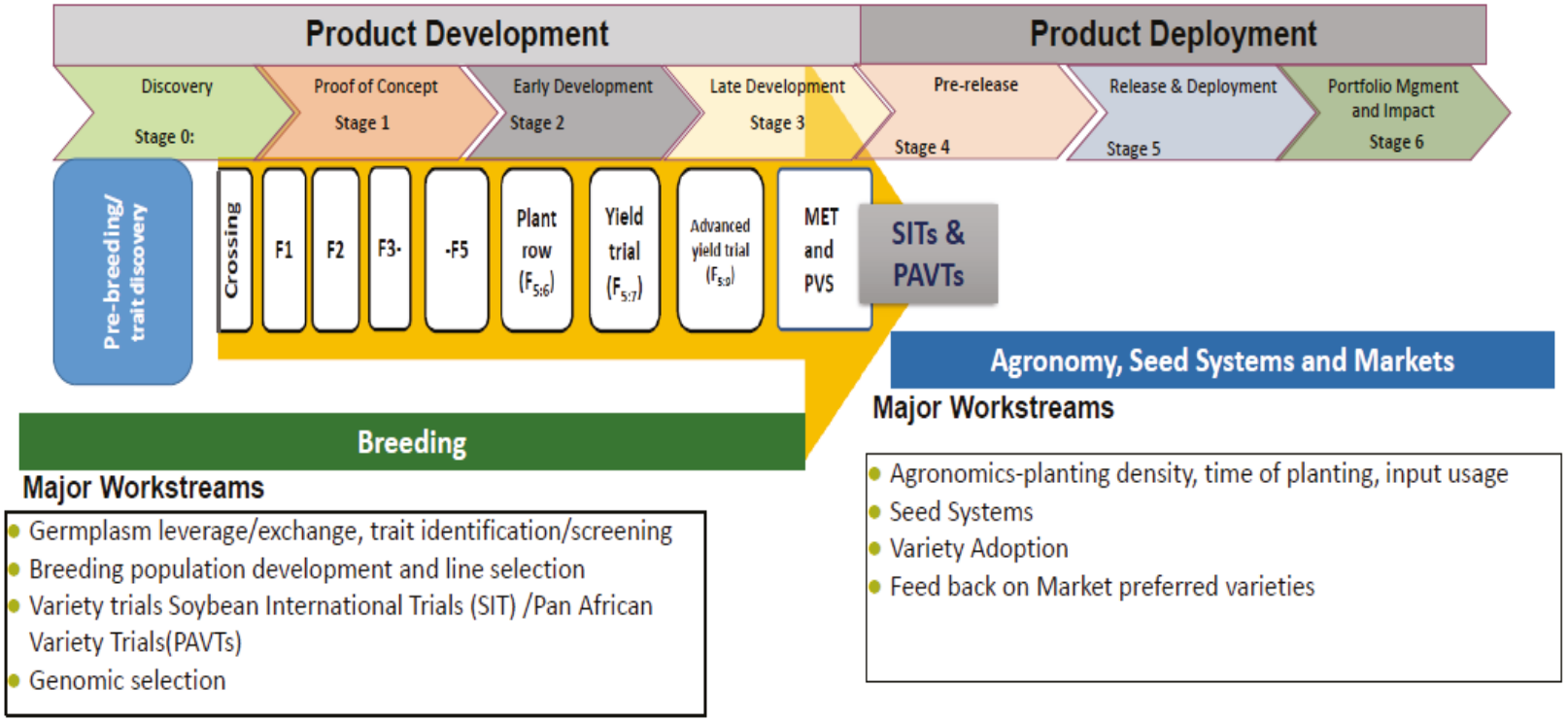

Figure 1. The stage-gate variety delivery process by the IITA soybean breeding program. Refining product profiles, trait prioritization, and market segmentation.

sector breeding programs in Africa. Figure 2 shows the number of countries and organizations that participated in the PAT during the 2019 season.

Several varieties that fit the defined product profiles have been identified with registration and release at different stages. The varieties which offer the highest yield potential to the lowland savanna are from Colombia. Table 1 summarizes the performance of the top varieties evaluated in Nigeria. Panorama 27D was identified as both high yielding and suitable for direct release in Nigeria.

Upgrading and implementing modern technologies Optimization of trial designs and field management practices to reduce error and maximize heritability and genetic gain is an essential aspect of the modernization of the soybean breeding program. With support from SIL, IITA

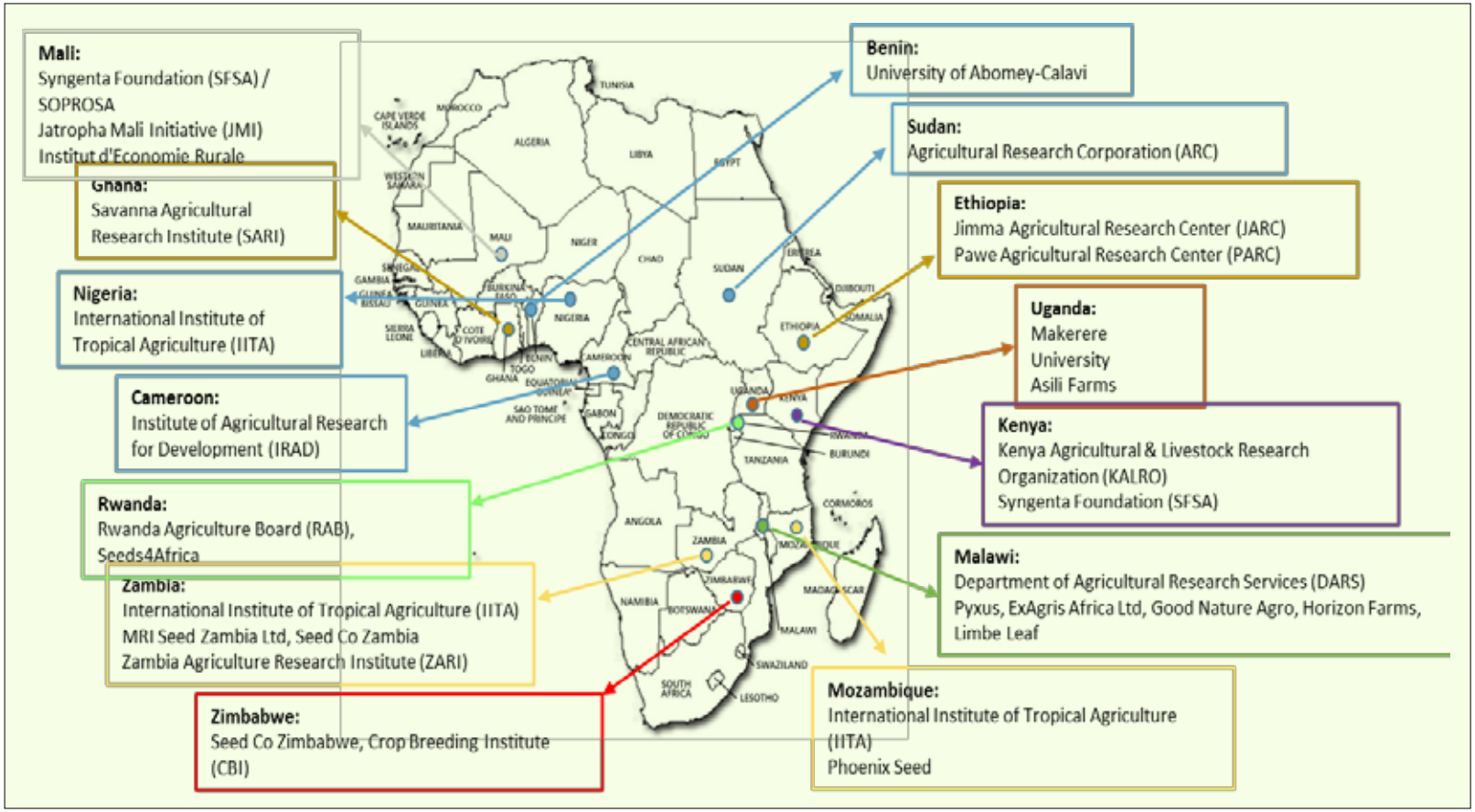

Figure 2. Pan African Variety Trial Network 2019 - countries and institutions.

Table 1. Mean yield (kg/ha) of the best 5 varieties, Pan African Variety Trials in Nigeria, 2019 season.

Variety	Ibadan	Zaria	Mean
PANORAMA-27-D	4733	3002	3868
SC-SIGNA	3251	2976	3113
TGX1951-3F (IITA check)	2967	3006	2986
QUARSHE	3055	2422	2739
JENGUMA	2669	2797	2733
Mean	2481.1	1686.2	2083.6
PROB	0.0008	<.0001	<.0001
SE	558.5	138.3	284.2

Figure 3. Trials planted with a mechanical planter at the IITA station in Lusaka, Zambia.

soybean breeding is one of the first programs to adopt mechanical planting (Fig. 3). Mechanized planting ensures precise planting depth and seed placement, allowing for uniform germination, hence better experimental data and accuracy for the breeding program. The speed of planting is also significantly increased. One can plant four-row plots of between 3,000-4,000 plots per day.

Digitization of data collection and transfer which include the use of the Breeding Management System has also been adopted with training offered to national program partners involved in the PAT.

The future Although a sustained rate of genetic gain is key to African agricultural transformation, the success of a breeding program is measured not only by variety turnover but also by the performance of the new varieties in farmers' fields. The ability to track metrics and identify bottlenecks requires a well structured breeding program.

In collaboration with Excellence in Breeding (EiB) and the private sector, there is still scope for continuous improvement of CGIAR breeding programs to effectively deliver genetic gains to farmers' fields in a cost-effective way similar to private sector partners.

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Breeding better bananas for African farmers

In the highlands of Eastern and Central Africa (ECA), 50% of the permanent cropped area is under highland cooking banana (Matooke and Mchare) cultivation. This represents around half of the total area under banana cultivation across Africa. ECA countries (Burundi, DR Congo, Kenya, Rwanda, Tanzania, and Uganda) annually produce 21 million tonnes of bananas with a value of US$4.3 billion.

Bananas are an indispensable part of life in this region providing up to one-fifth of the total calorie consumption per capita. Uganda has the highest consumption rates of banana in the world. The average daily per capita energy consumption in ECA is 147 kcal: 15-fold the global average and 6-fold the African average.

Matooke is the primary staple crop for over 13 million Ugandans (≈35% of the population), but is less critical in Tanzania where 3.3 million (about 7% of the population) consume it as a staple. In Tanzania, 20-30% of the population in selected rural regions depend on Mchare. Mchare can be extremely profitable, fetching farmgate prices 2-4 times higher than Matooke.

Household consumption accounts for the majority of the production, but they are also an important source of household income. Fresh market demand remains the largest market opportunity followed by processed banana goods, a growing value chain segment.

Yield gap and pests and diseases The estimated yield potential for Matooke is 70 t/ha/year, while current production figures indicate yields of just 5-30 t/ha/year. The yield potential for Mchare is 60 t/ha/year while current production is 11 t/ha/year. Causes for the yield gap include the lack of clean planting material, inferior agronomy, and susceptibility to pest and disease stresses.

Fusarium wilt, caused by *Fusarium oxysporum* f.sp. *cubense* (Foc), is a soil-borne disease with a number of pathotypes or races. Infection is often fatal and kills infected plants, but with susceptibility depending on Foc race and banana type/cultivar. Foc race 1 is present across Africa, while Tropical race 4 (TR4), which is severely destructive to Cavendish dessert banana types, has recently become established in Mozambique. It was previously not present in Africa.

Nematodes are microscopic worms with several species infecting banana, depending on locality/ geography and climate/altitude. Weevils are insect pests. Nematodes attack the roots and rhizomes, and weevils the rhizomes, both causing premature plant toppling and loss of banana bunches. Black Sigatoka (or Black Leaf Streak, BLS caused by *M. fijiensis*) results in leaf necrosis causing severe yield losses. Bacterial wilt is caused by the bacterium *Xanthomonas campestris* pv. *musacearum* and kills banana plants.

Breeding Breeding bananas is a long-term commitment, given its perennial nature and numerous issues relating to sterility. Over the last five years, IITA has established a formidable network of researchers and breeding programs across six continents through a project called Breeding Better Bananas. This highly interactive network has resulted in opening the exchange and

Banana subgroups: East African Highland Cooking banana: Matooke (left) and Mchare (right).

sharing of hybrids, expertise, and information across institutes and breeding programs.

The project is coordinated by IITA, is multidisciplinary, and involves research institutions in Tanzania (TARI-Tengeru, TARI-Maruku, IITA) and Uganda (NARO and IITA), and international research collaborators in Australia (University of Queensland), Belgium (KU Leuven University), Czech Republic (IEB), Brazil (EMBRAPA), France (Bioversity International), India (NRCB), Malaysia (University of Malaya), South Africa (Stellenbosch University), Sweden (SLU), and USA (Boyce Thompson Institute, Cornell University).

Scanning of a digital code for varietal identification and automatic display (inset) on fieldbook of data to be collected as part of the Banana Tracking System.

Local banana breeding capacity is being strengthened and national banana breeding pipelines are being developed. Farmers and consumers are being sensitized to the cultivation and use of improved, disease-resistant cooking type bananas, which enhance yield and income generation.

Achievements In East Africa, the project has strengthened the Matooke banana breeding program in Uganda and underpinned an infant banana breeding program in Tanzania on Mchare, both based on a specific product profile. Banana breeding efficiency has been significantly improved, as shown by the 3-fold increase in seed production and better understanding and knowledge of banana floristry and pollination. Using novel video techniques, the floral development of seed-fertile and seed-sterile cultivars were shown to differ and stigmas found to be more receptive before the flower opens, all of which enable more targeted pollination timings. Significant improvements in embryo rescue and germination rates were thus achieved. This has resulted in an accelerated production of progeny and the evaluation process, amounting to crosses and consequent selections for evaluation.

Over 200 Matooke hybrids have been selected for field evaluation, with thousands more in the pipeline. Of these, 122 were planted in the first joint evaluation of Matooke hybrids independently developed by NARO and IITA. Heterobeltiosis for bunch weight up to 249% versus its Matooke grandmother and 136% against its primary tetraploid hybrid parent was achieved. Broad sense heritability (across three cropping cycles) for yield potential and bunch weight were high (0.84 and 0.76, respectively).

A consumer evaluation system has been established that feeds back into the pipeline to ensure a robust mechanism to deliver new cultivars to farmers with preferred end-user traits, such as taste and cooking traits. This allows the project to dispose of unsuitable progeny early in the development cycle.

Seed set data from Matooke cultivars have also shown that seeds are mostly extracted from just a few cultivars. Currently, 541 Matooke hybrids from 3x-2x crosses and 13,598 Matooke hybrids from 4x-2x crosses are in EETs. Results also show that triploid hybrids next to tetraploids and diploids are generated from 3x-2x crosses, which require further investigation, as this will help avoid the 4x-2x crosses cycle, and shorten the breeding schedule. Some 1,572 hybrid Mchare are under early field evaluation, representing the creation of the first ever Mchare hybrids, while 79 doubled chromosome Mchare plants were generated for 8 cultivars, of which 60 lines have been planted in the field. Also, 22 improved Fusarium-resistant

Mapping populations: Hybrids were developed segregating for traits of interest for gene discovery.
Far left: fruit variation.
Middle and right: variation in corm response to banana weevil.

EMBRAPA diploids from Brazil were received for potential use in the breeding program. All material used is genotyped during the multiple stages of breeding to assure identity. The infrastructure was drastically improved with all fields irrigated and both the Matooke and Mchare breeding site supported by a molecular and pathology lab as well as in vitro labs and nurseries.

The best Matooke hyrbid were called NARITA giving credit to the joint collaboration and achievement by the Uganda banana breeding program NARO and IITA. The NARITAs have been assessed for various pest and disease resistance both in the screenhouse and the field, with good resistance being demonstrated against Foc Race 1, weevils, Sigatoka, and *Radopholus similis*.

Field and farmer testing of NARITA hybrids, including sensory evaluation, across five sites in Tanzania and Uganda over 2 cycles resulted in the selection of 4 hybrids planned to be released in Tanzania by end-2020. The most important desired visual traits are large bunch size, fruits, and hand size; moderate suckering, plant height, and resemblance to Matooke. In general, traits preferred by women reflect those of men. Across regional field testing sites, NARITA 23 was ranked the best by farmers, followed by NARITA 2 and NARITA 12. Some NARITAs outperformed and were preferred by farmers than the local cultivars in some locations but not all.

The project has set the stage for developing molecular tools to speed up selection in banana breeding. Preliminary assessments, including from Genome-Wide Association Study (GWAS), show that Chr3 is particularly important, including for TR4 resistance and probably weevil resistance, as well as for fruit filling, an important trait for breeding. Hundreds of lines of various populations have been phenotyped and genotyped to generate SNP markers. Numerous QTLs associated with resistance to pests and diseases (Fusarium, weevils, bacterial wilt) have been identified, as well as other important fruit traits, mapped from various genetic backgrounds and located on different chromosomes. Models for genomic prediction and the fruit filling QTL have been evaluated, which will be validated and deployed in Matooke breeding.

Knowledge on pest and disease populations and dynamics in the region has been improved and protocols for more rapid and efficient screening developed and implemented, and consistently fine-tuned. The accurate characterization of pathogens and pests has continued and used for evaluating hybrids and breeding materials for resistance. A total of 220 isolates of Foc Race 1, 369 isolates of *Pseudocercospora fijiensis*, and 12 populations of weevil have now been collected, stored, and used to assess genetic diversity among populations. Monoxenic populations of *R. similis* have been established in Kenya, Tanzania, and Uganda for routine use in screening purposes. *Pratylenchus goodeyi* and *P. coffeae* appear more prevalent than previously known and should be considered for resistance screening.

Screening of banana hybrids for Fusarium race 1 resistance (green plants are resistant and yellow-brown plants susceptible).

An open source system, Banana breeding Tracking Tool (BTracT), which accurately captures and efficiently tracks data throughout the breeding process, was developed and successfully implemented and is now fully operational. BTracT is fully interfaced with the banana breeding database, MusaBase, which provides a global repository for all breeding data as it is collected in real time. FieldBook data collection, linked to BTracT, accurately records data at all stages of the breeding program, synchronizing it automatically with MusaBase to archive all information and data and make it publicly available.

To create awareness and visibility for the project and on the importance of banana in the Great Lakes region and why improving banana breeding is key to ensure food security of the local communities, two videos were produced and published to reach a wider audience and the general public: "Journey to a better Mchare: Improving Tanzania cooking banana" (https://youtu.be/BzhNKTLN73c) and "Breeding Better Bananas - Improved Matooke for East and Central Africa" (https://youtu.be/yXbeDBg9SuI).

A range of training events have been undertaken during the project, including regular training in relation to MusaBase and data entry, breeding training, scientific writing in addition to exchange visits between partners and breeding programs to assess technical aspects as well as foster links and relations. Specific workshops for on-farm evaluation of NARITA, genomics, science writing, breeding techniques, and seed set have provided training opportunities and built capacity in partner institutions outside of the project and for associated postgraduate students.

A project website (http://breedingbetterbananas.org/) was developed that links directly with MusaBase (https://musabase.org/) and other relevant domains; a Twitter account (@BBetterBanana) was created in May 2018 has reached 210,687 users with a total of 649,671 impressions.

In total, 25 postgraduate and 1 graduate student have been associated with the project, with 6 females and 20 males.

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Modernizing cowpea breeding

Cowpea is an important grain legume crop grown in sub-Saharan Africa, which produces 90% of the annual global production of 6.5 million metric tons. The crop experiences multiple biotic and abiotic stresses that considerably limit its production. IITA and national partners in the region have bred varieties tolerant of several of these stresses.

There are, however, no improved varieties for all key production areas and market types, and none of them possess a broad suite of resistant traits. To significantly increase efficiencies of breeding programs, IITA and national agricultural research systems (NARS) established a collaboration with Monsanto/ Bayer.

This public/private collaborative project aimed to increase the scope, efficiency, and output of cowpea breeding programs, through learning from Bayer. This collaboration is intended to serve as a model for how the expertise of private sector breeding companies can be leveraged to help increase genetic gains in CGIAR and NARS breeding programs. Expected outcomes included significant increase in scale and the modernization of breeding approaches.

The project, Increasing the performance of cowpea breeding programs across West Africa, enabled IITA and four West African NARS, through collaboration with Bayer, to substantially improve the performance of their cowpea breeding programs by introducing best practices from the private plant breeding sector which can benefit public breeding programs. The project provided the opportunity to implement modern technologies and approaches in cowpea breeding.

Planter being tested in Minjibir, Nigeria.

The direct beneficiaries were the four national institutions and IITA's breeding programs, but all cowpea breeding programs in sub-Saharan Africa benefited since IITA interacts with them on several platforms (e.g., CGIAR Research Program [CRP] on Grain Legumes, Kirkhouse Trust project, Legume Innovation Lab, Crop Trust's wild crop relatives).

Another benefit was the availability of improved varieties that can help enhance the livelihoods of smallholder farmers and consumers in non-project countries. In addition, scientific capacity of cowpea researchers across the globe has been significantly improved.

Project implementers and partners from IITA, Bayer, and national research systems visiting a lab.

Intensive interactions between IITA, NARS, and Bayer covered several activities targeting modernization of participating breeding programs. The achievements can be grouped into five major areas:

Breeding management To substantially increase the impact of breeding programs, the emphasis of activities shifted from trait-driven to demand-led breeding. The consumers, farmers, and markets now guide efforts for product designs and management. Product profiles that maximize client satisfaction were developed.

Breeding strategies All the collaborating programs developed parental profiles displaying the reactions of parental lines to major production constraints or their fitness to identified market traits. The number of elite lines used in hybridization was increased by 50%. The project increased effective population sizes by up to 25% and implemented single seed descent workflows with molecular markers usage for quality control and marker-assisted breeding. The resulting increase in the size of F2 (by at least 40% at IITA) and increase in the genetic base of the populations have led to the increase in selection intensity (15-20%). To increase the number of generation cycles per year, irrigation facilities were established or upgraded. For example, IITA took advantage of the cropping season, off-season, and screenhouse facilities at both Kano and Ibadan, Nigeria, to obtain three to four generations of breeding materials each year.

Operational protocols The efficiency and effectiveness of the breeding program require standardized operational protocols. Seed storage was upgraded by creating inventory into the Breeding Management System (BMS). Some basic best practices for site selection were used. Standard operating procedures for data collection were developed. Strategies to reduce cost without losing efficiency of testing have been optimized.

Regional trials were carried out in all four countries at 12 locations. To increase mechanization and operational efficiencies towards better data quality, Bayer donated one refurbished cone planter, four seed threshers, and four seed counters to IITA. The team successfully set up a workflow towards 100% operational implementation of genotyping for seed purity and digital data capture.

Marker technologies With the support of Intertek, the project developed an SOP for leaf collection and delivery for genotyping. Genetic integrity and purity of breeding lines had been routinely ascertained with a set of 19 SNPs selected across the cowpea genome.

In addition, forward breeding has been implemented for aphids and bacterial blight after the conversion of markers associated with the resistance QTL to these two traits. Detailed QTL deployment strategies were developed based on the number and effect of QTLs and the donor of the QTLs.

Analytical tools Several discussions on analytical methods and tools essential for modernizing the breeding programs were conducted (for example, use of BreedingView and R for data analyses). BLUP was used in the advancement decisions given its accurate prediction of future performance. Towards the estimation of genetic gain, a strong recommendation was made concerning the use of common checks in the trials to minimize the effects of the environment, estimate the year effect, and compare against mean of cohort for advancement. R scripts for both the estimation of genetic trend and for multilocation analyses were discussed.

This project was designed to improve the effectiveness and efficiency of cowpea breeding programs. All areas of the breeding programs were analyzed and ideas for improvement were recommended and adopted. IITA and NARS breeding programs have been fully transformed and are ready to increase the rate of genetic gain of varieties from their program. A culture of continuous improvement has been instituted to sustain the implementation. Best practices from the private breeding companies are being deployed and their successes replicated in the public sector. High performing market-driven lines are being developed. Better food, nutrition and enhanced livelihoods of smallholders is expected to be achieved as a result of this modernization.

IITA, Bayer, and national partners in a meeting at IITA, Ibadan, Nigeria.

The project is funded by the Bill & Melinda Gates Foundation and includes the following partners: Institute for Agricultural Research (IAR), Zaria, Nigeria; Institut de l'Environnement et Recherches Agricoles (INERA), Burkina Faso; Institut d'Economie Rurale (IER), Mali; Savanna Agricultural Research Institute (SARI), Ghana; and Monsanto/Bayer, USA.

