

IITA

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CGIAR

2018 Annual Report

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Harnessing research and innovations

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Cover photo: Boots on the ground, eye in the sky: Linking drone-acquired imagery with farm-level georeferenced data to monitor cropland changes within smallholder farming systems in Rwanda. Inset: Rwandan women farmers educating each other on the use of mobile app to monitor crop growth, development and the effect of BAnana Xanthomonas Wilt (BXW) in the farm. Photos by Bode Olaoluwa, IITA.

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Agripreneurs use ICT tools to collect data. Photo by IYA.

Improving livelihoods



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Investing in cassava research and development to improve productivity and reduce poverty

Tesfamicheal Wossen, Arega Alene, Tahirou Abdoulaye, Shiferaw Feleke, Ismail Rabbi, and Victor Manyong

Technological change such as the development and dissemination of improved crop varieties is understood to be the major pathway through which agricultural research brings benefits to society.

Recognizing this fact, IITA, in collaboration with national and international research and development partners, have made substantial investments in developing and disseminating improved cassava varieties and complementary agronomic practices in Nigeria.

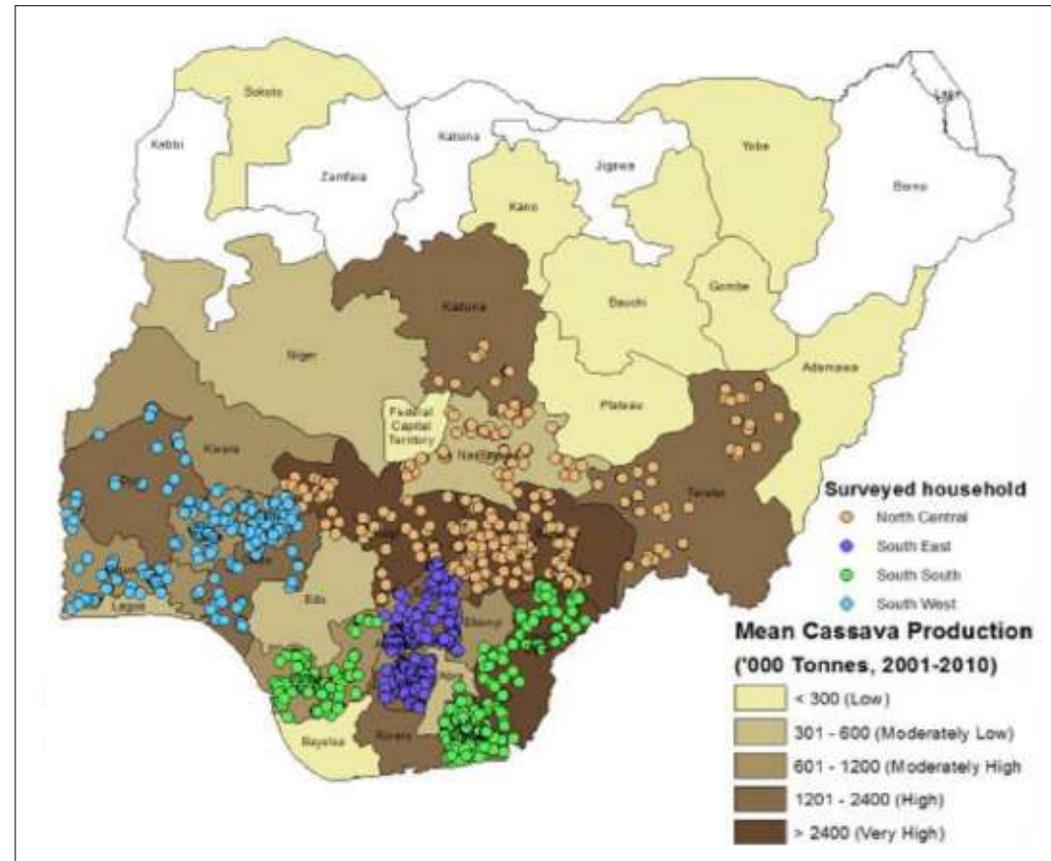
However, despite these major efforts and the importance of cassava for rural livelihood, there is a lack of comprehensive and rigorous evidence on adoption rates and impacts of improved cassava varieties on productivity and poverty related outcomes to justify investment on research for crop genetic improvement.

Measuring adoption for Impact