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Another project that helped modernize the cowpea breeding program is the Tropical Legumes III project - Improving Livelihoods for Smallholder Farmers: Enhanced Grain Legume Productivity and Production in sub-Saharan Africa and South Asia (TL-III). TL-III was implemented by IITA, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and International Center for Tropical Agriculture (CIAT) from 2015 to 2019 in collaboration with national partners in seven African countries and a state in India. The project had three complementary research components of (a) development of improved varieties, (b) improvement of capacity of crop breeding programs, and (c) establishment of sustainable seed delivery systems.

Farmer checks out improved cowpea variety developed by IITA.

TL-III was a Bill & Melinda Gates Foundation-funded initiative. It was designed to provide smallholder farmers with improved cultivars of four major grain legumes: common bean, cowpea, chickpea, and groundnut. The project aimed to strengthen international plant breeding programs and, most importantly, the breeding programs of national partners in sub-Saharan Africa and South Asia.

The project was designed to increase the productivity (by 20%) and production (by 10%) of groundnut, cowpea, common bean, and chickpea. These grain legume crops provide substantial nutritional, cropping system, and economic benefits to smallholder farmers.

Cowpea was the crop of focus for IITA in collaboration with INERA Burkina Faso, SARI Ghana, IER Mali, and IAR Nigeria.

Successes/achievements A total of eight cowpea varieties were released in four sub-Saharan African countries: two in Ghana, four in Nigeria, two in South Sudan, and two in Tanzania.

A study on the adoption of cowpea varieties in 10 Nigerian states of Borno, Bauchi, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, and Zamfara showed that 42% of the households were growing improved cowpea varieties. This was equivalent to 945,000 households. Nearly 30% of the cowpea area was under improved varieties, which was equivalent to over 1 million ha planted to improved cowpea. The farmers who adopted the improved varieties had 26% higher yield per hectare and 61% increase in net returns.

Through TL-III, the IITA cowpea breeding program was able to significantly modernize its operations. Some interventions to improve efficiency and effectiveness included undertaking the Breeding Program Assessment Tool (BPAT) assessment followed by recommendations for improvement and Program Improvement Plans (PIPs) such as improving physical infrastructure and human capacity to adapt to modern breeding requirements. The program developed two product profiles that are now guiding its breeding pipeline: (1) Short- and medium-duration grain-type cultivars with large white or brown grain for the Sahelian and Sudan Savanna zones; and (2) Medium- and late-maturing dual-purpose (grain + hay) cultivars

with large white or brown grain for the Guinea Savanna zone.

The program adopted the shuttle breeding approach where national agricultural research system (NARS) partners were incorporated in the research.

The use of modern breeding tools were promoted during this phase. The Integrated Breeding Platform (IBP) developed a Breeding Management System (BMS) that has helped in data management and analysis. Digitization of data collection, curation, and archiving plus experimental designs using BMS were implemented by the project. Most of the data are now captured using tablets and recently a barcoding system was introduced.

Breeding modernization was also initiated at the NARS level. All the programs underwent BPAT self-assessment from which PIPs were developed and implemented. Product profiles were then developed. All the programs have increased the number of crosses by at least 25% and subsequently increased the number of entries in their breeding pipelines by more than 80%. The number of both on-farm trials and demonstration sites have increased by more than 100%. The number of generations was also increased from 1 to at least 2 per year.

The Cowpea Breeding Program also adopted an inclusive, pluralistic, and integrated seed systems approach that recognizes the complementary roles of seed producers such as individuals, seed companies, government organizations, non-government organizations (NGOs), and farmer groups. The program engaged national partners to popularize new improved varieties using various complementary approaches such as field demonstrations, extension guides, field days, agricultural/seed fairs, and radio TV programs.

For the period 2015-2019, there were more than 1,345 demonstrations conducted, 54,000 extension guides distributed, 89 field days and 27 agricultural seed fairs held, and 139 radio/TV programs conducted in the four participating countries. Also more than 783 (1-9 kg), 1,457 (25 kg), and 1,090 (size 25-50 kg) seed packs were made available to farmers across the four countries. From 2015 to 2018, NARS partners were able to produce 56.6 t of breeder seeds, 1,684.6 t of foundation seeds, and 17,683 t of certified seeds.

IITA also contributed about 4,000 kg of cowpea foundation seed in 2017 to 'Seeds of Renaissance,' an initiative aimed towards rehabilitating farmers in the terrorist-ravaged North East of Nigeria.

Capacity building of NARS scientists A woman scientist from Burkina Faso was trained on plant breeding and a gender specialist from Nigeria was also trained at PhD level. There was a workshop for TL-III scientists on monitoring, evaluation, and learning (MEL). All NARS breeders have received training in genomics and molecular breeding at CEGSB-ICRISAT, Patancheru (India). Annual training were organized on the use of BMS at the national or regional levels, or across the project for both IITA and NARS scientists and technicians.

Leveraging on TL project funds and other sources, NARS programs were able to renovate their irrigation facilities (Ghana, Burkina Faso, Mali), screenhouses (Ghana, Nigeria, Mali), and cold rooms for seeds (Ghana Burkina, Mali, Nigeria). They have also been able to acquire other important items such as a generator and thresher (Burkina Faso), water pump (Nigeria), and tablets for data capture (Burkina Faso, Ghana, Mali, and Nigeria).

Future research or development The achievements of TL-III constitute a strong foundation for modernizing the IITA and NARS cowpea breeding programs. The strong collaboration established with NARS offers a solid testing network.

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Enhancing yam breeding for increased productivity and improved quality

An IITA-led project called AfricaYam involves a network of research organizations in the four leading producer countries of the West Africa yam belt: the National Root Crops Research Institute (NRCRI) and the Ebonyi State University (EBSU) in Nigeria; two research institutes under the Council for Scientific and Industrial Research (CSIR) in Ghana (Crops Research Institute and the Savanna Agricultural Research Institute); le Centre National de Recherche Agronomique (CNRA), Côte d'Ivoire; and l' Université d'Abomey-Calavi (UAC), Dassa Center, Benin.

Patrick Adebola, AfricaYam Project Leader (right) with Emmanuel Chamba of CSIR-SARI, (left) in a yam crossing block in Tamale, Ghana.

Key research organizations outside the region also play significant roles in the project. These are the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Guadeloupe, France; Iwate Biotechnology Research Center (IBRC), Japan; James Hutton Institute (JHI), UK; Japan International Research Center for Agricultural Sciences (JIRCAS); and Boyce Thompson Institute (BTI), Cornell, USA. The main project goal is to increase yam productivity while reducing production costs and environmental impact by developing and deploying end-user preferred varieties with a higher yield, excellent resistance to pests and diseases, and improved food quality.

Achievements

The project has made significant and steady progress.

Improved infrastructure and capacity development Before AfricaYam, many of the yam research programs in West Africa lacked the critical equipment and infrastructure to run effective yam breeding programs. The project made significant improvements in needed infrastructure and equipment at IITA and the national research systems

in Benin, Côte d'Ivoire, Ghana, and Nigeria. National programs received new vehicles, screenhouses, yam barns, and other small equipment. Yam breeders and technicians in each partner country got several specialized training, such as on automated data collection, management, and analysis, disease phenotyping, and breeding techniques, including controlled pollinations and trial management to ensure the collection of quality data.

The project facilitated several exchange visits among national partners and advanced institutions, which provided learning opportunities in new breeding techniques and tools. The exchange visits also improved communication among the programs leading to a better understanding of breeding schemes and variety identification systems used by IITA and the national programs in the four participating countries. At the end of phase I, the project had engaged a total of 37 students (10 PhD, 12 MSc, and 15 BSc). These have equipped the yam breeding programs of national institutes with additional human capacity.

Strong and active yam breeding community of practice

A Yam Breeding Community of Practice (CoP) was established (www.africayam.org) and currently has 283 registered members.

AfricaYam and IITA yam breeder Asrat Amele with May-Guri Saethre, IITA Deputy Director General Research for Development (left) inspecting field trials in Ibadan and with Robert Asiedu, R4D Director for West Africa, at the Abuja Station (right).

The CoP creates and maintains close links among yam breeding programs in West Africa and allows sharing of experiences and information on breeding methods, crossing techniques, best field practices, screening protocols, propagation methods, sharing of data and procedure updates on safe germplasm exchange between IITA and project partners.

Development of genomic resources

The project developed ample genomic resources and established several populations for genetic studies. The biparental mapping population and diversity panels of *Dioscorea rotundata* and *D. alata* were genotyped and phenotyped for crucial traits. Genotyping platforms, including genotyping-by-sequencing (GBS), Diversity Array Technology (DarT), and whole-genome resequencing (WGRS), were successfully applied and generated millions of single nucleotide polymorphism (SNP) markers. Iwate Biotechnology Research Center (IBRC) completed the first version (TDr96F1-PCv1) and the second version (TDr96_F1_PCv2)

Participants at the AfricaYam 2018 annual progress review and work planning meeting, Abidjan, Cote d'Ivoire.

of the reference genome of Guinea yam accession TDr96_F1. The recently released Version 2 is more accurate than the first version.

Population genomics, linkage as well as GWAS analysis were carried out to understand the genetic variation that is responsible for phenotypic variability in yam for key traits. Quantitative trait loci were identified for flower sex, tuber dry matter, tuber oxidative browning, and flowering intensity. The DNA marker linked to plant sex expression was validated and is being applied in *D. rotundata* breeding. Medium to high throughput phenotyping technologies for anthracnose and yam mosaic virus (YMV) have been developed and validated. These include cost-effective and high-throughput phenotyping tools for YMV (mechanical inoculation under screenhouse conditions and field phenotyping) and yam anthracnose disease (YAD) (DLA and field phenotyping).

Detached leaf assay (DLA), the 'Leaf Doctor', and 'ESTIMATE' applications were standardized and optimized. A Near Infrared Spectroscopy (NIRS) calibration model for the prediction of moisture, ash, protein, crude fiber, and tannin contents in dry tuber samples (flour) of diverse *D. rotundata* breeding lines was also developed.

Establishment of yam database (YamBase)

YamBase and associated statistical tools were developed through a partnership with the Boyce Thompson Institute (BTI) and made available to the yam breeding and research community. The database has enabled breeders to maintain and access their data, breed, and generate new knowledge about the genetic basis of important breeding traits through the use of embedded analysis tools and pipelines. Yam trait ontology (TDv.5.0) composed of 182 variables was finalized and published in a crop ontology and YamBase in February 2017 (http://www.cropontology.org/ontology/CO_343/Yam).

The database contains a yam genome browser, yam ontology tools, phenotyping tools, and social networking features. It has been updated and currently counts over 57,000 accessions with over 1,500 genotypes, seven breeding programs, 214 assayed traits, about 614,000 phenotype scores, and over 500 trials. The database has contributed to harmonizing data and standardizing procedures across breeding programs. It has also enhanced collaboration across partners and supports the yam breeding community of practice. These interactions with partner projects and other programs already have a positive impact.

Yam population and varietal development

Yam target environments were redefined for varietal testing, selection, and breeding (characterized by soil type, land use for yam, weather, prevalent diseases, farmers"' livelihood, and market linkages). Project members now have access to a map (based on GPS-derived coordinates) showing breeding sites and representative testing and selection sites for the target environments. A significant number of improved *D. alata* and *D. rotundata* genotypes were developed and shared among the national partners for further testing and commercial deployment. Also, heterotic groups were defined, new breeding populations were developed, and the existing populations were advanced to the next breeding stages.

Six *D. alata* varieties (4 in Ghana and 2 in Nigeria) and two *D. rotundata* varieties in Benin were released from the products of previous crosses and selections from local collections. Several new varieties have also been nominated and are in the pipeline for release. Products from crosses made by the project are currently in Cycle-1 under the population improvement pipeline, and those with varietal potential are in advanced performance testing (first multi-environment testing) under the clonal development pipeline. The first varietal release from AfricaYam crosses is anticipated in 2024.

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Managing natural resources

Demo plots in Mozambique.

Partners drive use of AKILIMO and uptake of agronomy recommendations

The African Cassava Agronomy Initiative (ACAI) project has developed and deployed AKILIMO in southern Nigeria and Tanzania. AKILIMO is a suite of decision support tools (DSTs, Fig. 1) that provides tailored recommendations to farmers and extension service providers based on digital soil and weather data combined with market and price information, and farmers' cropping objectives and risk attitude. They are available in diverse formats: digital to conventional paper-based.

This innovation has undergone a functional validation, confirming that using the tool effectively results in net revenue increases for at least 75% of users; and an architectural validation, ensuring a positive user experience with easy interpretation of recommendations. AKILIMO's core components include (i) a database holding primary georeferenced data on crop yield responses along with essential covariates; (ii) a suite of models and algorithms to predict yield response and yield gaps to provide tailored advice optimized for maximum return on investment; (iii) a user friendly mobile app (available on Google Play Store) for extension agents; (iv) simplified paper-based tools to provide tailored recommendations directly to farmers; (v) a detailed user guide, training modules and farmer-friendly videos that explain the principles of the recommendations; and (vi) Arifu's chatbot service, providing tailored recommendations directly through simple mobile phones as well as Viamo's 321 service.

Site-specific recommendations are available for fertilizer use (FR), fertilizer blending (FB), cassava weed management and the best planting practices (WM/BPP), intercropping, with maize in Nigeria and sweet potato in Zanzibar (IC), and increased starch content in cassava roots and scheduled planting and harvesting (HS/SP) to ensure a continuous supply of cassava roots to the processing industry.

ACAI is funded by the Bill & Melinda Gates Foundation and is implemented by IITA together with partners from strategic international, regional, and national research institutions, and partners from the private and public sectors, the primary or development partners.

During the inception workshop in 2015, the primary partners identified main issues that if addressed, would help resolve drawbacks that have prevented the cassava sector from achieving its full potential. The requests

Inspecting cassava plants.

Figure 1. Schematic presentation of the AKILIMO framework, stretching from field experimentation to understand agronomy by environment interactions taken to scale through crop and geospatial modeling (left), to a cloud-based prediction engine and database that feed diverse formats (printable guides, smart phone app or USSD, and IVR based services) of the individual decision support tools (center) to the delivery to the farmer, via extension agents or direct as in the case of USSD and IVR-based services (right).

from development partners formed the foundation of the ACAI demand-driven approach used in implementing the project to develop solutions in response to specific needs of partners. The issues identified were grouped into the six use cases: site-specific recommendations for fertilizer use (FR), site-specific fertilizer recommendation for fertilizer blending (FB), six steps to cassava weed management and the best planting practices (BPP), intercropping (IC), increased starch content in the cassava roots (HS, and scheduled planting (SP) to ensure a continuous supply of cassava roots to the processing industry.

Identifying research questions and implementing trials

The critical roles of national agricultural research system (NARS) partners include implementation of field trials to collect the data to calibrate and validate AKILIMO tools, while strategic international research partners contribute to the back-end prediction framework. IITA coordinated the trials implemented by the NARS and primary partners in the field.

The National Root Crops Research Institute (NRCRI) Umudike, and the Federal University of Agriculture in Abeokuta (FUNAAB) in Nigeria, and the Tanzania Agricultural Research Institute (TARI) collaborated in setting up and running thousands of on-farm trials for several use cases generating ground truth data to test the factors influencing production under real conditions in farmers' fields. Soil and plant samples and other field crop management data were collected and used in the prediction engine generating the recommendations. ACAI applied a coupled modeling approach combining crop growth models such as the Light Interception and Utilization model (LINTUL) and the Quantitative Evaluation of the Fertility of Tropical Soils model (QUEFTS) with geospatial statistics and economic optimizer algorithms to generate recommendations optimized for maximum net return on investment for FR, FB, and SH/SP. At the same time, through their extension networks, primary partners mobilized farmers so that most of these research trials could be conducted as on-farm but researcher-managed trials. At the close of 2019, for the cassava intercropping use case, ACAI had run 926 field trials covering 5 states in the south of Nigeria, and 4 ecological and administrative zones in Tanzania.

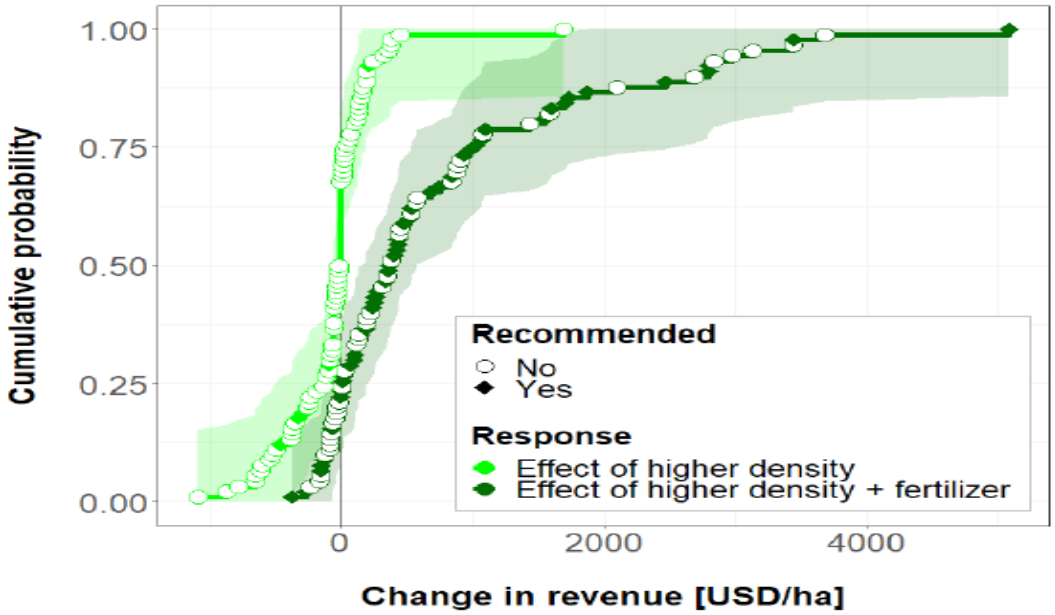

Figure 2. Example of validation results for the cassava-maize intercropping decision support tool in southern Nigeria. In about 75% of the cases the application of fertilizer (fixed rate of 90 N – 20 P – 37 K kg/ha) plus increased maize density (40,000 plants/ha) was more profitable than the control of no fertilizer application and low maize density (20.000 plants/ha) even when this was not the recommended practice. On average, fertilizer application increased revenue by US$1,200/ha, and losses were small. Increasing only maize plant density had little effect.

Validating the prototypes of the DSTs

Successful evaluation (Fig. 2) and approval of innovations is a crucial step towards the completion of the development process. In late 2018 and early 2019, ACAI released the earliest version of the AKILIMO decision support tools that provided recommendations based on

the data collected from the earliest research phase. Primary partners led the validation process with backstopping from NARS and IITA researchers. This way, ACAI and partners conducted validation trials in the 2018/2019 cassava growing season involving 4,084 households in Nigeria and Tanzania.

The project is currently running a second series of AKILIMO validation trials with partners to evaluate the accuracy of the advice provided and further recalibrate the models to address possible discrepancies in the recommendations. Given the highly variable soil and agroecological factors in the regions, ACAI aims to provide recommendations that result in increased returns-on-investment for over 75% of users, relative to standard recommendations or current practice.

The validation trials also provided opportunities to not only technically validate the performance of the prediction engine set in place, but also improve the 'look and feel' and user experience and create ownership and trust in the tools. Positive results from validation trials allowed the project to move forward in the development process and look at suitable formats of packaging and delivering the tools to the end-user. Through a series of participatory workshops, ACAI together with researchers, farmers, extension agents, representatives from project partners and consulting with experts, considered the demographics of AKILIMO end-users, socioeconomic factors, skills, literacy levels, and ease of access to available technologies. ACAI also evaluated possible formats for the tools, including Interactive Voice Response (IVR) system, Unstructured Supplementary Service Data (USSD), a smartphone application, and simple printable guides. All these formats have advantages and disadvantages, and none of the stakeholders expressed concerns about any of these formats, but rather expressly requested that all these be made available for testing and use.

The project's monitoring, evaluation and learning team were instrumental in crafting tools to capture and effect partner and end-user feedback, conduct feedback sessions, and data collection.

Scaling AKILIMO The final versions of the ACAI Decision Support tools were released in July 2019. During the pre-launch function, partners and the ACAI team branded the agronomy advice tools AKILIMO, with a tagline 'We know cassava' as the official trademark identities. AKILIMO is a portmanteau of two Swahili words: *akili* which loosely translates to intelligence or smart and *kilimo* which means agriculture. A logo was designed that combines elements of digital agriculture and a human face to reflect the importance of combining science-based advisory with user-centred design to successfully deliver agronomic recommendations to smallholders.

The focus for ACAI is to expand the reach and influence the adoption of the AKILIMO tools through strategic scaling and dissemination. ACAI has already brought on board extensive and diverse talents with experience in scaling new technologies.

In the same spirit of strong partnerships and sustainability, ACAI seeks to expand its secondary partnership to reach more farmers outside the project while intensifying efforts to influence the adoption of the tools within the primary partnerships. Secondary partners that are linked with existing primary partners have been identified. This helps long-term use of AKILIMO tools within their networks of smallholder farmers.

At the end of the project in 2020, ACAI would have impacted at least 120,000 households in Nigeria and Tanzania.

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Applying good agricultural technology practices for cassava

In many sub-Saharan African (SSA) countries, cassava yields are relatively low owing to the low adoption of good agronomic practices and other technologies for intensification. It is projected that an increase of 7.9 t/ha (70%) would be required to fill the SSA food gap by 2025.

The Cassava Compact Project, financed by the African Development Bank (AfDB) under the framework of the Technologies for African Agricultural Transformation (TAAT), seeks to achieve rapid cassava intensification through raising farm-level productivity, improving the efficiency of processing, and increasing market opportunities. Transforming cassava into an agro-industrialized crop will contribute to achieving significant poverty reduction and economic growth targets across the region.

The scaling innovation TAAT Cassava Compact is promoting the adoption of technology toolkits that involve the simultaneous use of at least three cassava productivity-enhancing technologies such as an improved variety, tillage (plow, harrow, or ridge), optimum spacing, fertilizer application, early planting, effective weed management and mechanization (planting, weeding and harvesting). The toolkits are good agricultural technology practices (GATP) that guarantee the doubling of farm outputs and sustainable intensive cassava production. TAAT Cassava Compact experts introduced the GATP to scaling partners such as researchers, extension personnel of Ministries of Agriculture, and NGOs in the project countries through the establishment of technology outreach farms where the technologies were situated. The partners were provided with theoretical

Technology outreach farms are established in project countries to showcase technologies, including good agricultural practices.

and practical skills on using the different toolkits on GATP, which embrace a different combination of good agronomic practices and mechanization.

About 90 GATP outreach farms combined with seed farms were established in Nigeria, Tanzania, Zambia, and Uganda in 2018-2019. Farmers' associations or groups with memberships ranging from 10 to 35 in the different communities hosted the farms. Criteria such as distance from the main road, drainage, soil type, soil fertility, slope, size of the farm, distance from processing centers (less than 10 km), and scale of the processing centers were used to select farm locations.

Using technology outreach farms for continuous training, scaling partners subsequently cascade the skills to a more significant number of small- and medium-scale cassava growers, youth, agriculture students, and other stakeholders. Local government authorities and policymakers in communities mobilize farmers and other groups for the field activities and training. Scaling experts from research centers, universities, extension departments of the Ministry of Agriculture, and NGOs regularly conducted field days and monitored the outreach farms for performance. The monitoring was done with the host farmers and other farmers from the communities. This activity, like farmer field schools, served as a platform for training additional farmers on improving cassava productivity through improved varieties, weed management, and other technologies such as mechanized planting.

Table 1. Performance of GATP farms in Nigeria.

Location	GATP farms (improved variety, tillage, use of herbicides)		Present-day practice	Yield increase (%)
	Variety introduced	Yield (t/ha; 12 months after planting)	(Yield obtained; t/ha; 12 months after planting)	Yield increase (%)
Iseyin	Provitamin A	23.8	5.8	310.3
Eruwa (site 1)	Provitamin A	20.0	12.2	63.9
Eruwa (site 2)	Provitamin A	19.4	9.8	98.0
Ikenne	White	24.2	8.4	188.1
Ife	White	30.8	14.3	115.4
Abia (site 1)	Provitamin A	24.2	7.2	237.4
Abia (site 2)	White	25.9	20.3	27.7
Average		***24.0***	***11.1***	***148.7***

Scaling experts emphasize the purpose of the technology outreach farms and stress the need for farmers to make observations and assess the effectiveness of the technology packages applied. Hosting farmers conducted appropriate field management actions at each outreach farm guided by supervising scaling experts such as local extension officers and researchers. Farmers' field days also allow lead farmers and extension/scaling partners to explain to other farmers the GATP in the local dialects. In Tanzania, the AKILIMO agronomy toolkits were introduced to farmers. Participating farmers were strategically linked to nearby commercial processing centers to sell additional outputs of farmers adopting the toolkits on their farms.

Outcomes In Nigeria, farmers that adopted the technology were often surprised to get a yield of 24.0 t/ha without hoe-weeding for 12 months compared with 11.1 t/ha typical in farms using labor-intensive present-day practices. The yield increases resulting from the use of GATP represented a 149% rise in productivity compared with the present-day practice (Table 1). In Tanzania, technology adopters obtained an average yield of 38.6 t/ha (quadrant approach) compared with 5.8 t/ha yield in farms where the local

Table 2. Performance of GATP farms in Tanzania.

Location	GATP farms			Present-day practice		Yield increase (%)
	Variety introduced	Yield (Quadrant method; t/ha)	Yield (Farmers' assessment; t/ha)	Variety planted	Yield (Quadrant method; t/ha)	
Kilemera	Kiroba	42.4	22.1	Msaada	7.5	465
	Chereko	38.8	19.2	Msaada	7.5	417
Kibaoni	Kiroba	35.6	13.6	Msaada	7.5	375
Mihekela	Kiroba	48.0	24.5	Nyankagile	5.0	860
Nyamato	Kiroba	36.0	20.0	Nyankagile	3.8	860
Bigwa	Kiroba	30.5	22.5	Nyamkagile	3.8	713
Mtamba	Kiroba	-	12.5	Mzuri kuonja	5.0	
Average		**38.6**	**20.3**		**5.8**	**615**

production practice was used. However, some contact farmers reported 20.3 t/ha for the GATP farms using their estimation method. Hence the productivity increase in Tanzania was between 292.6 and 615% for GATP farms over the traditional production practices. (Table 2).

In Nigeria, staff of agricultural research and extension institutions and other partners, farmers, youth, spray service providers (SSP), and agricultural trainees across sites were trained on calibration techniques, including the use of the IITA herbicide calculator app. In all countries, extensive discussions and demos were held on the safe use of herbicides and how personal protective equipment safety gadgets are worn. Such training in community centers promote the link between farmers and SSPs who are regularly engaged by the farmers to spray their farms on demand.

Partnerships with scaling partners remained vital in deploying the technology. Cassava Compact formed strong technology delivery partnerships made up of over 100 research institutions, local authorities, projects, and programs for technology deployment in the 12 intervention countries. In collaboration with partner institutions, about 50,000 people were trained, and more than 40 new entrepreneurs were engaged in small- to medium-scale enterprises. The concept of developing seed farms together with the GATP farms offered opportunities for farmers to have access to newly bred improved varieties.

Future developments Outreach activities for the diffusion of yield-boosting technologies and innovations in SSA could share the knowledge and skills to farmers, women, and youth, resulting in greater adoption, increased productivity, and additional food outputs. The additional cassava outputs must be processed, and farmers offered access to a market that provides a suitable price. Therefore, a simultaneous introduction of cost-effective processing technologies and investments in processing industries in the rural areas is imperative for sustained adoption of the GATP and its component technologies such as improved varieties and agronomic practices.

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Making healthy crops

Mother and son delivering quality cassava planting material. Cassava Seed Entrepreneur (CSE) Antonia gets IT assistance from her son to register on IITA's SeedTracker app which is being used by the Tanzania Official Seed Certification Institute (TOSCI) to maintain optimal health in cassava planting material being grown for sale.

Delivering healthy cassava planting material in East Africa

Cassava is the second most important staple crop in East and Central Africa after maize, providing food security to hundreds of millions of rural and urban households. Successive virus disease pandemics, however, have resulted in losses worth hundreds of millions of dollars each year, threatening the livelihoods of all those who depend on this source of calories. IITA has partnered with national research programs in the region to identify and promote varieties resistant to cassava mosaic virus (CMV), but this was curtailed by viruses causing cassava brown streak disease (CBSD), to which these varieties did not have resistance.

Recently, conventional and marker-assisted breeding have been used to develop several varieties with good levels of resistance to both viral diseases. But some obvious and perennial challenges remain. Firstly, cassava is a clonally propagated crop with a low multiplication ratio, which means that it can take many years before a new variety becomes readily accessible to farmers.

Secondly, it is difficult to maintain the health of planting material over multiple cropping cycles in heavily infected production zones. The first challenge is being overcome using improved methods for rapid propagation. Systems for the screenhouse-based multiplication of virus-tested cassava plantlets derived from tissue culture have been established in several countries in East Africa. Most recently, the semi-autotrophic

Rapid screenhouse multiplication of disease-free planting material of CBSD and CMD-resistant variety – Mkuranga 1 – produced at the pre-basic level by the Tanzania Agricultural Research Institute (TARI).

hydroponics (SAH) technology has been introduced to eastern Democratic Republic of Congo (DRC), Rwanda, and Tanzania. This allows for the multiplication of more than 200,000 SAH plantlets in a year from starting material of just 100 tissue culture plants, with SAH plantlets planted directly into an irrigated field. The greater challenge facing cassava seed systems in East Africa is protecting plant health from early generation seed up to the level of seed production within rural farming communities.

Producing healthy cassava planting material

Pathogens causing diseases are easily spread from one generation of cassava plants to the next, as farmers use cuttings from parent plants to establish a new crop. This problem is particularly acute in East Africa, where the viruses causing CMD and CBSD are prevalent. The first step in overcoming this problem is to obtain source material from tissue culture, which ensures virus-free plantlets .

The first efforts to establish 'clean' fields of cassava planting material of improved varieties were undertaken in 2011 at Kunga, Tanga Region, north-eastern Tanzania. Cuttings from screenhouse-hardened virus-indexed tissue culture plantlets of variety Kiroba were obtained from the Tanzania Agricultural Research Institute's (TARI) Kibaha research station. The Kunga site was isolated from other cassava fields and had very low vector and virus disease pressure due to its location in the Usambara Mountains. Unfortunately, the site proved too cool for vigorous cassava growth, and in 2012 the materials were moved to an isolated lower altitude farm at Mwele, near Tanga. Over a period of several seasons, and by applying measures to ensure that whiteflies were controlled, and virus-infected plants were removed, it was demonstrated that it was possible to maintain cassava planting material that is virus-free.

Developing guidelines for producing clean cassava 'seed'

From 2012 onwards, IITA worked closely with the Tanzania Official Seed Certification Institute (TOSCI) to draft, validate, and publish guidelines for certifying cassava 'seed' at pre-basic, basic, and certified levels. These were formally gazetted and appended to the Seed Act in January 2017. Guidelines for quality declared seed (QDS), produced at community level, were to be added iater. Capacity of TOSCI seed inspectors to implement the new quality assurance system was strengthened through training workshops. Furthermore, the capability of TOSCI to conduct the required virus tests for pre-basic cassava planting material was enhanced by designing testing protocols, training lab technicians, and providing key pieces of lab equipment to TOSCI's HQ in Morogoro. The sustainability of this system was improved through TOSCI's revision of its fee structure for inspections and lab testing, which was incorporated into guidelines appended to the Seed Act in 2017.

Building a modern and sustainable seed delivery system

A system for certifying the quality of any seed can only exist within a sustainable and commercial seed system. To achieve this, IITA partnered with TARI, TOSCI, and the Mennonite Economic Development Associates (MEDA) in running a Bill & Melinda Gates Foundation-funded project called Building an Economically-Sustainable Seed System in Tanzania for Cassava (BEST-Cassava). One of the project's key achievements has been the establishment of a country-wide network of >400 cassava seed entrepreneurs (CSEs). These seed producers operate at all levels of the system, from pre-basic to QDS, and have been trained in 'clean' seed production, business models, and marketing by the MEDA team.

Efficiency and responsiveness of the seed certification system delivered by TOSCI have been enhanced through the incorporation of IITA's SeedTracker e-certification platform. TOSCI officers are now routinely using this system for registration

and certification of CSEs. CSEs themselves are also benefiting from the opportunity to market their seed more widely, as anyone accessing the www.seedtracker.org website can see the locations of all registered cassava seed producers in Tanzania. Finally, TOSCI has led the training of extension officers who will take on the role of Authorized Seed Inspectors (ASIs). This is greatly extending the coverage of the cassava seed quality assurance system in Tanzania and making it simpler and cheaper for QDS producers to get certified and thereby grow their businesses.

Scaling modernized cassava seed systems

The success in meeting the high-quality seed needs of tens of thousands of cassava growers in Tanzania has encouraged the implementation of similar initiatives in Burundi, Rwanda, and eastern DRC. As new opportunities arise for the production and marketing of both fresh and processed cassava products, the modernized quality-assured seed systems being developed are set to make a major contribution to the transformation of African agriculture.

The first high altitude 'clean seed' multiplication site for cassava in Tanzania at Kunga in the East Usambara Mountains.

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Putting the power of pest and disease diagnosis in farmers' hands

Latifa Mrisho demonstrating the use of PlantVillageNuru to a farmer in Mkuranga, Tanzania.

Twenty to 40% of global crop production is lost to pest and disease damage, costing more than US$200 billion every year. Consequently, one of the top priorities of agricultural researchers worldwide is finding ways to identify, monitor, and control crop pests and diseases.

The first step in this process is identification. People have been able to recognize some of the most apparent pests and diseases since the earliest days of farming. Pestilence from locusts is described in many of the ancient religious texts. Causal agents of diseases, however, by their microscopic nature, have only been accurately distinguished in more recent times. The development of microscopy and biochemical assays delivered large-scale improvements in the accuracy of pathogen identification, and from the late 20th century, the DNA revolution allowed for the development of diagnostic tests that could identify any organism. Nevertheless, most farmers and farm workers continue to use visual symptoms or appearance to identify crop pests and diseases, mainly since accurate diagnostics are either too expensive for farmers or inaccessible.

Mobile phone technology has spread rapidly across the globe over the last 30 years, and current expansion is most rapid of all in Africa. The coupling of phones with the Internet and high-spec cameras has also now offered unique new opportunities for these portable devices to be used as mobile pest/disease diagnostic units.

Delivering a diagnostic tool using mobile phone technology

In 2016, IITA began working with the PlantVillage team of David Hughes, at Pennsylvania State University, USA, on innovative technologies for diagnosing cassava pests and diseases. It quickly became clear that the best bet for a diagnostic that could support millions of farmers directly was a mobile phone-based system that used artificial intelligence (AI).

Thousands of images were collected of the most crucial pest/disease symptom types, including cassava mosaic disease, cassava brown streak disease, cassava green mite damage as well as symptom-free healthy leaves. The images were then annotated by IITA pest/disease experts to indicate the leaf portions showing characteristic symptoms. The Penn State team then applied machine learning techniques to train computers to recognize each of the symptom types.

The final step was to build these AI models into a smartphone app, which would prompt the user to point the phone's camera at cassava leaves and then deliver an instant diagnosis of the disease or pest damage. The app was called PlantVillageNuru, with 'Nuru' being the Swahili word for light.

Users of PlantVillageNuru could download the app when online, but a key quality of the new app was that once installed, it could be used offline, allowing farmers in their fields anywhere to make diagnoses. PlantVillageNuru was made available for free download on Google's PlayStore in June 2018. In addition to providing instant pest/disease diagnosis, the app also provides guidance on control, and helps farmers to source healthy planting material of improved varieties by linking users to the IITA SeedTracker app.

Humans vs AI in cassava disease detection: who wins?

As PlantVillageNuru was made available to farmers worldwide, it was important to compare its performance with likely users and to use this comparison to measure improvements in the app over time. To achieve this, a set of 170 images of cassava leaves was assembled, with different pest/disease damage symptoms or no symptoms at all. A team of experts confirmed the diagnoses of each of the images, and these were assembled

Nuru detection of cassava mosaic disease (CMD).

Nuru detection of cassava brown streak disease (CBSD).

into a PowerPoint presentation referred to as the Cassava Symptom Recognition Assessment Tool (CaSRAT). IITA researchers – Latifa Mrisho and Neema Mbilinyi – then set out to use the tool to see how well Nuru compared in its diagnoses to different groups of people, including researchers, extensionists, and farmers in coastal Tanzania, either trained or untrained.

They found that trained researchers had the highest levels of correct diagnosis (85%), followed by trained extensionists (49%), while groups with the lowest scores were untrained farmers (16%) and untrained researchers (21%). Although the accuracy of Nuru was only 40% in 2018, subsequent upgrades have increased this to 65%, which is higher than all other groups apart from the trained researchers. Further work by Latifa and colleagues in western Kenya has also shown that using PlantVillageNuru over a period of just one week can lead to improvements in pest/disease recognition by farmers and extensionists, highlighting the value of the app as a training tool.

Seed health experts from Burundi and Rwanda testing out TOSCI's cassava certification protocol.

Scaling

PlantVillageNuru has already been used by farmers from across Africa to generate more than 15,000 reports. Fortunately, millions of cassava farmers have access to smartphones, so there is huge potential for further scaling. Penn State and IITA are therefore, partnering with a range of other initiatives to drive this process forward. A BigData Platform, CGIAR-Inspire scaling grant, is supporting further training and awareness raising in five countries of East and Central Africa, and PlantVillage is working with the WAVE and Technologies for African Agricultural Transformation (TAAT) projects to scale Nuru use in 11 countries of West and Central Africa. A partnership with CGIAR's Roots, Tubers, and Bananas (RTB) program is also facilitating the application of the approach to other RTB crops, such as potato and sweet potato. These developments give great encouragement to the team working on Nuru that millions of farmers will soon have the power of pest and disease diagnostics in their hands.

Latifa recalls from her experience in introducing the app, "This tool offered the means to tackle challenges that farmers face in growing crops and the opportunity to learn how to improve productivity. Having access to information they need to improve their productivity gives farmers and agricultural officers power and control over their livelihoods." It is clear, therefore, that this smart app is set to play a vitally important role in transforming African agriculture in the coming years.

IITA's Neema Mbilinyi and Mathias Ndalahwa demonstrate PlantVillageNuru during a farmers' open day in Tanzania.

Authors: James Legg, Juma Yabeja, IITA-Tanzania; Lava Kumar, IITA-Nigeria (Ibadan); Regina Kapinga, Edward Kanju, IITA-Uganda; Silver Tumwegamire, IITA-Rwanda; Rudolph Shirima, Gloria Ceasar, Hekima Mtoji, IITA-Tanzania; Busayo Ogunya, (Ibadan); George Swella, Tanzania Official Seed Certification Institute; Kiddo Mtunda, Heneriko Kulembeka, Tanzania Agricultural Research Institute; Stephen Magige, David Eagle, Mennonite Economic Development Associates.

Improved soybean varieties increase farmers' incomes

Soybean production is an essential component of the maize-based smallholder cropping systems in Malawi. It increases soil fertility by fixing nitrogen in the soil, leading to improved crop yields. Furthermore, soybean is fast becoming a significant source of cash income as well as an essential contributor to food and nutrition security. Soybean production is also less risky as it is more tolerant of pests and diseases and has good grain storage quality compared to other cereals. In view of these benefits, soybean has been identified and targeted as a strategic crop to diversify the cropping system in Malawi that is heavily reliant on maize and tobacco.

Despite the crucial role of soybean in maize-based farming systems, current soybean yields on smallholder farmers' fields in Malawi are low. On average, farmers harvest 0.98 t/ha of soybean, which is below the African average of 1.2 t/ha and the global average of 2.7 t /ha. The low productivity level of soybean is partly due to low adoption of improved varieties, use of poor quality seed, and inefficient and traditional production technologies. To increase soybean yields in Malawi, national and international research and extension efforts have focused on developing and

Researcher checking the growth of soybean plants in the field.

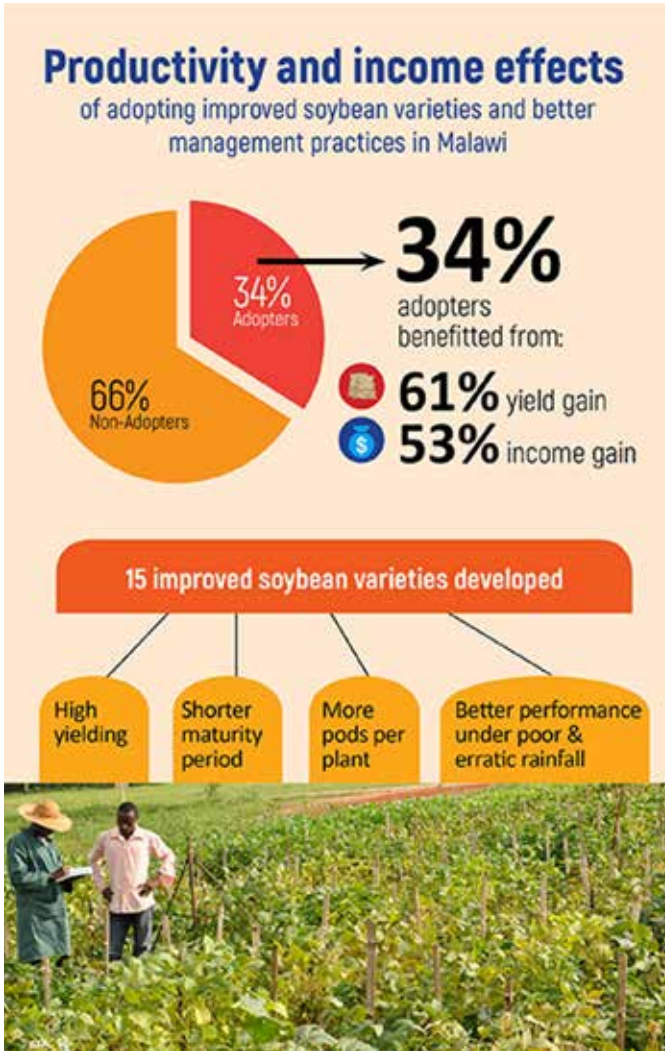
disseminating improved soybean varieties and complementary agronomic practices. For instance, between 1985 and 2011, about 15 improved soybean varieties with multiple stress tolerance and high yield potential were released and disseminated throughout the country along with other complementary agronomic practices such as optimum planting dates, optimum plant population, row spacing, and use of inoculants and phosphorus fertilizers. These agronomic practices, when combined with improved varieties, can increase grain yields by more than two-fold.

These new varieties are high yielding, have a shorter maturity period and more pods per plant, and perform better under poor and erratic rainfall. Since 2010, these new varieties and agronomic practices such as the use of inoculant, accurate planting dates, close row spacing that can smother weeds, and correct and timely application of phosphorus fertilizers have been widely popularized and disseminated through large-scale, science-based "research-in-development" projects such as "Putting Nitrogen Fixation to Work for Smallholder Farmers growing legume crops in Africa (N2Africa)" funded by the Bill & Melinda Gates Foundation and "Malawi Improved Seed System and Technology (MISST)" funded by USAID Feed the Future initiative.

Those projects were led by IITA, Government of Malawi, NGOs, and community-based enterprises. Through these projects, over 80,000 smallholder farmers in more than 10 districts of the country have gained access to good quality seed of improved soybean varieties along with complementary training on better agronomic practices. Such agronomic training were supported by on-farm demonstrations, field days, and seed fairs.

Despite the promotion and dissemination of improved varieties and agronomic practices, there is a lack of empirical evidence on the adoption and impacts of improved soybean varieties and agronomic practices. A study led by IITA was conducted to assess the uptake and effects of new soybean varieties and agronomic practices in Malawi.

About 1,237 farmers on 1,465 plots were studied, with over a third of sampled farmers adopting the new varieties and agronomic practices, which resulted in 61% yield gain and 53% income gain. The study results, which have been published in a peer-reviewed journal article titled "The productivity and income effects of the adoption of improved soybean varieties and agronomic practices in Malawi" show that adopters are younger, more educated, and have larger cultivated land. Adopters also tend to be members of a farmers' organization, participate in seed markets, and have access to extension services. This implies that adoption is greatly influenced by access to information.



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Source: https://www.sciencedirect.com/science/article/abs/pii/S0305750X19302797

Clean cassava seed systems in Burundi, DR Congo, and Rwanda

Burundi, DR Congo (DRC), and Rwanda form part of the Great Lakes region and have known disrupted food production systems, partly caused by recent civil strife. Cassava is a popular crop in the region but on-farm productivity is low (at about 8 t/ha) due to several factors, including 1 predominant use of local varieties that are low yielding and susceptible to pests and diseases; 2 disease outbreaks, especially viral diseases (cassava mosaic disease, CMD; cassava brown streak disease, CBSD) and pathogen disease (cassava root necrosis disease, CRND); and 3 reliance on informal seed systems.

Farmer participate in variety selection, Moso Burundi.

Indeed, these three countries constitute a frontline for CBSD's westward spread (originating in East Africa) to Central and, ultimately West Africa. The region is, therefore, an important area of action for IITA to stop the further spread of CBSD. IITA and partners have scaled the use of improved resistance and commercial clean seed systems as dual complementary strategies to combat these viral diseases and restore cassava productivity.

The goal of the project is to contribute to food security and improved livelihoods in the three target countries. The overall objective is to build sustainable clean seed delivery systems that help farmers access improved high-yielding and resistant varieties and hence control the spread and impacts of these deadly viral diseases.

IITA has partnered with a diverse set of stakeholders along the seed value chain to lay the foundation for functional, clean seed delivery systems in the three countries (Table 1). IITA, as a partner, continues to offer leadership, technological options for adaptation, advocate for policy change, and build personnel and physical capacities of key stakeholders.

Table 1. IITA key partners for project implementation in the three countries.

Partner category	Institutions/Organizations	Roles and responsibilities
National agricultural research programs	• Rwanda Agricultural and Animal Resource Development Board (RAB), Rwanda • Institut des Sciences Agronomiques du Burundi (ISABU), Burundi • Institut National pour l'Etude et la Recherche Agronomiques (INERA), DR Congo	• Provide and register improved varieties • Produce quality pre-basic seeds • Train cassava seed value chain actors
Seed regulation agencies	• RAB seed systems division, Rwanda • Office National de Contrôle et de Certification de Semences (ONCCS), Burundi • Service National de Semence (SENASEM), DR Congo	• Undertake seed inspection and certification • Oversee variety registration or homologation
Policymakers	• Rwanda Standards Board (RSB) • National Seed Advisory Committee	• Develop or review cassava seed policy
Non-government organizations	• One Acre Fund • INGABO syndicate • Rwanda Youth in Agribusiness Forum (RYAF) • RESEAU BURUNDI 2000+ (RBU2000+) • Centre d'Appui au Développement Intégral /Mbankana (CADIM), DR Congo	• Mobilize seed multipliers and farmers • Facilitate linkages of the actors
Seed multipliers networks	• Rwanda Seed Multipliers Organization (RWSMO) • Collectif des Producteurs des Semences du Burundi (COPROSEBU) • Association des Producteurs et Transformateurs du Manioc du Congo (APTM)	• Multiply quality seed • Coordinate seed multiplication and marketing

Project achievements

Identification of improved resistant varieties Having the right varieties is vital for any seed system. Studies show a general lack of improved resistant varieties by farmers in all the three countries, although the situation is a little better in Rwanda. Elite clones have been introduced and tested in key locations. In Rwanda and Burundi, varieties that include NASE14, NAROCASS1, Mkumba, F10-30-R2, and KBH2002/026 as well as Ilona and Lumonu in DRC have been earmarked for release and are already being multiplied. In Rwanda, many farmers have adopted NASE14 and is popular for cassava flour production. More clones with CBSD/CMD dual resistance, including yellow fleshed, are in the breeding pipeline and will soon be ready.

Tissue culture capacities for seed systems IITA has spearheaded continuous efforts to build both human and infrastructure capacities in each of the target countries. For example, technicians from the three countries were trained in Uganda (National Agricultural Research Organisation, NARO) on tissue culture (TC) techniques and post-flask management. Also, climate chamber, biosafety cabins, and water purification systems were installed in Rwanda and Burundi. In DRC, TC capacities are part of the President Olusegun Obasanjo Research Center in Kalambo.

Pre-basic seed production and management Screenhouse (SH)-based macropropagation and semi-autotrophic hydroponics (SAH) micropropagation techniques are the two low-cost and easy to-adapt approaches being promoted by IITA for pre-basic seed multiplication and management. SAH capacities have been built and are operational in Rwanda and DRC where to date (1st cycle) up to 4,817 and 365,000, respectively, have been multiplied. These facilities are managed by national research partners in Rwanda and Burundi and by IITA in DRC.

Decentralized commercial seed multipliers Commercial seed multipliers are critical for the sustainable supply of quality planting materials. In the three countries, efforts are ongoing to orient the existing cassava seed multipliers into the formal system while enhancing their business skills. This process is still in the initial stages and four seed centers have been trained and supported to set up their own seed crop that is registered by the regulatory agencies.

Seed distribution and marketing Seeds have been distributed to farmers, benefiting 12,500 households across DRC. An estimated 1,921 ha of seed will be ready for distribution next season in DRC. In Rwanda, millions of NASE and NAROCASS1 planting materials have been distributed by the government as an emergency response. In both Rwanda and Burundi, the clean seed system started by the CBSD Control Project is yet to reach on-farm distribution. Four pilot commercial basic seed centers (to be expanded to 10 centers) have been established in each of the two countries and will sell their first crop of inspected seed by end-2020. In Burundi, it is anticipated that the availability of this planting material may catalyze lifting of the more than 5-year provincial quarantine for cassava.

Seed policy formulation Cassava seed standards that conform to the local pest and disease realities have been developed and are now ready for use.

Capacities for seed quality control Cassava seed quality control is minimal, but IITA has engaged the relevant agencies for this purpose. In Rwanda and Burundi, the regulatory agencies have received training and equipment to facilitate their work, while in DRC, the training has been scheduled. The regulators visited a sister agency in Tanzania that is already advanced in implementing cassava seed inspection and certification in a commercialized setting.

Future research

In the future, the project will focus on building coordinated seed multiplier networks linking quality early generation seed and certified seed multiplication and distribution systems. The introduction and use of the IITA-developed seed tracker app may be essential for this purpose. There is also a need to firm up the cassava seed certification systems and capacities, research into viable business models at different stages of the seed value chain, as well as research on cost-reducing cassava seed production systems or practices.

To be able to meet these goals and objectives, IITA is implementing diverse but well-coordinated and synergistic projects such as CBSD Control Project in Rwanda and Burundi funded by IFAD; Cassava Agribusiness Seed Systems (CASS) in Rwanda and Burundi funded by the Dutch Government; Programme Intégré de Croissance Agricole dans le Grands Lacs (PICAGL) financed by the World Bank; Actions to control CBSD in DRC funded by USAID; and Technologies for African Agricultural Transformation Program (TAAT) funded by the African Development Bank (AfDB). The projects are also supported by other IITA projects (e.g., GoSeed, 5CP, BEST Cassava, and BASICS).

The governments of the three target countries have contributed personnel and physical research infrastructure through partner national research institutions, i.e., ISABU, INERA, and RAB.

IITA Virologist and Head of Germplasm Health Unit (center) visiting the tissue culture lab producing semi-autotropic hydroponics (SAH) cassava plants in The President Olusegun Obasanjo Research Center, IITA, Kalambo, DR Congo.

Authors: Tumwegamire Silver, IITA-Rwanda; Sikirou Mouritala, IITA-DR Congo (Kinshasa); IITA-DR Congo (Kalambo); Adetoro Najimu, IITA-Nigeria (Ibadan); Akande Adebowale, IITA-DR Congo (Kalambo); Bamba Zoumana, IITA-DR Congo (Kinshasa); and Vanlauwe Bernard, (Nairobi, Central Africa).

Improving livelihoods

A young woman undergoes training to learn how to operate a machine on the farm.

Youth influencing youth policy through research

African development partners are committed to supporting youth entrepreneurship programs, as evidenced by the implementation of the AfDB-funded ENABLE Youth program that operates in several African countries led by IITA.

With financial support from the International Fund for Agricultural Development (IFAD), IITA launched a three-year project (2018-2020) titled "Enhancing Capacity to Apply Research Evidence (CARE) in policy for youth engagement in agribusiness and rural economic activities in Africa," also known as '*youth researching youth*.' A core tenet of the project is the recognition that young scholars have a better grasp of their peers' real needs, aspirations, challenges, and perspectives on agriculture. As such, the project aims to enhance the capacity of young African scholars to increase the availability, exchange, dissemination, and use of agribusiness research evidence in policymaking and program implementation.

Under this program, IITA/CARE awarded research fellowships to 50 young scholars (MSc/PhD and entry-level professionals) from 10 countries in two annual competitive research fellowship schemes in 2018 and 2019 (Fig. 1). Female research fellows account for one-third (32%) of the total number of awardees over the two years, with female PhD, MSc students and entry-level professionals accounting for 10%, 16%, and 6%, respectively.

Research capacity development

The training component of the fellowship program enabled the research fellows to acquire skills and knowledge in research design, data collection, data analysis, and scientific and policy brief writing. They designed and undertook their research under the supervision of IITA social scientists and fulfilled the partial requirements of their MSc or PhD programs.

"The IITA/CARE project was beneficial for the successful completion of my doctoral research," Akinyi Sassi, a PhD research fellow affiliated with the Open University of Tanzania, said. "The training on research methods, scientific and policy brief writing improved my knowledge, especially the training on policy brief writing, as it was my first time receiving training on the subject. I am thrilled and thankful to be among the recipients of the 2018 IITA fellowship," she added.

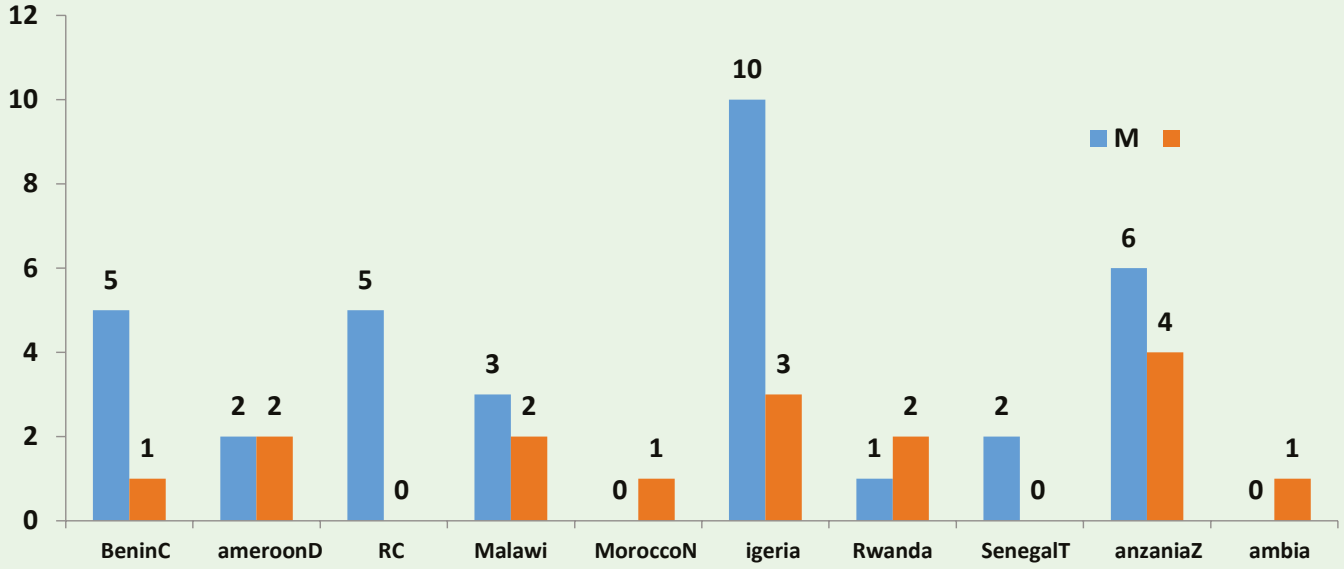


Figure 1. Number of female and male research fellowship awardees of the IFAD-funded IITA/CARE initiative by country, 2018–19.

A similar view was expressed by Adewale Ogunmodede, an MSc research fellow affiliated with the University of Ibadan, Nigeria. *"The training has helped sharpen and develop my research and writing skills," he said. "Upon completion of the fellowship at IITA, I secured a position as a researcher with an international research institute,"* he added.

Communication of research findings

The fellows communicated their research findings through paper presentations, journal articles, and policy briefs. In September 2019, four young African scholars from Benin, Cameron, Malawi, and Tanzania presented their research findings at a symposium organized by IITA as part of the 6th African Conference of Agricultural Economists (ACAE) in Abuja, Nigeria. The symposium provided an opportunity for these young scholars to communicate their research findings to a broader and professional audience.

Speaking at the symposium, Cynthia Mkong, who conducted her research under the supervision of Senior Agricultural Economist Tahirou Abdoulaye, noted that in Cameroon, a pre-university agricultural background is a significant factor driving the decision of undergraduate students to major in agriculture. *"Undergraduate students who had prior farming experience and excellent marks in high school leaving examinations are less likely to choose agriculture as their major field of study," she said. "Unless the negative perception towards agriculture is addressed, the country will miss out on qualified agricultural graduates who can contribute to agricultural transformation,"* she added.

2018 IITA/ CARE research fellows at research methodology training in Ibadan, Nigeria in July 2018.

To reach the scientific community, three research fellows (two females and one male) published their research findings in academic journals indexed in the Web of Science and SCOPUS. Adewale Ogunmodede from Nigeria and Adella Ng'atigwa from Tanzania, both of whom conducted their research under the supervision of R4D Director for East Africa Victor Manyong, respectively, published their research findings in *Sustainability*[1] and *Agriculture*[2].

Dadirai Mkombe, from Malawi, who did her research under the supervision of Monitoring and Evaluation Officer Adane Tufa, published her results in *Development Southern Africa*[3]. Ogunmodede demonstrated that the N-Power Agro-program of Nigeria has a significant positive impact on employment and income generation through participation in agribusiness, saying that similar programs are out in other African countries. Ng'atigwa investigated the extent and determinants of youth participation in the horticulture business in the Njombe Region of Tanzania, suggesting the need for increased youth capacity development in postharvest management and agro-processing. Mkombe demonstrated that foreign direct investment (FDI) has no significant effect on youth unemployment in the Southern African Development Community. The results suggest that governments in the region need to ensure that FDI inflows be channeled towards sectors that have high labor absorption capacity.

To reach policymakers, the fellows have published 17 policy briefs available on the CARE webpage on the IITA website. They have also developed two other knowledge products (technical report and manuscripts) each, submitting at least one manuscript to an academic journal for publication.

Future research or development

CARE is designed to empower young African scholars with research capacity and strengthen the science-policy interface (use of research evidence in the policy) for youth engagement in agribusiness and other productive employment opportunities. As such, the success of the project is defined as the increase in the research fellows' capacity to plan, research, and generate findings that can contribute to policy dialogue in Africa. The increase in research capacity is measured by the quantity and quality of the knowledge products, which are expected to contribute to changing youth mindsets of general indifference towards agriculture and other rural employment opportunities. While the project is on track to achieve its expected outputs, additional efforts are needed to improve the quality of research, expedite the publication of the knowledge products, and maximize the uptake of youth research findings by policymakers, development partners, and other relevant stakeholders.

Adewale Ogunmodede receiving a certificate of completion of the policy brief and scientific writing training at IITA Ibadan from Victor Manyong, R4D Director, East Africa and theme leader, social science and agribusiness.

Authors: Shiferaw Feleke, IITA-Tanzania (Dar es Salaam); Mastewal Yami, Ethiopia; Tahirou Abdoulaye, IITA-Niger/Mali; Arega D. Alene, Adane Tufa, IITA-Malawi; Tesfamicheal Wossen, IITA-Kenya; Zoumana Bamba, IITA-DR Congo (Kinshasa); and Victor Manyong, IITA-Tanzania (Dar es Salaam).

Improving efficiency in social science research using ICT tools

Efficiency in any operation is critical for the evaluation of outputs. In research, in general, and socioeconomic research in particular, the quality of data and the speed at which they are processed largely determine the efficiency of a program. It is not unusual to get the baseline report of a project in the middle of its execution or even towards its end. This is not necessarily a failure of project managers but part of the constraints they face due to the data collection tools available to them. Besides the project timeline, data collection tools play an essential role in effectively executing project activities.

A researcher using a digital device to collect data in the field.

Traditionally, data was obtained using pen-and-aper personal interviewing (PAPI) tools. PAPI methods often require almost no programming skills to implement the survey and give project managers a great deal of flexibility in implementing the survey design, particularly for qualitative surveys that require open-ended or qualitative responses in local languages. However, data collection using PAPI tools is also prone to survey errors. All of these investigations, triangulations, and corrections take time and cause delays, particularly to produce baseline indicators, monitor, and track changes in performance indicators efficiently as well as in delivering project outputs.

As part of bigger efforts to improve research quality and efficiency, IITA social scientists have switched from the traditional PAPI method of data collection to computer-assisted personal Interviewing (CAPI) method that relies on electronic gadgets. The CAPI method has several features that make it different from PAPI.

i. Its ability to produce an almost immediate electronic dataset that is ready for review and analysis. The elimination of the data entry stage significantly reduces the turn-around time to produce a dataset upon completion of interviews.

ii. The automated routing structure that is built into the questionnaire. Questions

can be disabled if deemed irrelevant by previous responses or if not intended for certain types of respondents.

iii. The ability to configure consistency checks into the software. These checks can flag inconsistencies, missing data, or unlikely values.

iv. The ability of CAPI interviews to include attachments, such as images or audio recordings.

CAPI requires programming skills and to transfer questionnaire designs into an electronic format that are not very difficult to acquire. The use of CAPI also requires the purchase of gadgets with costs that have been decreasing over time. Overall, the benefits of using CAPI, in terms of better data quality, availability, and survey costs, outweigh the investment costs to acquire the technology, particularly for complex large-scale surveys.

Switching from PAPI to CAPI takes care of the data quality and efficiency challenges of PAPI. CAPI helps to ensure high-quality data by facilitating logic checks and real-time validations during the interview. In addition, by programming consistency checks for values, CAPI tools can reduce the number of implausible values for some variables of interest such as income, age, land size, etc. (Fig. 1). For instance, if the age of respondents is expected to fall within a certain range (e.g.,18-80 years), automatic consistency checks can be programmed into CAPI tools to ensure that the age of respondents is limited between the lower and upper bound values (Fig. 2).

Similarly, to ensure data quality, logic checks or validations can also be directly programmed into CAPI tools. For instance, if a farmer grows three different cassava varieties on a given plot, it is logical to assume that the sum of the proportion of area allocated to each type adds up to 100 percent. This could be automatically programmed for validation during the survey.

CAPI tools also allow project leaders and survey supervisors to monitor the activities of enumerators by capturing the interview start and end times as well as GPS locations of respondents. In addition, since data are collected in electronic format, it can be uploaded in real time to a central server for consistency and data quality checks by supervisors, making the data readily available for analysis right after data collection is completed. This dramatically reduces the time required to transfer data from the questionnaire to electronic format and, by extension, delays in data availability. CAPI tools also minimize data loss due to missing questionnaires or poor legibility.

Studies using CAPI method

The IITA socioeconomics team has successfully collected data using CAPI tools in projects such as Cassava Monitoring Survey (CMS), Stress Tolerant Maize for Africa (STMA) survey, and Nigeria Baseline and Varietal Monitoring Survey (NIBAS). Through CAPI tools, the team has been able to capture survey information in near real time, undertake data quality checks on a daily basis, and monitor enumerator tasks. Prior to each survey, all enumerators were trained on how to use tablets.

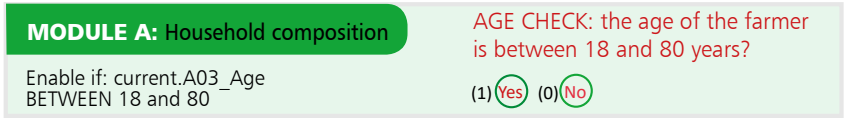


Figure 1. Consistency check for implausible values.

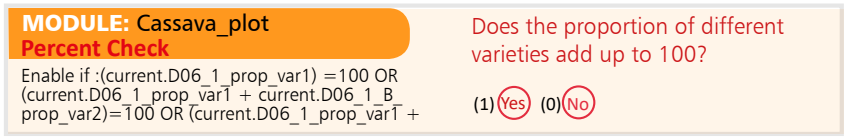


Figure 2. Logical check to ensure data quality.

To ensure data quality, during the enumerator training and questionnaire pretest stages, the survey supervisors and project programming teams undertook quality checks for programming and translation errors. In addition, the supervisors often provided real-time guidance to all enumerators during the data collection. These large-scale surveys by IITA were successfully conducted using the Surveybe software (https://surveybe.com). Other popular CAPI tools include CSPro (https://www.census.gov/population/international/software/cspro/) and Open Data Kit (ODK) (https://opendatakit.org).

Authors: Tahirou Abdoulaye, IITA-Niger/Mali; Arega Alene, IITA-Malawi; Tesfamicheal Wossen, IITA-Kenya; and Victor Manyong, IITA-Tanzania (Dar es Salaam).

Enhancing uptake of technologies through youth-led agribusiness Cameroon

For over 30 years, IITA has significantly invested in research for development in Cameroon, particularly on seed systems, integrated pest management, integrated soil fertility management, and nutrition. The scaling out technologies and innovations developed by IITA and other development partners have been limited, however, due to weak extension services. Since the creation of the Partnership for Delivery directorate at IITA, the trend is changing drastically through programs like Technologies for African Agricultural Transformation (TAAT) and ENABLE Youth.

Aspiring agripreneurs of YABIC Bonaberi listening to an overview of business opportunities of the agricultural value chains development project.

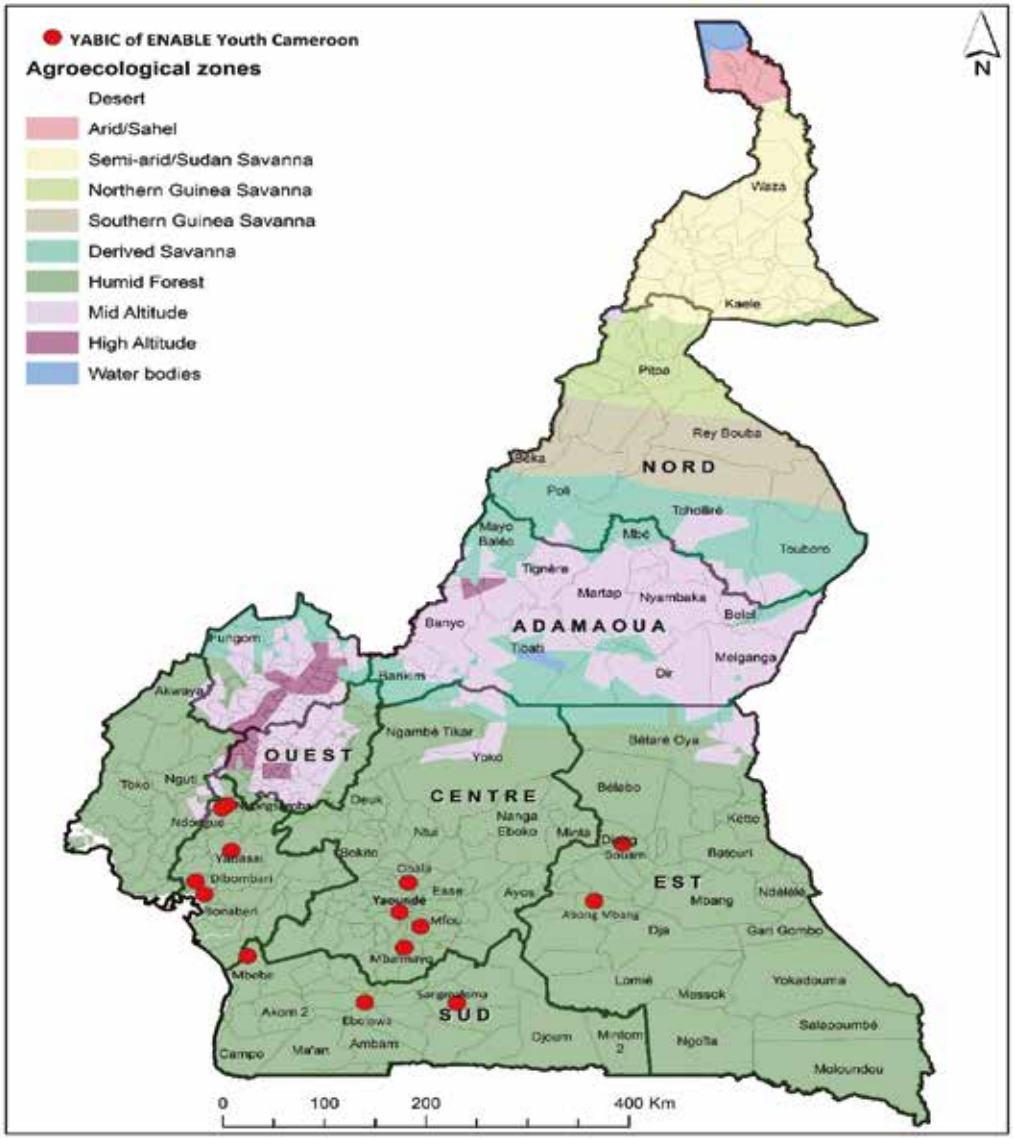
Since May 2018, IITA has extended its ENABLE Youth Program initiated in 2012 through the ENABLE Youth Cameroon (EYC) initiative, which is implemented through the Ministry of Agriculture and Rural Development (MINADER). It is part of the Agricultural Value Chain Development Project of the Ministry, which is financed by an African Development Bank loan. EYC focuses on identifying business opportunities along various agricultural value chains to create business and employment opportunities for young men and women.

Currently, 512 aspiring agripreneurs have been enrolled, of a total target of 1,536 within three years, of whom 45% should be women. After the business incubation, the goal is to create at least 600 agribusinesses and 6,000 jobs for youth. The experiential learning is centered on value chain analysis, identification of business opportunities, pilot enterprises, internship, networking, awareness creation, and development of bankable business plans, loan application, and finally, the creation of the agribusiness of interest.

Initially planned for implementation in five regions of Cameroon (Center, South, East, Littoral, and South West), the Youth Agri-Business Incubation Centers (YABIC) have already started in the first four. Currently, the design of 48 pilot enterprises in the categories of modern farming (24), value addition (12), and marketing (12) has been completed, while 378 individual and associate business plans on modern farming, value addition, and marketing are quite advanced, pending loan application.

To enhance the know-how of aspiring agripreneurs, they undertook professional visits to gather information on potential service providers, existing agribusinesses for internship opportunities, gaps in the marketplace based on consumers' needs, as well as communities and youth outreach to build networks of future partners.

Networking has started yielding results. Selected aspiring agripreneurs have



Locations of the 14 Youth Agri-Business Incubation Centers of ENABLE Youth Cameroon.

participated in initiatives such as the United Nations Development Program (UNDP) Challenge 2019 for Innovation in Youth Entrepreneurship in Cameroon, Tony Elumelu Foundation, AYADA laboratory, and Youth Connekt Africa.

Between March and July 2019, four EYC Agripreneurs were among the 1,300 young entrepreneurs who participated in the UNDP Cameroon Youth Entrepreneurship Innovation Challenge 2019. All four were shortlisted to participate in the bootcamp organized for 60 finalists. The exceptional performance of EYC's agripreneurs enabled them to win three awards in the first category and one award in the second category.

In addition to the cash prize of US$15,000, Gwangwa'a Priestly Tabe, who was the national champion, received a fully sponsored trip to attend the 3rd edition of the Youth Connekt Africa (YCA) 2019 Summit in Kigali, Rwanda, on the theme "Boosting an Industrious Young Africa", on 9-11 October 2019. His interactions during the YCA gave him the opportunity to do a month-long internship in Uganda to finalize his ideas for his business AgriBiz Home. Upon his return from this internship, he started his business. Thanks to the money received from the UNDP Youth entrepreneurship Challenge 2019, as well as $5,000 from the Tony Elumelu Foundation and $3,000 from the AYADA laboratory and the experience gained during the internship, his first products are expected in the market

in June 2020. Priestley is yet to complete the EYC training, and remains actively engaged, in addition to the success already recorded.

In addition to the network, EYC continues to broaden the scope of the partnership. For instance, on 2-6 December 2019, EYC hosted a government delegation from Gambia for a study tour to share experiences and opportunities for future collaboration. Discussions are ongoing with partners in Chad to backstop their ENABLE Youth Program. Other potential partner organizations considered for collaboration include the US Agency for International Development, Japanese International Cooperation Agency, the United Nations High Commission for Refugees, and the Africa Financial and Technical Assistance.

Gwangwa'a Priestly Tabe of YABIC Dibombari (right) together with his trainer (left) during his internship in Uganda

In addition to the quality of the incubation, the success of EYC depends mainly on the commitment of aspiring agripreneurs and access to bank loans. The experience of EYC shows the youth's outstanding commitment, irrespective of the educational and experiential background.The mindset change has been a success based on the first cohort of 512 candidates. The delay in confirming the financial operator that will administer the facilitation funds, and consequently the microfinance institutions that will grant loans to the agripreneurs, has been a significant challenge. The operator will be confirmed in 2020.

Based on timely access to loans, it would be important to assess the barriers to creating youth-led agribusinesses and employment, and options to overcome them. In 2020 and 2021, data would be gathered in and beyond Cameroon to inform future policy decisions to creating an enabling environment.

Authors: Cargele Masso, A. Michelle Diyani, M. Abdel-Rassoul, M. Nyako, E. Mbida, E. Dan-Aigewi, G. Forgione, E. Thiengue, Y. Aboubakar, G. Nsofon, IITA-Cameroon.

Reviving the aquaculture value chain in DR Congo

In DR Congo, the fishery and aquaculture sector constitutes an essential source of economic activity, surpassing livestock, accounting for 12% of agricultural GDP. The industry contributes to 40% of total animal protein intake in the country. The annual average per capita fish consumption is about 5.9 kg—low compared to the continental average of approximately 9.4 kg. Most fish consumed in the country is imported from neighboring countries and China. However, DRC has vast environmental resources to produce what is required for home consumption and could even become a net exporter of fish.

A survey between 2018 and 2019 showed an influx of 20 MT of imported fish per week entering the city of Bukavu in South Kivu. A large portion of this—about 54 tonnes—is imported by a group of nine women every two months from China. The two types of fish imported are Tilapia and Pacifique.

Several challenges prevent the country from realizing its potential. Among these are the challenges of having consistent access to quantity and quality broodstock, feed, and access to the market. These are worsened by decades of political instability and civil war. Broodstocks and feed, which constitute more than 80% of the production cost and are expensive, are not locally available and have to be imported. Some farmers try to make their feed, but struggle to find the right quality ingredients and the best formulation.

With the return to political stability in recent years, efforts are being put in place to revive the sector and develop the fish value chain. A three-year aquaculture project is implemented by IITA in collaboration with WorldFish and funded by the International Fund for Agricultural Development (IFAD).

Another project, Tilapia fish production in cages in South-Kivu (PPTC-SK) implemented by IITA with the High Institute of Pedagogy (ISP) and the Higher Institute of Rural Development (ISDR) aims at developing the tilapia value chain from feed production, fingerlings, production to market access facilitation by promoting youth engagement in aquaculture. The tilapia project is funded by the Fund of Industrial Development (FPI) under the 100 days emergency program of DRC President Felix Tshisekedi.

The projects aim to:

1. Improve the productivity of aquaculture by developing good quality broodstocks and farming systems
2. Identify and support the development of fish value chains while enhancing the benefits for women, youth, and vulnerable groups

Fish products from the project.

3. Provide a knowledge base on best practices and policy that supports future public and private investments and the expansion of sustainable aquaculture and value chains in all DRC provinces, starting within Kinshasa and South Kivu.

The ultimate goal is a self-sufficient Bukavu that produces fish, and gives direct and indirect employment to 1,500 young people and 4,000 others, respectively.

Successes

Four modern hatcheries have been built and are now operational in Kalambo and Kinshasa, with a combined output capacity of 2 million fingerlings of both tilapia (*Oreochromis niloticus*) and catfish (*Clarias gariepenus*).

Sixteen representatives of fish producers' associations have been trained on the proper establishment of earth ponds in South Kivu (Ruzizi plain, Walungu, and Kabare) and Kinshasa hinterland. In rural Kinshasa watershed, eight fish farming associations were established in Mongata, Mitsudi, Mampu, Mbankana, CADIM, Menkao, Kimpoko/Maluku, Ndjili Brasserie, and Kimwenza. Six training events on best management practices related to fish pond management, pond creation, fish feed manufacturing, fish nutrition, fish broodstock management, and fish reproduction have been conducted in South Kivu Province in both highland and lowland regions.

The project has distributed 65,000 tilapia fingerlings to fish farmers' associations throughout the low altitude (Kamanyola) locations and 30,000 fingerlings of catfish fry distributed to fish farmers in the high altitude (Walungu) sites. These fingerlings are the first products from the first two modern hatcheries installed in South

Inside IITA – Kalambo hatcheries. Hatching equipment for tilapia and catfish fingerling production.

Table 1. Calculated profit margins per earth pond (20 m x 20 m) around Kinshasa for tilapia, catfish, and other local fish mixed.

Reported/surveyed/calculated for earth pond production	Tilapia	Catfish	Local endemic fish mixture*
Average total annual production (kg)	264	1057	1,,975
Current market price (US$ per kg)	4.6	8.6	10.9
Total annual earnings (US$)	1,214	9,092	21,528
Reported / calculated cost of production (US$)	735	735	735
Calculated profit margins (US$)	480	8,356	20,793
Calculated benefit-cost ratio	1.7	12.4	29.3

*The local endemic mixture comprises the following fish species: Mabundu (*Sparus aurata*), Monganza (*Triglochin striate* Cenchrus), Mungusu (*Parachanna obscurus),* Nzombo (*Protopterus dolloi)*, Mpoka *(Labeobarbus*), Mopongo (*Gonimbrasia belina*), and Mboto (*Distichodus fasciolatus*).

Kivu. Twelve thousand fingerlings, lime, mineral fertilizers (NPK), and various tools and accessories were given to eight fish farmers' associations of the broader Kinshasa watershed.

A local fish feed formulation was developed and used to produce local fish feeds. The use of IITA agro-technologies and crops such as soybean, maize, and cassava flour as local ingredients mixed with fish meal, mineral, and vitamin premix and dried cow blood has yielded a noticeable weight increase among both tilapia and catfish grown in Kinshasa.

Fourteen youth groups with a total membership of 420 received 50 cages and over 300,000 fingerlings.

After distributing 150 cages to youth groups engaged in the fishery value chain, it is expected that the PPTC-SK project will contribute to reversing the trend of importation of fish in the South-Kivu province by producing on average an expected 20 tons of fish per week by the end of 2020.

IITA's main contribution in this value chain is the facilitation of the production of relatively cheap fish feed using local ingredients (cassava, maize, soybean). This undertaking will drastically reduce the cost of fish feed that accounts for 40-80% of the overall production cost.

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Ensuring impact & delivery

Producing and packing Aflasafe, IITA, Ibadan, Nigeria.

Scaling readiness: A scientific approach to scaling innovations

Scaling innovations is one of the biggest challenges facing research and development organizations. The international community invests significant resources in the design and testing of innovations to overcome challenges such as food insecurity, malnutrition, and environmental degradation. Many of those innovations start as an idea that is then developed in a laboratory and finally tested with end-users. Although initial results and testing are often promising, few lead to real impact at scale.

For the past three years, a group of dedicated scientists representing IITA, Wageningen University, and other CGIAR centers have worked on designing and testing of scaling readiness as an integral part of the CGIAR Research Program on Roots, Tubers, and Bananas (RTB). During this period, scaling readiness was tested and used in more than 20 projects in 25 countries in Africa, Asia, and Latin America.

What is scaling readiness?

Scaling readiness is an approach that translates state-of-the-art innovation science into a practical tool that guides research-for-development teams and organizations in making scaling work. Through five simple steps (Fig. 1), it encourages project teams to critically reflect how 'ready' innovations are for scaling and what appropriate actions could accelerate or enhance scaling. It provides scientific tools to support decision making on what scaling bottlenecks address what could be the most cost-effective scaling strategy and which partners to engage. Scaling readiness uses metrics and indicators that are also being used by NASA and the European Union (EU); similar approaches are being used in the R4D sector by, for example, GIZ, Bill & Melinda Gates Foundation, and CGIAR Systems Organization.

Dr Kenton Dashiell, Deputy Director General, Partnerships for Delivery, giving a talk during the P4D Retreat in Benin.

Figure 1. Five Steps of Scaling Readiness to develop, implement, and monitor scaling strategies in projects. The arrows indicate the iterative process that Scaling Readiness supports, from **1** Characterizing innovations and interventions and scaling context, **2** Diagnosing bottlenecks for scaling, **3** Strategizing on ways to overcome bottlenecks, **4** Agreeing with stakeholders on the strategy and action plan, and **5** Navigating scaling strategy implementation. Once a bottleneck is adequately addressed, a new cycle of Scaling Readiness assessment and bottleneck identification is triggered.

Through its standardized data collection and analysis approach, Scaling Readiness can be used to monitor a portfolio of innovation and scaling investments. It also supports prioritization, and decisions on advancing those innovations that can achieve societal outcomes at scale in the most resource-efficient way.

How does Scaling Readiness work?

Innovations scale as part of packages, which are context specific. The stylized example in Figure 2 shows that a *new seed variety* can only be of use for farmers when there are *novel seed quality assurance policies*, *certified seed multipliers*, *seed producers business models*, etc. If any of these enabling conditions is absent, then the *new seed variety* will not end up in the hands of farmers and will not improve livelihoods at scale.

Scaling readiness unpacks innovations and scores their readiness and use. This enables the identification of scaling bottlenecks and supports decision making on which activities and partnerships are required to overcome the bottleneck. The example presented in Figure 2 shows that the bottleneck is the low readiness and use of the *novel seed quality assurance policy*. This provides a basis for the development, implementation, and monitoring of a scaling strategy to overcome the bottleneck.

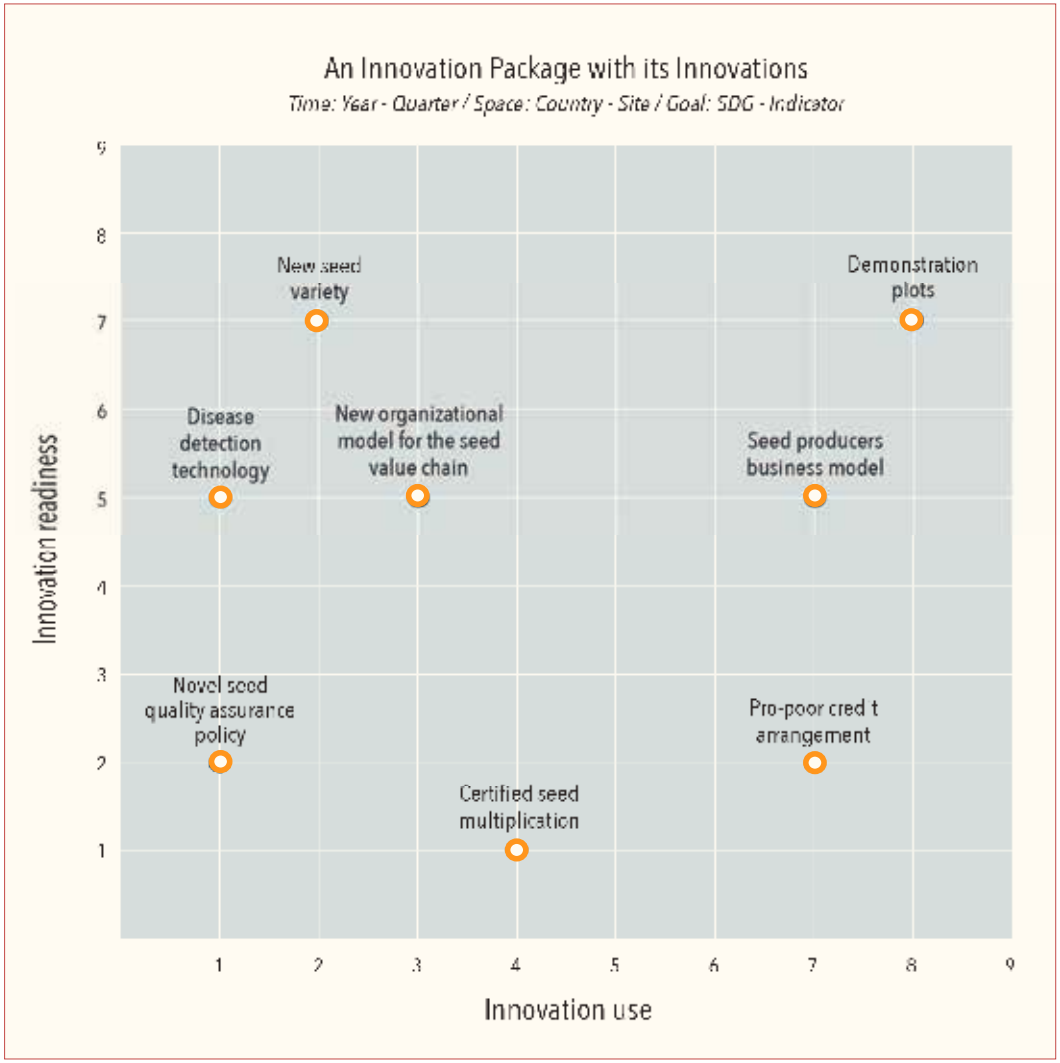


Figure 2. Stylized example of an innovation package (with 8 innovations) that has been assessed for innovation readiness (y-axis) and innovation use (x-axis) specific to space, time, and project goals.

Use of Scaling Readiness in IITA

Several IITA projects actively use Scaling Readiness, including AKILIMO, TRICOT, and Cassava Flash Dryer, all funded through the CGIAR RTB Scaling Fund. One of the projects that has pioneered the use of Scaling Readiness in IITA is the Cassava Peel Project that converts wet cassava peels into energy-rich, high-quality animal feed.

"As project leader and scaling champion of the Cassava Peel Project, I knew that the technology we had developed was ready to go to scale. By using Scaling Readiness, the project team became much more aware of the non-technological innovations required for the cassava peel innovation to scale (Fig. 3). We started paying much more attention to our partnerships, user perceptions, and produce pricing. We realized that the biggest bottleneck was lack of a market for cassava-based animal feed, which then formed the heart of our scaling strategy," says Dr Iheanacho Okike, IITA Cassava Peel Scaling Champion.

The project partnered with the IITA Cassava Seed Tracker team to develop a Cassava Peel Tracker which allows entrepreneurs to locate the cassava processing centers nearest to them, along with the amount of peel for sale each day.

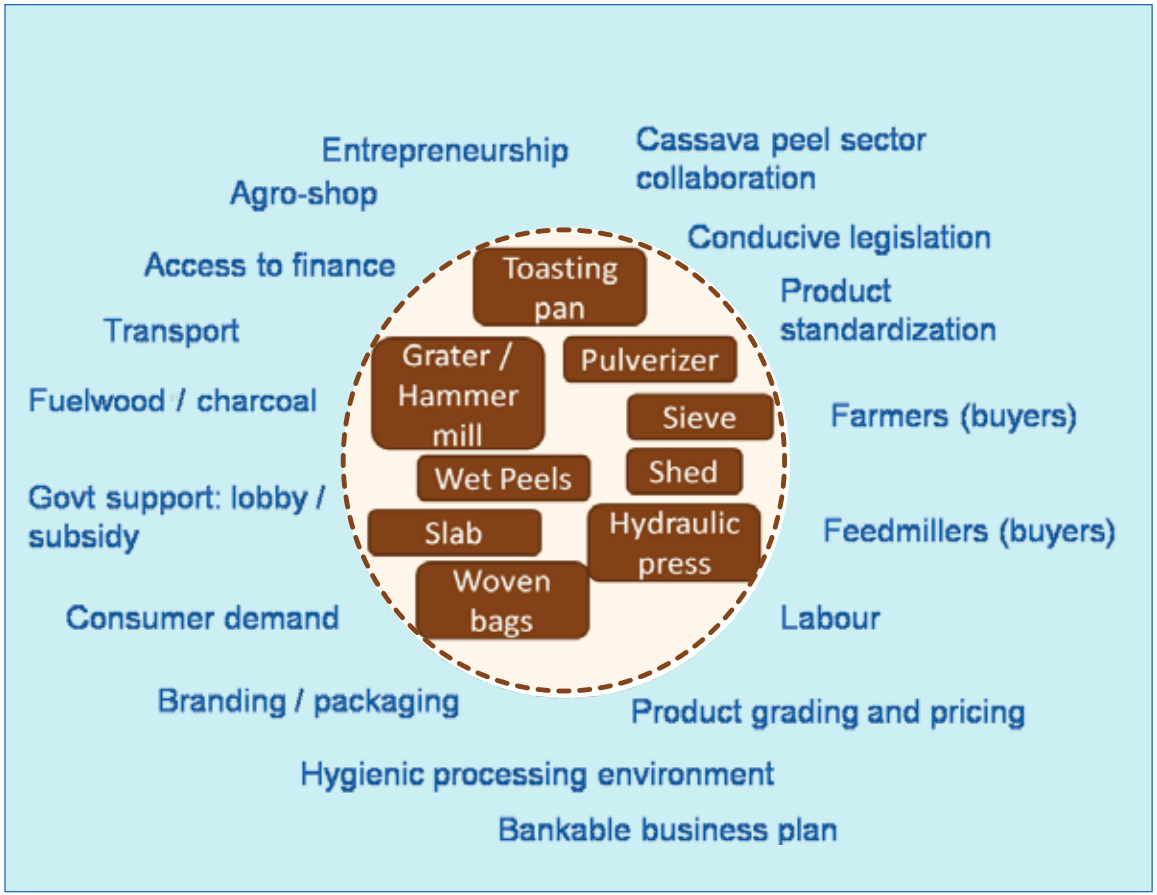


Figure 3. Simplified representation of the Cassava Peel project's Innovation Package with the technological innovation at the center (in brown) and the non-technological innovations in blue lettering.

Bridging IITA's research and delivery divisions

Scaling readiness has not gone unnoticed in IITA and on several occasions the IITA leadership has been exposed to the approach. In 2019, during a strategic retreat in Benin, IITA scientists, directors, and managers of the Partnerships for Delivery (P4D) Directorate, including Business Incubation Platform (BIP) and Technologies for African Agricultural Transformation (TAAT) learnt how Scaling Readiness could support their units and directorate in better strategy development and decision-making. Scaling readiness can form the bridge between IITA R4D and P4D where increasing the readiness and quality of innovations forms the heart of R4D, and increasing the use of innovations forms the heart of P4D.

Scaling readiness has been firmly embraced by the P4D Directorate. Deputy Director General for P4D Kenton Dashiell explains: "We have found that Scaling Readiness is an excellent model for P4D projects and can help us to be more efficient and impactful in our work. Scaling readiness can support us to better write our proposals, connect with the best donors, and manage the work we are doing."

Authors: Marc Schut, Murat Sartas, IITA-Rwanda; Pieter Pypers, IITA-Kenya (Nairobi, Central Africa); Iheanacho Okike, IITA-Nigeria (Ibadan); Bernard Vanlauwe, IITA-Kenya (Nairobi, Central Africa); and Kenton Dashiell, IITA-Nigeria (Ibadan).

IITA Youth in Agribusiness initiative… taking a STEP ahead

The IITA Youth Agripreneurs (IYA) started as a youth-led exploration of agribusiness incubation in August 2012 that established diverse learning enterprises. It expanded through the creation of additional groups. A set of operating strategies evolved based on gender equality, teamwork, leadership, and enterprise experimentation. Stakeholders and several agencies were attracted to the IYA approach and funds were made available to both formalize and expand its operations.

The Agripreneurs approach is built upon reorienting educated youth toward self-employment in agriculture and growing those businesses to provide decent employment and build rural economies.

Maintaining its footprint as one of the leading youth-in-agribusiness initiatives in Africa, IYA channeled its activities in 2019 towards realizing the outcomes in the 2012 strategy. At inception, IYA had highlighted some of the outcomes of the intended program—creation of jobs and self-employment through the establishment of independent agribusiness enterprises, establishment of an independent organization focused on youth in agribusiness-related activities, employment by some trained youth in private and public institutions, employment of some in the IITA Business Incubation Platform, opportunities for some to pursue further studies at various professional levels, while a few would be retained to run the organizations.

The outcomes have evolved as planned, and year 2019 witnessed synthesis of actions towards effective agribusiness delivery.

A practical session for ENABLE-TAAT interns.

Director General of IITA, Dr Nteranya Sanginga with pupils of IITA International School during the preparatory stage of the Start Them Early Program.

In 2019, another initiative under the unit, Start Them Early Program (STEP), gained recognition and focused on engaging young people in agriculture in selected secondary schools in DR Congo, Kenya, and Nigeria. STEP was initiated in 2018 after IITA received the Africa Food Prize. The strategy behind STEP was to 'catch them young,' ensuring that secondary school students develop interest in agriculture and embrace agriculture as a business at a young age. The initiative aimed to help young people to think of agriculture as a first option for business. The program is funded by the International Development Research Centre (IDRC) and Technical Center for Agricultural and Rural Cooperation (CTA).

STEP organized its inception workshop, identified host schools in the countries of implementation, conducted a baseline survey, developed the training tools to meet the needs of the target age groups, and introduced ICT support services to schools in rural areas.

The STEP team developed selection criteria for identifying schools to serve as centers for project implementation. Nine secondary schools were selected across the project implementation locations.

A baseline survey of the program conducted in the year revealed some interesting facts about the attitudes of secondary school students towards a career choice in agriculture and agribusiness. Survey results revealed that a slight majority (54%) imagined agriculture as playing a role in their future, with a preference for animal enterprise (42%), field cropping (30%), and food processing (15%) as the most attractive options.

About 46% of those surveyed were not attracted to agriculture for various reasons. Some of the reasons are related to the perception and hard labor envisaged in agriculture. Thirty percent say its requirement for "excessively hard labor" prevent them from venturing into agriculture while 20% think that the return on labor put into it is relatively poor. Twenty-one percent say that the overall unfavorable image of farmers is part of their non-attraction to agriculture. At the same time, 25% of these youth stated that they lack the land or facilities needed to practice farming and this excluded it as an option in their career planning.

The unique approach in delivering training to the target beneficiaries includes coursework, pilot incubation enterprises and extracurricular activities, value chain development per country, training materials, parent/teacher involvement, school open days, gender and reproductive health training, selection of facilitators/volunteers, and training of trainers' programs.

IYA successes led to donors funding the establishment and implementation of projects like Empowering Novel Agri-Business-Led Employment (ENABLE)-Youth and ENABLE-TAAT (Technologies for African Agricultural Transformation) funded by the African Development Bank, the Chevron-funded Community Youth in Agribusiness Group (CYAG), and Youth Employment in Agribusiness and Sustainable Agriculture (YEASA) funded by the International Fund for Agricultural Development (IFAD), the Integrated Project of Agricultural Growth in

the Great Lakes (PICAGL) funded by the World Bank, to mention a few.

The implementation of ENABLE-TAAT continued during the year with training conducted, advocacy activities resulting in partnerships with many organizations, and food-basket demonstration fields established to promote nutrient-fortified TAAT commodities. The project continued to monitor agribusinesses established in 2018 and provided mentorship support.

ENABLE-Youth continued to record successes, especially in Cameroon and Madagascar, with more countries indicating interest to participate in the pilot phase. The political instability in Sudan in 2019 restricted project activities and resulted in a poor macroeconomic environment that has affected the growth of businesses. Still the project established 13 Youth Agribusiness Incubation Centers (YABICs), which operate as training and business units that will become self-sustaining upon completion of the program in 2022. Some youth trained under the program in Madagascar received funding from a financial institution to establish businesses. The technical advisors have been instrumental to the success of the program.

IYA was recognized for its commitment towards improving both agribusiness opportunities and creditworthiness of youth across Africa in 2019. The award, which is the first of its kind and funded by the government

Some ENABLE-Youth Cameroon beneficiaries learning fish processing in a practical session.

A STEP team member conducting training for student-beneficiaries.

Left | Somebeneficiaries of ENABLE-Youth in Cameroon

Right | Evelyn Ohanwusi receiving the FAO-funded innovation award on behalf of IYA. The award fund was used to start activities in Cotonou, Republic of Benin.

of Switzerland, was presented during the 41st conference of the Food and Agriculture Organization (FAO) at the organization's headquarters in Rome. The award came with a cash prize of $20,000, which IYA pledged to use in establishing a Youth in Agribusiness program in the Republic of Benin. IYA partnered with a project funded by IFAD, the Youth Employment in Agribusiness and Sustainable Agriculture (YEASA) Project to train youth and provide them with inputs to start small and medium enterprises.

The YEASA project started in February 2019. It aims at building the technical, entrepreneurial, and soft skills of young adults (18–35 years), as a means of improving their productive capacity and increasing benefits from existing agrifood systems. The project is implemented by three institutions: Afe Babalola University Ado-Ekiti (ABUAD), the grant recipient, IITA, and AfricaRice Center as subrecipients. The project is set to empower 1,000 young adults living in rural areas of the Republic of Benin (Parakou and Cotonou) and Nigeria (Oyo and Ekiti) for a period of three years. The target beneficiaries will have the opportunity to choose from agricultural commodities such as moringa, soybean/cowpea, maize, plantain, mango, cassava, rice, and aquaculture; also feedmill and agricultural machinery fabrication. IITA is expected to empower 200 young rural adults in Nigeria and the Republic of Benin along the value chains of maize, cassava, plantain, cowpea, and soybean, and machine fabrication for 3 years.

Through this project, 57 youth were trained in Nigeria and the Republic of Benin. Forty-seven of them received starter packs after drafting and successfully pitching their business ideas.

The Chevron-funded project in the Niger Delta region has recorded the establishment of 45 new agribusinesses. The group made a significant contribution towards evaluating the impact of a change in the mindset of young people in embracing agriculture as a business.

Success at last for the Frotchery Farms Team

Frotchery Farms Limited is one of the pioneer spin-offs of IYA. The company was

established three years ago and focuses on catfish production and value addition. In 2019, its product was certified by Nigeria's food regulatory body—National Agency for Food and Drug Administration and Control (NAFDAC). The certification, coming after three years of continuous application, will enable the company to make their products available across the Nigerian market.

With the NAFDAC number, it became imperative to rebrand the product and introduce new packaging of international standards. The company received the support of an angel investor who facilitated product branding and packaging. A business review for 2019 revealed an extension to 13 additional market outlets and an 81% increase in customer base.

Seeking business expansion

Another passionate Agripreneur who is known for her efforts in promoting agribusiness along the cassava value chain is Oluwaseun Ogidan. Seun was trained by IYA. She started her business with savings and support from relatives. In 2019, Seun cultivated 30 hectares of cassava and intercropped with 20 hectares of pro-vitamin A maize at Ago-Owu in Osun State to get quick returns. Her plan for 2020 is to cultivate 100 hectares of cassava and intercrop with 50 hectares of maize. She is currently seeking support to own a processing facility which would also serve as an additional source of income.

The Frotchery team presenting their branded products to one of their angel investors, Mrs Charlotte Sanginga.

"We believe in gender equality. We encourage women to take up dignifying work in agriculture."

Author: Adetola Adenmosun, IITA-Nigeria (Ibadan).

Digital extension: Reaching farmers at scale and helping to root out weeds

For Ngunan Chiichii, a farmer in Benue State, north central Nigeria, cassava farming has become an exciting venture because even with her *palasa* phone (non-smart phone), she can now access improved agronomy recommendations in her palm, to control weeds and get better yield from her cassava farm.

IITA communication and knowledge specialist Godwin Atser shows farmers how to use the app Herbicides Calculator using non-smart phones.

The challenge of African farmers in context

Mrs Chiichii, a mother of 5, was among thousands of farmers that used to spend hundreds of hours annually stooping to control weeds using hoes and machetes on a hectare of cassava farm in Benue.

"At some point, I wanted to quit cassava cultivation, but on second thoughts, I decided to continue because it provides my family food, and I also make money from selling the stems," she said recently.

Today, recommendations on cassava weed management and best planting practices developed by two projects at IITA—the Cassava Weed Management Project (CWMP) and the African Cassava Agronomy Initiative (ACAI), received via mobile phones have helped Mrs Chiichii and thousands of farmers to solve the problem of weeds and get better yield from cassava.

Across Nigeria, cassava is a major staple, contributing to food security, incomes, employment, and livelihoods. Despite the importance of cassava, growers are yet to maximize the benefit of the root crop because

of poor yield per hectare. Efforts to intensify cassava production have been stymied by weed infestations and poor agronomy. The presence of weeds in cassava fields forces women such as Chiichii to spend hundreds of hours per annum to keep cassava farms weed free. Hoe weeding takes 50% to 80% of the total labor budget in Nigeria. In some cases, farmers pull out their children from school to support weeding.

The innovation

In the last 5 years, CMWP and ACAI, both funded by the Bill & Melinda Gates Foundation, assessed alternative approaches to managing weeds in cassava fields and best planting practices and recommended steps farmers can take to reduce the drudgery of hoe-weeding and improve their yields and profitability.

Findings of the research have been put in an extension message (toolkit) known as the *"Six Steps to Cassava Weed Management & Best Planting Practices toolkit"* for dissemination to farmers at scale. The *toolkit* is a suite of recommendations integrating the use of herbicides and best-bet agronomic practices (improved variety, appropriate spacing, tillage, and fertilizer application) that when adopted by farmers, doubles their yield from the national average of 9 t/ha to more than 20 t/ha.

Woman farmer trains in using small machines to lighten the work load on the farm.

Challenge of scaling

However, getting the rec!ommendations across to farmers such as Chiichii was a big challenge because of the weak extension system in Nigeria (1 extension agent serving 4,000 farmers). Furthermore, the high cost of the training and visit extension approach was prohibitive and inefficient to deliver the recommendations at scale.

The digital approach to the rescue

To surmount the dissemination hurdles, CMWP and ACAI piloted a digital extension plan using interactive voice recording (IVR) of Viamo (also known as 3-2-1), combined with the use of radio, videos, and social media (Facebook, WhatsApp, Twitter, and LinkedIn) to get the recommendations on agronomy out to farmers.

Through this approach, farmers such as ChiiChii now get information on cassava cultivation by dialing 3-2-1 for free up to 10 times in a month. Another beauty of the 3-2-1 service is that it does not require smartphones. With an ordinary phone, farmers can dial and get the recommendations (information) in their dialect for free.

The use of digital extension tools by these projects is taking advantage of the mobile subscriber-base in Nigeria—mobile phone subscriptions are about 150 million, and 97.2 million persons use the Internet. In addition, the availability of cheap smartphones has given access to about 15 million persons on improved weed control practices and agronomy on platforms such as WhatsApp, YouTube, and Facebook.

By 2019, the digital plan had reached 220,000 farmers through various digital platforms, including Facebook, IVR, Twitter, SMS, Youtube, and WhatsApp. In addition, a radio program (Farming on Radio) was established with three local radio stations with a combined listenership of 2.9 million people.

Besides disseminating the agronomy recommendations, these projects have also developed a mobile phone app known as IITA Herbicides Calculator to empower farmers, extension service providers, and spray service providers on how to calibrate and correctly spray herbicides without overspraying or underspraying.

Using this app, Chiichii has become more efficient on how to use herbicides without causing damage to the environment or humans. Hundreds of farmers and extension service providers have downloaded the app and are now using it on their farms.

The story is not different for farmer Chukwudi Obisike who is based in South East Nigeria. In addition to receiving advisory services via mobile, Obisike is using the IITA Herbicides Calculator to train farmers in his community on calibration and the right application of herbicides. He is also using the Six Steps to Cassava Weed Management & Best Planting Practices videos to grow his cassava and train other farmers.

Looking forward

While digital agriculture, as experienced by Chiichii and Obisike, provides opportunities for researchers to reach farmers at scale, it cannot happen in isolation. Traditional extension still has a role to play. Digital tools should be mainstreamed in both private and public extension systems. For instance, the use of videos was more effective when combined with the traditional extension system.

Secondly, awareness is still critical. For instance, in the beginning, the IVR using the 3-2-1 service of Viamo had low patronage. However, as it was combined with radio jingles, more users were attracted.

Lastly, data in Africa is relatively expensive, and coverage in some cases is limited. These undermine the effectiveness of the use of digital tools that are web-based or, in some cases, limit coverage and adoption.

Authors: Godwin Atser, Alfred Dixon, and Friday Ekeleme, IITA-Nigeria (Ibadan).

Agripreneurs using machines for weeding in the farm.

Integrated digital tools for accelerating agricultural transformation in sub-Saharan Africa

In the last decade information and communication technologies (ICTs) have fast emerged as frontline tools for transforming agricultural systems in sub-Saharan Africa. Governments, developmental organizations, and the donor community are increasingly depending on ICTs to unleash the potential of rural economies and bridge agricultural value chains for enhanced profitability.

Using digital tools in the farm is now beginning to be a common sight in African countries.

IITA has been at the forefront of using ICTs for research management and knowledge sharing, including extension, scaling out, e-learning, collaboration, and agricultural services enhancement.

IITA believes that sharing and delivery of knowledge and products for adoption by intended end-users using digital platforms are critical to achieve research and development outcomes. The use of ICTs to facilitate awareness creation, promote behavioral change among knowledge users, e.g., farmers or processors, and facilitate adoption of technologies could contribute to the success of delivery efforts.

IITA has used ICTs for precision agriculture, digitalization of the research process, knowledge sharing, and service delivery through tailor-made digital tools, data repositories, and web platforms. Many of these developments emanated from various R4D projects and were designed to fit the project purpose with a scope for broader applications.

A workshop titled 'Smart Tools for Smart Farming' held at IITA-Ibadan, Nigeria in November 2019 attempted to improve coordination and develop

complementarity between and among ICT tool applications and users. This workshop brought together IITA teams and collaborators to showcase various apps developed in IITA.

A follow-up workshop was organized a month later to introduce IITA-developed digital tools to extension workers, media, and collaborators working in the same digital space and agricultural solutions or topics. Together, these workshops enhanced the visibility of various ICTs used at different levels of the agricultural value chain. They also served to catalyze the coming together of practitioners and the establishment of a working group that would develop the beginnings of a strategy on digital delivery and knowledge sharing for IITA.

These workshops emphasized the need to integrate and coordinate such efforts as it provides IITA the leverage to showcase its expertise and experiences in this field, among several other benefits.

A Working Group on Digital Delivery was formed to improve the coordination, collaboration, and communication among the various developers of ICTs currently in use for research, development, and delivery at IITA. This is expected to enhance synergy between the ICT applications, reduce redundancy, and expand the reach of digital delivery of solutions to farmers and end-users for increased impact.

The Working Group undertook a survey to determine the available digital tools and the talents involved in the in-house development of such tools. This baseline survey revealed the use of over 50 ICT applications and mobile apps developed in-house (Table 1). High usage of ICTs by the IITA community is not surprising, but many of these developments were uncoordinated, resulting in some redundancies and poor awareness about the state of development and progress outside the project structure, underuse of high potential apps beyond the intended scope, and data fragmentation.

The Working Group also came up with a strategy document that outlines several elements to enhance delivery and knowledge sharing:

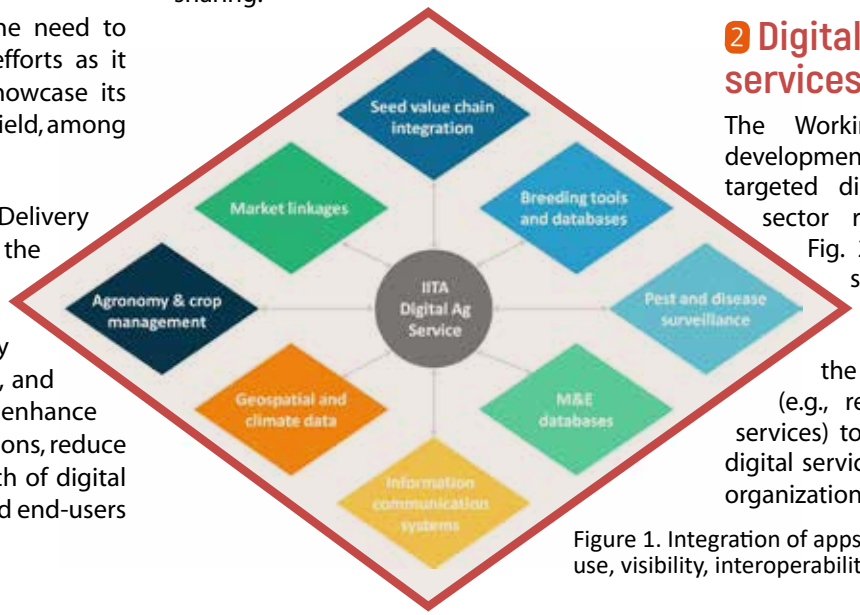


Figure 1. Integration of apps for enhanced use, visibility, interoperability, and maintenance.

1 Develop digital strategy and platform

A draft strategy was formulated and a framework created for delivering research knowledge using digital tools, platforms, and approaches to ensure widescale adoption and impact. Tentatively called IITA Digital Agriculture Service (IDAS), the platform will integrate a broad spectrum of ICTs in use for research, development and delivery, and knowledge sharing (Fig. 1). IDAS is expected to improve the efficiency of service delivery, visibility, simultaneous promotion of complementary apps; harmonize front- and back-end service support; nurture new ideas; create avenues for interoperability of databases using APIs for big data generation, and machine learning for trends, analytics, data visualization, data-driven decisions, and forecasting.

2 Digitalize agricultural services and extension

The Working Group will oversee the development of a suite of ICT packages for targeted digitalization schemes (e.g., seed sector reforms using the SeedTracker, Fig. 2), and promote and modernize service delivery and extension. IITA's strengths lie in its unique ICTs, experience, and understanding of the needs of farmers and end-users (e.g., research, extension and advisory services) to design and develop user-centric digital services that meet the requirements of organizational goals.

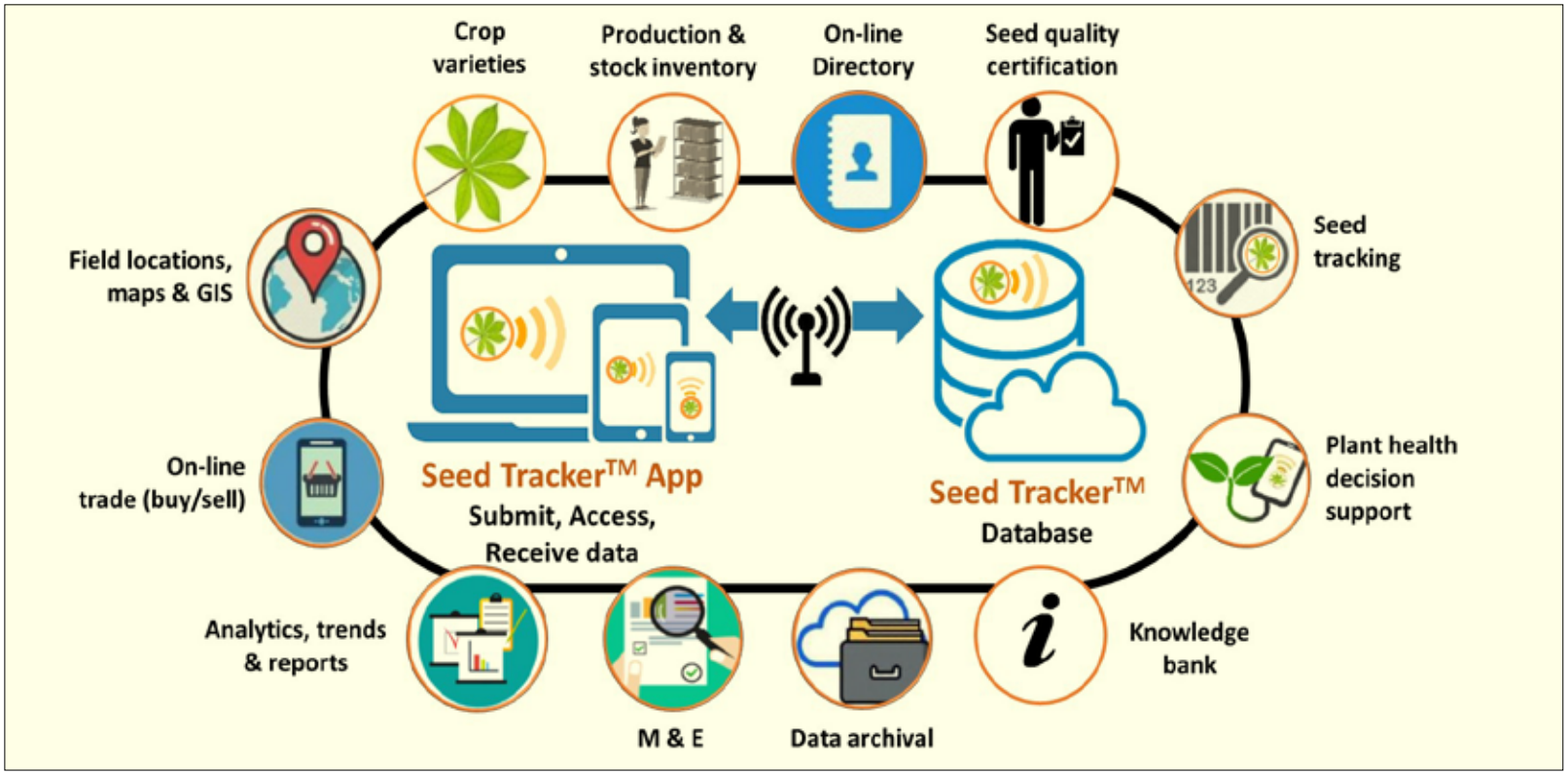


Figure 2. Digitalization of seed value chain, seed certification, and national seed inventory using SeedTracker app, showing how we can modernize service delivery, knowledge sharing, and extension.

3 Deliver smart service to farmers

IITA has tailored ICTs for crop management advisory service delivery to farmers and farmer organizations, and extension agents in government and nongovernmental organizations through smartphones (e.g., development of a package of best agronomic practices for ready dissemination to end-users using AKILIMO, see related story on page 25, this annual report). Combining the use of ICTs with mass media or traditional media, such as radio/Internet radio, videos, and mobile projectors further expands the reach of these ICTs.

4 Promote e-learning to deliver knowledge

Part of the plan is to develop an e-learning platform on IDAS to promote remote learning and skill building. IDAS offers a new way to enhance education and facilitate capacity building among players in the agricultural

space, ranging from secondary school children being introduced to agriculture to value chain actors, agrodealers, to extension workers and trainers, to youth agripreneurs and women entrepreneurs. This involves working with the formal school system in introducing agriculture subjects and providing opportunities for exposure and experiential learning; providing mechanisms for bringing youth or women entrepreneurs together to learn about agribusiness using an online educational platform; and bringing training courses on agriculture to users via a digital learning portal. Integrating IITA knowledge resources with ICTs is a powerful and cost-effective way to enhance learning and knowledge and skills acquisition.

5 Expand digital footprint

This involves developing and promoting the use of standard digital tools available in IDAS for specific applications to enhance the digital footprint and outreach of IITA applications. Through collaboration among the Working Group on Digital Delivery, IT, Scaling out team, Communication and Knowledge Center, and the various communities of practice, IDAS will become the central platform for enhancing and developing new ICTs required for future applications and offer strategic advice to users aiming to develop new applications (e.g., a 'nutrition app' for making recommendations on use of crops and varieties to address hidden hunger). Existing IT infrastructure provides the required backbone for the various apps with room for upgrades and expansions.

6 Establish and coordinate ICT Community of Practice

Within IITA, a multidisciplinary unit will be created to align researchers, ICT developers and users, communicators, and content generators to improve tool development and promote digital tools for data-driven precision agriculture, stimulating innovation and capacity development for ICT use across the agricultural value chain. The ICT practitioners include apps developers and users at IITA and are spread across hubs and in some cases work with partners in other continents.

The Working Group will evolve into an institute-wide ICT Community of Practice (iCOP) to bridge interest groups within IITA and realize the objectives discussed above for greater efficiency and impact.

IITA's combined expertise and experience in this area provides a fertile ground for developing grants and proposals that provide solutions to agricultural challenges and that could attract donor funding, nontraditional partnerships, and alignments with governments for enhancing agricultural transformation in sub-Saharan Africa.

Table 1. Summary of apps by application

- **Seed and product value chain integration and market access**
  - Seed Tracker
  - Business Connector
  - e-market
  - GoSeed eCommerce
- **Crop management and agronomy**
  - AKILIMO
  - Herbicide calculator
  - IBSTI/ESI
  - Mwanga
  - Shade tree advice tool
  - Stepwise
- **Breeding tools and databases**
  - BTracT
  - CloneTracker
  - ViTSel
  - BMS
  - CassavaBase, Yambase, Musabase
  - Genebank inventory management
  - Soils4Africa
- **Pest and disease surveillance**
  - NURU
  - ICT4BXW
  - Crop Disease Surveillance
  - FAW Scouting and Management
- **Geospatial information and climate database**
  - GIS Weather Information System
  - Geospatial Data Repository
- **M&E platform**
  - MEL
- **Institutional research databases**
  - West Africa Trial site map application
  - DSpace (Bibliography)
  - CKAN (Research data repository)
- **Management Information Systems**
  - PAR, HURIX, Oracle applications used for administration management (financials, human resources, facilities management, etc.)
- **Information and Communication Tools**
  - Radio IITA, IITA website, Knowledge portal (knowledge management and knowledge sharing platform), IITA iReport, and IITA News
- **Project-specific websites for knowledge sharing**
  - P4D, AflaSafe, IITA GoSeed, BASICS, YIIFSWA

Radio IITA.

Authors: Lava Kumar, Katherine Lopez, Godwin Atser, and Alfred Dixon, IITA-Nigeria (Ibadan).

IITA Business Incubation Platform: Commercializing and scaling innovations

IITA set up the Business Incubation Platform (BIP) to commercialize and scale up innovations from IITA and other CGIAR institutions in Africa. It is 100% owned by IITA. These innovations for farmers are validated in laboratories and trial fields and incubated and evaluated for their scaling readiness and feasibility as a sustainable product, service, or a new variety for a specific market segment. The final step is commercialization with a private sector partner to generate more impact and funding for new research.

Packaging Nodumax, Nodumax factory in IITA, Ibadan, Nigeria.

For several years now, BIP has been evolving into a fully commercial operation. Recently, BIP announced the appointment of its advisory board members led by Nkiru Opareke, CEO/COO of Enviro Gro Farms to provide leadership and overall guidance. The other members of the board include Kenton Dashiell (IITA Deputy Director General, Partnerships for Delivery) Hilde Koper-Limbourg (IITA DDG Corporate Services), Victoria Salin (Professor, Department of Agricultural Economics, Texas A&M University, IITA Board of Trustees), Frederick Schreurs (CEO, IITA-BIP), Yemisi Iranloye (MD/CEO, Psaltry International Ltd), Akinbayo Atere (Founder, Arterius Capital & Advisory Ltd), and Ayoyinka Olajide-Awosedo (Board Secretary).

Technologies and initiatives scaled by IITA-BIP include Aflasafe (via the Aflasafe Technical Transfer and Commercialization project, aTTC), Nodumax, IITA GoSeed, Agriserve consultancy, and Agriserve Youth Outgrowers.

IITA GoSeed

Through IITA GoSeed, new varieties have been made available in the marketplace in partnership with seed companies. The team has successfully onboarded over 30 entrepreneurs as foundation and commercial seed producers to help build the cassava seed system in Nigeria.

Presently, with the COVID-19 pandemic, IITA GoSeed supplied more than 15,000 bundles of cassava stems to Olabel Farms, Riparian Farms, Traxivvest Farms, and Mile 12 Plus farms. IITA GoSeed launched the first e-commerce platform (www.iitagoseed.com) in West Africa for selling early generation seeds. A soybean variety registration will be supported by an investor, who will prefinance its seed production. This will ensure that there is enough seeds available to sell to seed companies which will increase yield from 1 t/ha to 3.5 t/ha.

IITA GoSeed Cassava currently leverages on the semi-autotrophic hydroponics (SAH) technology to rapidly multiply improved varieties of cassava seeds. Some 60 prospective women cassava seed producers attended a meeting that empowers them to actively produce seed; six have been onboarded as seed producers. GoSeed is therefore helping to start sustainable seed businesses, creating jobs for outgrowers, and helping increase farmers' yields and income.

Nodumax

Nodumax is an inoculant that helps to increase the yield of soybean by at least 30-40%. United Phosphorus Limited (UPL) and Springfield are private sector partners that will soon become its distributor and manufacturer in West Africa to ensure that demand is met and to reach more farmers. UPL will also pay for product registration in eastern Africa to ensure that more farmers across the continent benefit from this innovation.

Through consistent data collection and evaluation, it has been proven that Nodumax has the ability to increase soybean yield on average by 35-40%. This initiative, combined with good agricultural practices (GAP supported by the IITA Weed Science unit) increased the yield to 2.5 t/ha. The introduction of improved varieties led to a yield increase from the Nigerian average of 1 t/ha to 3.5 t/ha. This resulted in higher income for farmers in Nigeria by US$560-937 per hectare.

A joint exhibition of BIP-Agriserve and joint venture partner CropNuts from Kenya.

Aflasafe

Alasafe is a biopesticide used against aflatoxins in maize and other crops. Its widespread use by farmers has increased access to safe maize in the marketplace and has contributed to reducing health risks for consumers. Alasafe helps lower aflatoxin contamination in crops by up to 100%. Development and testing of more products are under way in 12 countries in sub-Saharan Africa. Aflasafe is now manufactured in four countries and commercially available in eight countries.

The aTTC project handles the commercialization strategy of Aflasafe. Aflasafe products have been used by smallholder farmers in more than 315,000 ha to produce aflatoxin standard-compliant maize and groundnut. This is contributing to improving the health of farmers and consumers; and income and trade opportunities of farmers, aggregators, distributors, and traders in several sub-Saharan African countries. Harvest Field, an investor, has taken over the production and commercialization. The factory in Ibadan will be relocated to Lagos, Nigeria, and a new training and research and commercialization (ARDICT) facility for Aflasafe will be set up at IITA-Ibadan.

Aflasafe production, IITA, Ibadan, Nigeria.

Agriserve Consultancy

This is an almost finalized joint venture between CropNuts from Kenya and Agriserve, a unit of IITA-BIP that offers services such as soil suitability tests, land classification, soil surveys, and fertilizer recommendations to farmers. Also, business plan development services are offered in cooperation with the IITA-BIP Youth Outgrowers. The team has offered different consultancy services to several clients such as public and private organizations across Africa.

IITA-BIP Youth Outgrowers

This is a unit of IITA-BIP that runs a scheme where seeds or grains are grown through outgrowers (farmers/agripreneurs) across different locations for a guaranteed off-taker. This innovation has created jobs with decent pay and work conditions of $5000-12,000 per year for Nigerians, and has helped with market linkages and providing quality raw materials to processing companies. Also,

IITA-BIP youth outgrowers have developed outgrower schemes/business plans for investors. The team, with support from IITA GoSeed and IITA Weed Science, achieved a 6.3 t/ha yield for maize, 2.5-3.5 t/ha for soybean, and)23 t/ha for yam with the support of the IITA Yam Agronomist.

Private partnerships

IITA-BIP understands that partnership and collaboration are key approaches to maximize growth. It therefore partnered with private organizations for commercialization and scale. These firms include Rijk Zwaan Seeds, East West Seed, CONTEC Global, Alluvial Limited, Phosphorus Limited (UPL), Springfield, KOPPERT, Kenya Agricultural and Livestock Research Organization (KALRO), BAMTAARE (Aflasafe manufacturing and distribution in Senegal and Gambia), A to Z Ltd (Aflasafe manufacturing and distribution in Tanzania), NGN Netherlands (Impact cluster set-up for circular economy protein production of waste via insects in Nigeria), Bayer, Monsanto, SeedCo Pty, Cortiva/Pioneer Seed, and donors such as USAID and Bill & Melinda Gates Foundation.

IITA-BIP also works closely with the Harvard Business School. The collaboration has resulted into a case study development about the IITA-BIP concept. The International Institute for Management Development (IMD) in Lausanne currently supports IITA-BIP in its strategy development.

GoSeed team at an exhibition showcasing some of IITA's improved varieties.

A youth from the Agriserve Youth Outgrower inspecting maize for feed.

Authors: Frederick Schreurs and Victor Salleh, IITA-BIP (Ibadan).

Enhancing health & nutrition

Women are one of the main beneficiaries of innovations such as improved varieties, safe and nutritious seeds, and vale chain ehancements.

Aflasafe – healthy grains, healthy consumers, more trade and income

A perseverant long-term effort that continues to slowly but surely make positive impacts on lives, health, livelihoods, and trade in Africa is the ongoing work on aflatoxin mitigation strategies centered on Aflasafe. Aflasafe is a natural biocontrol product developed with partners to manage aflatoxin contamination on important food crops in the field and in storage. No other technology provides such a safe, robust, and consistent protection from aflatoxins.

IITA formed the Aflasafe team in 2002. Working with various partners, the team has created a revolution in the way CGIAR research products are delivered to farmers. Joint efforts of the Aflasafe team, national and international institutions, farmers, private sector partners, and donors are contributing to the transformation of Africa's maize and groundnut food systems towards aflatoxin-safe foods from field to fork.

The Aflasafe factory in Ibadan, Nigeria, is a crowd-drawer and receives hundreds of visitors every year. Photo shows Benito Zeledon of Aflasafe touring visitors.

The team continues to overcome many obstacles such as aflatoxin denialism, doubts on the efficacy of the technology, concerns about registering the products in Africa, skepticism about farmers' adoption, thinking that there are no aflatoxin-conscious buyers, assuming that private sector investment was impossible, and therefore the use of the technology was bound to be donor money dependent. On the other hand, perseverance, awareness creation, meetings, advocacy, and multiple year trials in several countries have proved otherwise.

The research and development efforts conducted by the Aflasafe team is now setting the pace on how biocontrol products should be developed, tested, registered, and transferred to public and private sector partners. Aflasafe belongs to the first generation of non-seed CGIAR technologies, successfully and sustainably making it from the lab to the farm. Adoption and use of this award-winning and impactful technology will ensure the safety of African food systems, improve the health of farmers and consumers, and generate income and trade opportunities for farmers, aggregators, distributors, and traders.

In summary, 2019 was a year to remember. Multiple recognitions at the individual, national, regional, and continental levels were received. Aflasafe, as a component of the A4NH CGIAR Research Program was highlighted among other major impact stories in the CGIAR system.

Director General N. Sanginga in a huddle with Dr Ranajit Bandyopadhyay (left) and Engr. Lawrence Kaptoge at the Aflasafe factory in Ibadan.

Important 2019 milestones:

- Aflasafe SN01 was manufactured for the first time in Senegal by the company BAMTAARE, using an innovative process, the Dry Spore Technology. This long-awaited solution, created to satisfy the needs of IITA partners, will simplify the manufacturing process. The BAMTAARE production allowed treating almost 20,000 ha of crops in Senegal and The Gambia. In addition, 1 ton was sent to Mali for efficacy trials under the Climate Smart Agriculture Technologies (CSAT)-Mali project. Efficacy results were excellent in both commercial and research trials.

- IITA signed a Technology Transfer and Licensing Agreement with A to Z Textile Mills, Ltd. The agreement established a plan for local manufacture, distribution, and sale of Aflasafe TZ01 in Tanzania. This follows IITA's three-phase approach to develop a country-specific commercialization strategy, select investors, and execute the investor's business plan.

- In Ghana, the Ghana Standards Authority launched a National Aflatoxin Sensitization and Management initiative to enhance and extend aflatoxin awareness across the country. This is an initiative funded by the Alliance for a Green Revolution in Africa (AGRA).

- The Ghana Commodity Exchange (GCX) signed a memorandum of understanding with IITA to provide a suite of information products

to increase awareness about aflatoxin and its management, centered on biocontrol.

- In Burkina Faso, the Ministry of Trade, Industry, and Handicrafts, in collaboration with the national farmers' organization, launched a national project to control aflatoxin in maize. This project was funded by the World Trade Organization's Standards and Trade Development Facility. This project facilitates the strengthening of aflatoxin-safe value chains.

- In Togo, IITA is providing advice and assistance on management strategies and Aflasafe product development. An interim committee, chaired by the Ministry of Agriculture, was established to set up an aflatoxin working group and develop a road map for the development of an Aflasafe product tailored to the country's needs. The Ministry of Agriculture organized a stakeholder workshop in December to discuss aflatoxins in the country and to brainstorm a road map to address the problem. The Ministry invited IITA to deliver the keynote presentation on aflatoxins, explain the science behind Aflasafe, and advise on the best way to design aflatoxin management strategies.

- L'Agence Française de Développement (AFD) announced a 2.8 million Euro potential grant for the development of an Aflasafe product for Sudan. This is the first time that AFD funds an IITA project. The investment will support a five-year project to develop and commercialize Aflasafe and complement other national public-private efforts in Sudan. In late 2019, Samil Industrial Co., in collaboration with IITA and the Partnership for Aflatoxin Control in Africa (PACA), hosted a workshop in Khartoum to inaugurate the Multi-stakeholder Partnership for Aflatoxin Mitigation in Sudan – a unique example of a private sector company leading a national initiative to reduce aflatoxin contamination across Africa.

- The first Aflasafe for Africa conference was held in Arusha, Tanzania, on 4-5 November. It brought together partners to report their progress on commercializing Aflasafe, share experiences and lessons learned, build the capacity of other partners on new developments in Aflasafe technology and production, and forge connections between partners, regulators, suppliers of manufacturing equipment and consumables, and aflatoxin-conscious commodity buyers.

- Several publications were written including on (i) atoxigenic strain selection, (ii) efficacy of aflatoxin biocontrol products including a 10-year study in Nigeria, and a 5-year study in Senegal, which demonstrated the effectiveness of the technology under contrasting conditions, its adoption in large scale, and its economic benefits.

To date, 14 Aflasafe products have been registered in 10 African countries (Nigeria, Kenya, Senegal, The Gambia, Burkina Faso, Ghana, Zambia, Tanzania, Malawi, and Mozambique) with more under development in 12 countries.

Aflasafe is now manufactured in four countries and is commercially available in eight, with six African countries including its use in their National Agricultural Investment Plans. More importantly, smallholder farmers have used the product on more than 315,000 ha to produce aflatoxin standard-compliant maize and groundnut.

The work of the Aflasafe team is collectively resulting in reduced aflatoxin contamination in participating countries and is stimulating the demand for Aflasafe on the continent and elsewhere.

Maize farmers now enjoy aflatoxin-free maize crops, thanks to Aflasafe.

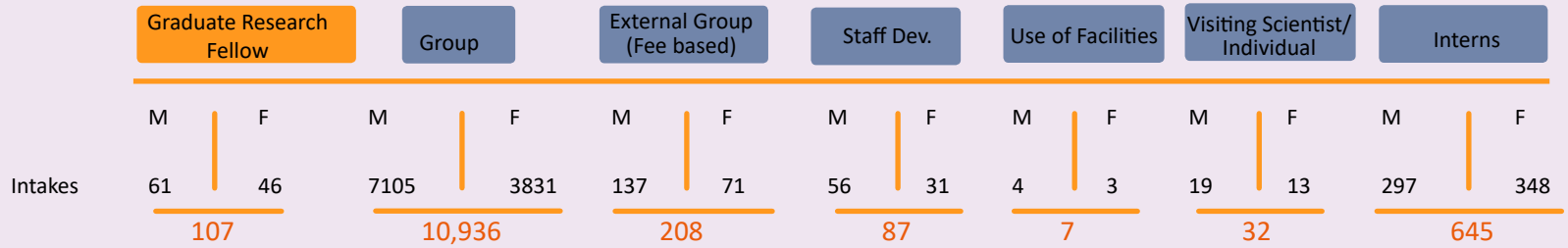
Authors: Ranajit Bandyopadhyay, Alejandro Ortega-Beltran, IITA-Nigeria (Ibadan) and Matieyedou Konlambigue, IITA-Ghana (Accra).

Training & seminars

Youth agripreneurs doing training on food processing for fellow youth.

Training

Types of Training



Group Training

A total of 221 group training were conducted covering Bioinformatics, Cassava Production, Agribusiness, Project Management, Agronomy, Business Plan, Gender and Youth, Aflatoxin Management, Postharvest, Plant Breeding, Integrated Pest Management, R Statistical Programming, Molecular Techniques, Banana Tracking Tool (BTracT), Data Collection, Experimental Design etc. with 10,936 participants (65% male and 35% female) in 19 different countries (Benin, DRC, Ghana, Kenya, Malawi, Mali, Austria, Burundi, Cameroon, Comoros, Cote d'Ivoire, Niger, Sierra Leone, USA, Nigeria, Rwanda, Tanzania, Uganda, Zambia).

Table 1 shows the number of training workshops organized per country, broken down into male and female participants.

Table 1. Training workshops

Country	Training organized (no.)	Male (no.)	Female (no.)	Total (no.)	Country	Training organized (no.)	Male (no.)	Female (no.)	Total (no.)
Austria	1	9	3	**12**	USA	1	6	0	**6**
Benin	3	92	24	**116**	Kenya	5	55	23	**78**
Burundi	11	421	179	**600**	Zambia	2	13	9	**22**
Cameroon	4	33	8	**41**	Malawi	7	393	393	**786**
Comoros	2	51	20	**71**	Mali	2	28	5	**33**
Cote d'Ivoire	1	18	3	**21**	Niger	1	57	7	**64**
DRC	3	42	3	**45**	Rwanda	11	196	60	**256**
Ghana	8	105	53	**158**	Tanzania	16	514	168	**682**
Nigeria	125	4909	2724	**7633**	Uganda	3	31	9	**40**
Sierra Leone	1	12	8	**20**	Online	11	120	132	**252**
					Total	**207**	**7105**	**3831**	**10936**

Staff Development

Table 2. Staff development programs

S/N	Title	Date	Location	Collaborating Unit	Total No.	Male	Female
1	Gender Awareness and Mainstreaming in the Workplace.	4-5 April	Ibadan	Consultant	14	12	2
2	Office Administration and Management	26-28 June	Ibadan	Consultant	6	4	2
3	Microsoft Excel (Intermediary)	2-5 July	Ibadan	Finance	8	5	3
4	Report Writing Skill	30-31 July	Ibadan	Communication	16	7	9
5	Statistical Analysis Using R programming	27-30 August	Ibadan	Cassava	18	10	8
6	Graduate Supervision and Mentoring Skills	16-17 September	Ibadan	Consultant	5	4	1
7	Project Management	18-20 September	Ibadan	Consultant	12	9	3
8	Writing a Winning Proposal	12-15 November	Ibadan	Consultant	8	5	3
					87	**56**	**31**
	Webinars						
1	Awareness and sensitization on sexual harassment for P4D staff	12 April	Online	CDO and HR			285
2	Interns Group Orientation	15 November	Ibadan	CDO and HR	67	38	29
3	Overview of Microsoft 0365 (Outlook, Teams, Skype, OneDrive, SysAid)	February – March	Online	CDO and IT	63	40	23
	Training for Interns						
1	Enhancing Reports and Presentation Skills (IARSAF)	5-6 March	Ibadan	CDO and Communication	31	12	19
2	Data Management Training (IARSAF)	12-14 March	Ibadan	CDO and DIMU	34	20	14
3	Writing a Winning Curriculum Vitae (NYSC)	20-22 March	Ibadan	CDO and HR	63	35	28
4	Statistical Analysis Using R programming (NYSC)	18-19 March	Ibadan	CDO and Biometrics	63	35	28
					191	102	89

External Group Training (fee based)

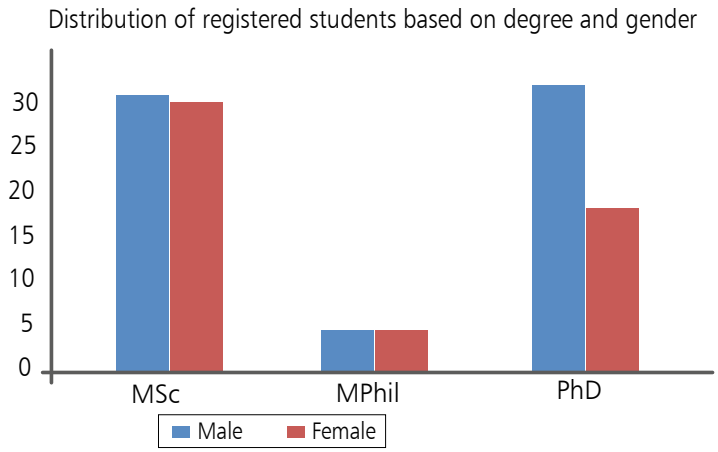
Thirteen external group training were implemented as shown in the table below.

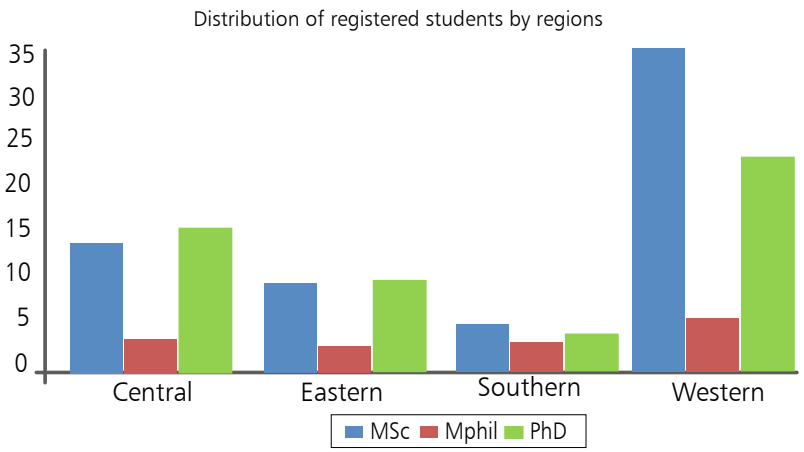
Table 3. List of external training programs

Training	Participants	Male	Female
Agribusiness Development and Management Training	8	6	2
Basic Bioinformatics Workshop	35	18	17
GIS Training	4	4	0
Hands-on Basic Molecular Techniques Workshop	19	8	11
IITA Monitoring and Evaluation (M&E) Training Workshop	15	11	4
Master class on Weed Management Using Mobile Apps for spray service providers	14	14	0
One Day Introductory Agribusiness Training	25	16	9
Policy Brief and Scientific Writing	30	21	9
Quality Seed Production	4	3	1
Research Evidence for Intermediaries Workshop	20	13	7
Research Methodology and Data Management	30	21	9
SAS Training	4	2	2
Total	**208**	**137**	**71**

Graduate Research Fellow

A total of 107 students registered for MSc and PhD programs in 2019 (61 males and 46 females).
The table below shows the distribution across regions, gender, and degrees.

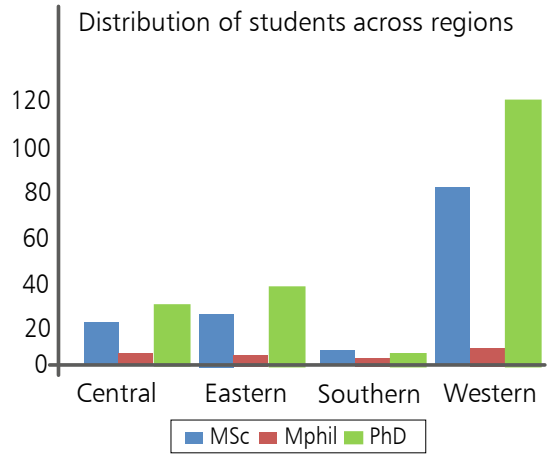


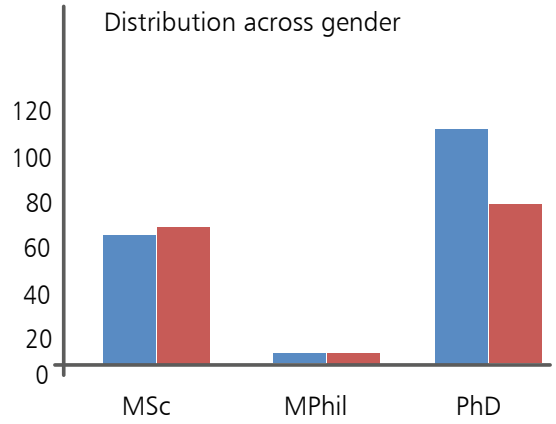


The total number of registered graduate research fellows as at 31 December 2019 was 313. This included newly registered and ongoing students from year 2018. The distribution across countries and stations and degrees are indicated in Table 4.

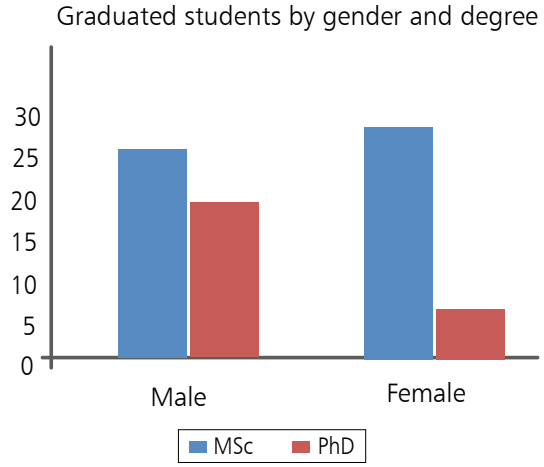
Table 4. List of Graduate Research Fellows.

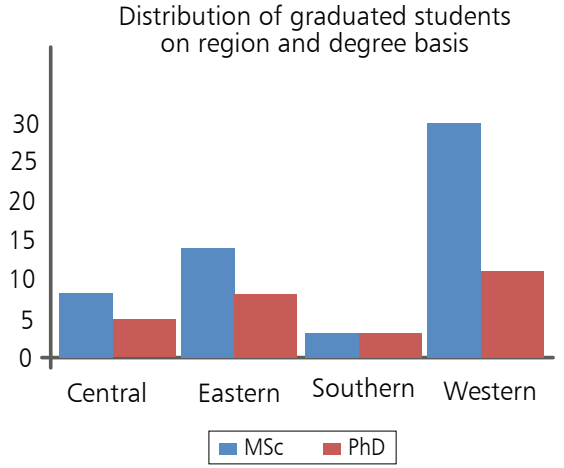
Country	PhD		MPhil		MSc	
	Male	Female	Male	Female	Male	Female
Belgium	2	0	0	0	0	1
Benin Republic	3	1	0	0	0	0
Burundi	2	2	0	0	7	1
Cameroon	7	4	0	0	0	0
DRC	5	3	0	0	3	1
Ethiopia	1	0	0	0	0	0
Ghana	7	6	2	2	4	1
Kenya	9	5	0	0	5	3
Malawi	3	0	0	0	1	2
Niger	0	1	0	0	0	0
Nigeria	55	44	0	0	30	44
Rwanda	0	1	0	0	1	4
Tanzania	8	7	0	0	6	5
Uganda	5	1	0	0	4	1
Zambia	2	0	0	0	0	1





Seventy-four graduate research students completed their program during the year. The distribution across gender, region, and degrees is shown below.





Internship

A total of 645 interns were recruited: 137 graduate interns (56 males & 81 females) at five IITA locations (Kenya, Nigeria, Rwanda, DRC, and Cameroon), 424 IT/SIWES (211 males & 213 females) from 36 higher institutions across Nigeria, 3 batches of NYSC with a total number of 84 (30 males & 54 females). IT/SIWES and NYSC are interns applicable in Nigeria only. Tables 5 and 6 / Figures 1&2 show the distribution of graduate interns across IITA locations and IT/SIWES interns in Nigeria.

Table 5. Graduate Interns.

Country	Male (no.)	Female (no.)	Total (no.)
Kenya	0	4	4
Nigeria	54	73	127
Rwanda	0	2	2
DRC	2	0	2
Cameroon	0	2	2
Total	56	81	137

Table 6. IT/SIWES and NYSC Interns.

Country	Male (no.)	Female (no.)	Total (no.)
IT/SIWES	211	213	424
NYSC	30	54	84
Total	241	267	508

Figure 1. Graduate Interns.

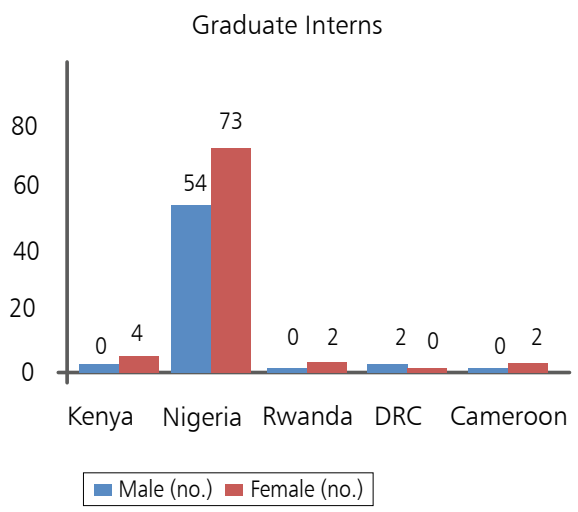
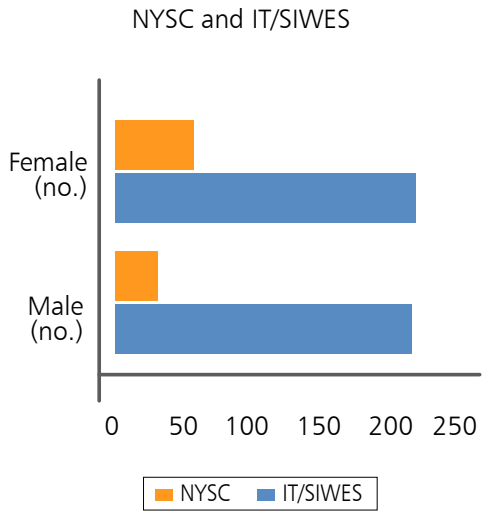


Figure 2. IT/SIWES and NYSC Interns.



Talent Grant

A total of 18 awards were given.

No.	Hubs	No.	Male	Female	Type	
1	Western Africa	11	9	2	Individual	17
2	Eastern Africa	3	0	3	Group	1
3	Central Africa	2	2	0		
4	Southern Africa	2	2	0		
		18				18

Publications

Young researchers using Knowledge Center facilities in IITA, Ibadan, Nigeria.

Publications

In 2019, IITA scientists published 234 articles in peer-reviewed Thomson-indexed journals. The top 50 articles with the highest impact factor from the different hubs are presented here by research theme.

Biotech & Plant Breeding

Tripathi, L., Ntui, V. O. & Tripathi, J. Application of genetic modification and genome editing for developing climate-smart banana. *Food and Energy Security*, 2019. 1–16. Impact factor: **4.781**

Amah, D., van Biljon, A., Maziya-Dixon, B., Labuschagne, M. & Swennen, R. Effects of In vitro polyploidization on agronomic characteristics and fruit carotenoid content; implications for banana genetic improvement. *Frontiers in Plant Science*. 10: 1450, 2019. 1–12. Impact factor: **4.106**

Batte, M., Swennen, R., Uwimana, B., Akech, V., Brown, A., Tumuhimbise, R. , Hovmalm, H. P., Geleta, M. & Ortiz, R. Crossbreeding east African highland bananas: lessons learnt relevant to the botany of the crop after 21 years of genetic enhancement. *Frontiers in Plant Science*. 10: 81, 2019. 1–9. Impact factor: **4.106**

Gedil, M. & Menkir, A. An integrated molecular and conventional breeding scheme for enhancing genetic gain in maize in Africa. *Frontiers in Plant Science*, 10: 1430, 2019. 1–17. Impact factor: **4.106**

Ikeogu, U. N., Akdemir, D., Wolfe, M., Okeke, U. G., Chinedozi, A., Jannink, J. & Egesi, C. Genetic correlation, genome-wide association and genomic prediction of portable NIRS predicted carotenoids in cassava roots. *Frontiers in Plant Science*. 10:1570, 2019. 1–11. Impact factor: **4.106**

IITA scientist explaining about the IITA display at an exhibition.

Merga, I. F., Tripathi, L., Hvoslef-Eide, A. K. & Gebre, E. Application of genetic engineering for control of bacterial wilt disease of enset, Ethiopia's sustainability crop. *Frontiers in Plant Science*. 10: 133, 2019. 1–8. Impact factor: **4.106**

Simonikova, D., Nemeckova, A., Karafiatova, M., Uwimana, B., Swennen, R., Dolezel, J. & Hribova, E. Chromosome painting facilitates anchoring reference genome sequence to chromosomes In Situ and integrated karyotyping in banana (*Musa* spp.). *Frontiers in Plant Science*. 10: 1503, 2019. 1–12. Impact factor: **4.106**

van Wesemael, J., Kissel, E., Eyland, D., Lawson, T., Swennen, R., & Carpentier, S. Using growth and transpiration phenotyping under controlled conditions to select water efficient banana genotypes. Frontiers in Plant Science, 10: 352, 2019. 1–14. Impact factor: **4.106**

Agre, A. P., Asibe, F., Darkwa, K., Edemodu, A., Bauchet, G. J., Asiedu, R., Adebola, P. O. & Asfaw, A. Phenotypic and molecular assessment of genetic structure and diversity in a panel of winged yam (*Dioscorea alata*) clones and cultivars. *Scientific Reports*. 9: 18221, 2019. 1–11. Impact factor: **4.011**

Annor, B., Badu-Apraku, B., Nyadanu, D., Akromah, R. & Fakorede, M. Testcross performance and combining ability of early maturing maize inbreds under multiple-stress environments. *Scientific Reports*. 9: 13809, 2019. 1–11. Impact factor: **4.011**

Drapal, M., de Carvalho, E. B., Rouard, M., Amah, D., Sardos, J., & Van den Houwe, I., Brown, A., Roux, N., Swennen, R. & Fraser, P. D. Metabolite profiling characterises chemotypes of musa diploids and triploids at juvenile and preflowering growth stages. *Scientific Reports. 9:* 4657, 2019. 1–10. Impact factor: **4.011**

Tripathi, L., Tripathi, J., Shah, T., Muiruri, K. S. & Katari, M. S. Molecular basis of disease resistance in banana progenitor *Musa balbisiana* against *Xanthomonas campestris* pv. *musacearum*. *Scientific Reports*, 9: 7007, 2019. 1–17. Impact factor: **4.011**

Nyine, M., Uwimana, B., Akech, V., Brown, A., Ortiz, R., Dolezel, J., Lorenzen, J. & Swennen, R. Association genetics of bunch weight and its component traits in east African highland banana (*Musa* spp. AAA group). *Theoretical and Applied Genetics*, 2019. 1–14. Impact factor: **3.926**

Badu-Apraku, B., Talabi, A. O., Fakorede, M., Fasanmade, Y., Gedil, M., Magorokosho, C. & Asiedu, R. Yield gains and associated changes in an early yellow bi-parental maize population following genomic selection for Striga resistance and drought tolerance. *BMC Plant Biology*. 19: 129, 2019. 1–17. Impact factor: **3.670**

Natural Resource Management

Stevenson, J., Vanlauwe, B., Macours, K., Johnson, N., Krishnan, L., Place, F., Spielman, D., Hughes, K. & Vlek, P. Farmer adoption of plot- and farm-level natural resource management practices: between rhetoric and reality. *Global Food Security*. 20, 2019. 101–104. Impact factor: **5.456**

Buchen, C., Roobroeck, D., Augustin, J., Behrendt, U., Boeckx, P. & Ulrich, A. High N2O consumption potential of weakly disturbed fen mires with dissimilar denitrifier community structure. *Soil Biology & Biochemistry*, 130, 2019. 63–72. Impact factor: **5.290**

Leip, A., Ledgard, S., Uwizeye, A., Palhares, J. C. P., Aller, M. F., Amon, B., Binder, M., Cordovil, C. M., De Camillis, C., Dong, H., Fusi, A., Helin, J., Hortenhuber, S., Hristov, A. N., Koelsch, R., Liu, C., Masso, C., Nkongolo, N. V., Patra, A. K., Redding, M. R., Rufino, M. C., Sakrabani, R., Thomas, G., Vertes, F. & Wang, Y. The value of manure – manure as co-product in life cycle assessment. *Journal of Environmental Management*. 241, 2019. 293–304. Impact factor: **4.865**

Segnini, A., Posadas, A., da Silva, W. T., Milori, D. M., Gavilan, C., Claessens, L. & Quiroz, R. Quantifying soil carbon stocks and humification through spectroscopic methods: a scoping assessment in EMBU-Kenya. *Journal of Environmental*

Management. 234, 2019. 476–483. Impact factor: **4.865**

Mathenge, C., Thuita, M., Masso, C., Gweyi-Onyango, J. & Vanlauwe, B. Variability of soybean response to rhizobia inoculant, vermicompost, and a legume-specific fertilizer blend in Siaya County of Kenya. *Soil and Tillage Research*. 194: 104290, 2019. 1–13. Impact factor: **4.675**

Roobroeck, D., Hood-Nowotny, R., Nakubulwa, D., Tumuhairwe, J. B., Mwanjalolo, M. J., Ndawula, I. & Vanlauwe, B. Biophysical potential of crop residues for biochar carbon sequestration and co-benefits, in Uganda. *Ecological Applications*, 2019. 1–10. Impact factor: **4.378**

Hendriks, C.M.J., Stoorvogel, J., Lutz, F. & Claessens, L. When can legacy soil data be used, and when should new data be collected instead? *Geoderma*. 348, 2019. 181–188. Impact factor: **4.336**

Ampaire, E., Acosta, M., Huyer, S., Kigonya, R., Muchunguzi, P., Muna, R. & Jassogne, L. Gender in climate change, agriculture, and natural resource policies: insights from east Africa. *Climatic Change*, 2019. 1–18. Impact factor: **4.168**

Wichern, J., Descheemaeker, K., Giller, K., Ebanyat, P., Taulya, G. & van Wijk, M. T. Vulnerability and adaptation options to climate change for rural livelihoods—a country-wide analysis for Uganda. *Agricultural Systems*. 176, 1–14. Impact factor: **4.131**

Marinho, F., Oehl, F., da silva, I. R., Coyne, D., da Nobrega Veras, J. S. & Maia, L. C. High diversity of arbuscular mycorrhizal fungi in natural and anthropized sites of a Brazilian tropical dry forest (Caatinga). *Fungal Ecology*. 40, 2019. 82–91. Impact factor: **3.990**

Vanlauwe, B., Hungria, M., Kanampiu, F. The role of legumes in the sustainable intensification of African smallholder agriculture: lessons learnt and challenges for the future. *Agriculture, Ecosystems and Environment*, 2019. 1–13. Impact factor: **3.954**

Katterer, T., Roobroeck, D., Andren, O., Kimutai, G., Karltun, E., Kirchmann, H., Nyberg, G., Vanlauwe, B. & Roing de Nowina, K. Biochar addition persistently increased soil fertility and yields in maize-soybean rotations over 10 years in sub-humid regions of Kenya. *Field Crops Research*. 235, 2019. 18–26. Impact factor: **3.868**

Schoorl, J. M., Veldkamp, A., Claessens, L., Wijbrans, J. R., Olago, D. O. & Lievens, C. Late quaternary lahars and lava dams: fluvial responses of the upper Tana river (Kenya). *Geomorphology*. 341, 2019. 28–45. Impact factor: **3.681**

Nutrition/Human health

Carvajal-Yepes, M., Cardwell, K., Nelson, A., Garrett, K. A., Giovani, B., Saunders, D. G. O., Kamoun, S., Legg, J., Verdier, V., Lessel, J., Neher, R. A., Day, R. S., Day, R., Pardey, P., Gullino, M. L., Records, A. R., Bextine, B., Leach, J. E., Staiger, S. & Tohme, J. A global surveillance system for crop diseases. *Science*. 364: 6447, 2019. 1237–1239. Impact factor: **41.037**

Weedall, G. D., Mugenzi, L. M., Menze, B. D., Tchouakui, M., Ibrahim, S. S., Amvongo-Adjia, N., Irving, H., Wondji, M. J., Tchoupo, M., Djouaka, R. F., Riveron, J. & Wondji, C. S. A cytochrome P450 allele confers pyrethroid resistance on a major African malaria vector, reducing insecticide-treated bednet efficacy. *Translational Medicine*. 11(484): eaat7386, 2019. 1–13. Impact factor: **17.161**

Udomkun, P., Tirawattanawanich, C., Ilukor, J., Sridonpai, P., Njukwe, E., Nimbona, P. & Vanlauwe, B. Promoting the use of locally produced crops in making cereal-legume-based composite flours: an assessment of nutrient, antinutrient, mineral molar ratios, and aflatoxin content. *Food Chemistry*. 286, 2019. 651–658. Impact factor: **5.399**

Gondwe, T., Alamu, E. O., Mdziniso, P. & Maziya-Dixon, B. Cowpea (*Vigna unguiculata* (L.) Walp) for food security: an evaluation of end-user traits of improved varieties in Swaziland. *Scientific Reports*. 9: 15991, 2019. 1–6. Impact factor: **4.011**

Shumo, M., Osuga, I.M., Khamis, F.M., Tanga, C.M., Fiaboe, K., Subramanian, S., Ekesi, S., Van Huis, A. & Borgemeister, C. The nutritive value of black soldier fly larvae reared on common organic waste streams in Kenya. *Scientific Reports*. 9: 10110, 2019. 1—13. Impact factor: **4.011**

Plant Production/Health

Aregbesola, O. Z., Legg, J., Sigsgaard, L., Lund, O. and Rapisarda, C. Potential impact of climate change on whiteflies and implications for the spread of vectored viruses. Journal of Pest Science. 92(2), 2019. 381–392. Impact factor: **5.133**

Agbetiameh, D., Ortega-Beltran, A., Awuah, R. T., Atehnkeng, J., Islam, M. S., Callicott, K., Cotty, P. & Bandyopadhyay, R. Potential of atoxigenic Aspergillus flavus vegetative compatibility groups associated with maize and groundnut in Ghana as biocontrol agents for aflatoxin management. *Frontiers in Microbiology*. 10: 2069, 2019. Impact factor: **4.259**

Bandyopadhyay, R., Atehnkeng, J., Ortega-Beltran, A., Akande, A., Falade, T. D. O. & Cotty, P. "Ground-truthing" efficacy of biological control for aflatoxin mitigation in farmers' fields in Nigeria: from field trials to commercial usage, a 10-year study. *Frontiers in Microbiology*. 10: 2528, 2019. 1–23. Impact factor: **4.259**

Kachapulula, P., Bandyopadhyay, R. & Cotty, P. Aflatoxin contamination of non-cultivated fruits in Zambia. *Frontiers in Microbiology* 10: 1840, 2019. 1–9. Impact factor: **4.259**

Shenge, K. C., Adhikari, B. N., Akande, A., Callicott, K., Atehnkeng, J., Ortega-Beltran, A., Kumar, P. L., Bandyopadhyay, R. & Cotty, P. *Frontiers in Microbiology* 10: 1840, 2019. 1–9. Impact factor: **4.259**

Wolfgang, A., Taffner, J., Guimaraes, R. A., Coyne, D. & Berg, G. Novel strategies for soil-borne diseases: exploiting the Microbiome and volatile-based mechanisms toward controlling Meloidogyne-based disease complexes. *Frontiers in Microbiology*. 10: 1296, 2019. 1–15. Impact factor: **4.259**

Bubici, G., Kaushal, M., Prigigallo, M. I., Gomez-Lama Cabanas, C. & Mercado-Blanco, J. Biological control agents against Fusarium wilt of banana. *Frontiers in Microbiology*. 10: 616, 2019. 1–33. Impact factor: **4.259**

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Our finances & supporters

Woman vendor selling yam roots in a market in Ibadan, Nigeria, counts her money at the end of the market day.

Funding overview

Funding for 2019 was US$100.040 million, of which 99.61% came from CRP and Non-CRP funding windows and 0.39% from other sources. Expenditures were US$99.576 million (net of indirect costs recovery of US$10.100 million) of which 89.9% was used for program expenses and 10.1% for management and general expenses.

The governments and agencies that provided the largest share of our funding in 2018 and 2019 are shown in Figure 1 (top 10 donors).IITA`s 2019 total budget-cum-total expenditure are respectively depicted in Figures 2 and 3. Table 1 shows Investment by CRP and Non-CRP funding windows. Table 2 gives an indication of the financial health of IITA, while Table 3 lists the various investors.

A vibrant and colorful grains market in Nigeria.

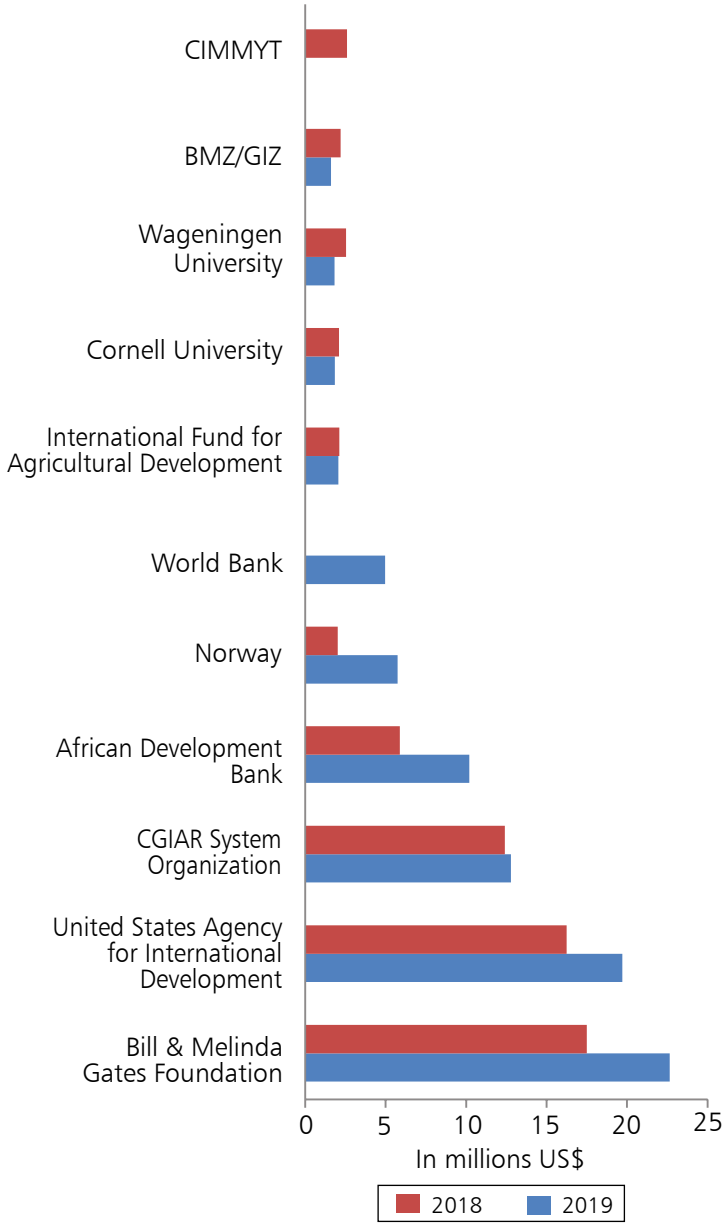

Figure 1. Funding: top 10 donors, 2018 and 2019.

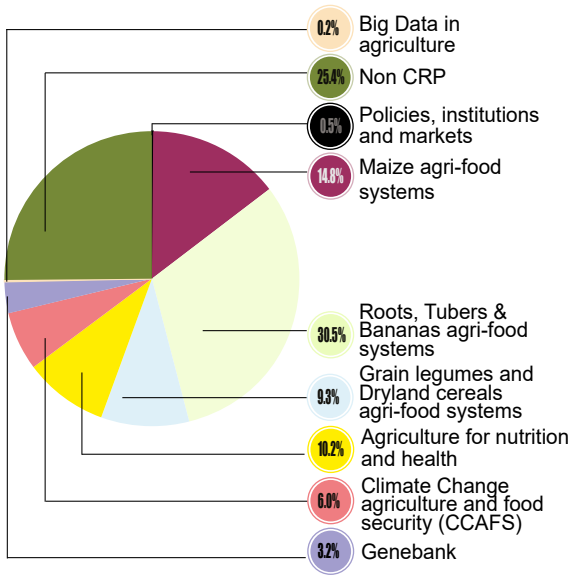

Figure 2. 2019 Investment by CRP and Non-CRP Funding Windows - Budget.

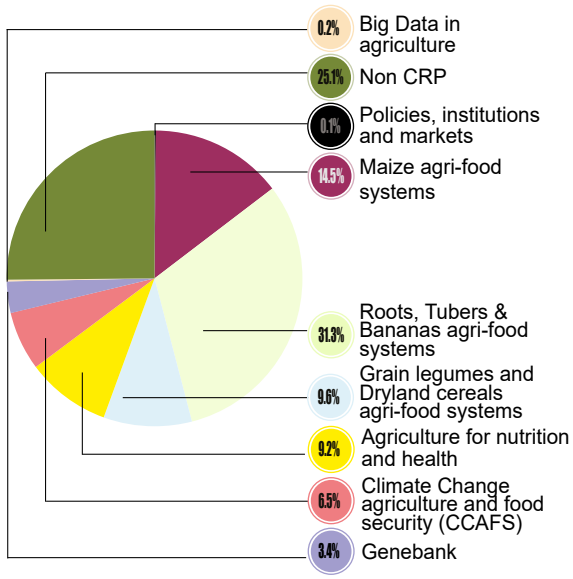

Figure 3. 2019 Investment by CRP and Non-CRP Funding Windows - Expenditure.

Table 1. 2019 Investment by CRP and Non-CRP Funding Windows.

CRP / Non-CRP	Budget ($`000) W1/W2	Budget ($`000) Window 3 / Bilateral Project	Budget ($`000) Total	Actual Expenses ($`000) W1/W2	Actual Expenses ($`000) Window 3 / Bilateral Project	Actual Expenses ($`000) Total
Policies, Institutions and Markets	139	375	514	139	9	148
Maize agri-food systems	1,840	14,361	16,201	1,840	12,594	14,434
Roots, Tubers and Bananas agri-food systems	5,182	28,334	33,516	4,602	26,596	31,198
Grain Legumes and Dryland Cereals agri-food systems	974	9,278	10,252	974	8,628	9,602
Agriculture for Nutrition and Health	1,637	9,504	11,141	1,620	7,557	9,177
Climate Change, agriculture and food security (CCAFS)	259	6,364	6,623	259	6,174	6,433
Genebank Platform	3,296	197	3,493	3,296	118	3,414
Big Data in agriculture	54	122	176	54	136	190
CRP / Platform	**13,382**	**68,535**	**81,917**	**12,786**	**61,811**	**74,597**
Non-CRP	**-**	**27,821**	**27,821**	**-**	**25,055**	**25,055**
	13,382	**96,356**	**109,738**	**12,786**	**86,866**	**99,652**

Table 2. Performance indicators: Financial health.

	2019	2018
Long-term Financial Stability (adequacy of reserves)	29.4 days	30.9 days
Indirect Cost Rates	15.17%	15.98%
Cash Management on Restricted Operations	0.99	1.30
Audit Opinion	Unqualified / Clean Bill of Financial Health	

Table 3. List of IITA investors.

Investors	2019	2018
	(expressed in US$ thousands)	
African Development Bank	10,197	5,883
African Union Commission	230	-
AgBiome	110	8
AGRA	193	-
ANADARKO	1,033	601
Austria	7	304
Belgium	924	676
Bill & Melinda Gates Foundation	22,655	17,503
BMZ/GIZ	1,605	2,219
Burundi	-	778
Cameroon	-	1,519
CGIAR System Organization	12,786	12,420
Chemonics	-	6
Chevron Nigeria Limited	85	101
CIRAD	8	154
Commission of the European Communities	244	224
Cornell University	1,850	2,118
Delloite Consulting LLP	1,019	577
Democratic Republic of Congo	584	420
Donald Danforth Plant Science Centre	254	332
Florida Atlantic University (FAU)	-	339
Food and Agriculture Organization	378	159
Friedrich-Alexander-University Erlangen-Nuremberg	188	-
Global Crop Diversity Trust	37	183
Institute of Development Studies, University of Sussex	92	66
International Centre for Tropical Agriculture	-	1,247
International Crop Research Institute for the Semid-Arid Tropics	-	1,215
International Development Research Centre	70	-
International Fertilizer Development Centre	99	11
International Food Policy Research Institute	-	565
International Fund for Agricultural Development	2,078	2,136
International Livestock Research Institute	278	496
International Maize and Wheat Improvement Centre	-	2,617
International Potato Centre	-	1,296
International Relief and Development	100	-
Ireland	450	590
Japan	431	544
Leventis Foundation	73	65
Liberia	148	463
Madagascar	249	91
Michigan State University	70	145
MoFA Sudan	382	410
National Agricultural Research Organization	1,060	379
Natural Resources Institute	58	228
NCSU-North Carolina State University	156	66
Netherlands	96	392
Nigeria	705	1,099
Norway	5,744	2,022
OCP S.A., Morocco	153	8
Purdue University	130	204
Queens University Belfast	-	341
Queensland University of Technology	430	398
Rothamsted Research Limited	191	47
Saint Loius University (SLU)	-	303
Sweden	293	86
Switzerland	938	16
Tanzania	555	557
Technical Centre for Agricultural and Rural Cooperation	472	38
United Kingdom - Department for International Development	41	-
United States Agency for International Development	19,712	16,245
University of California	26	33
University of Edinburgh	158	-
University of Florida	30	174
University of Illinois	151	112
University of Lausanne	163	139
Wageningen University	1,836	2,544
Wellcome Trust - Liverpool School of Tropical Medicine	339	-
World Bank	4,977	23
Miscellaneous Projects	2,799	3,510
Grand Total	**100,123**	**87,445**

Board of Trustees

Headquarters and hubs

Bird’s eye view of the beautiful campus of The President Olusegun Obasanjo Research Center, IITA-DRC station in Kalambo.

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IITA is member of the CGIAR System Organization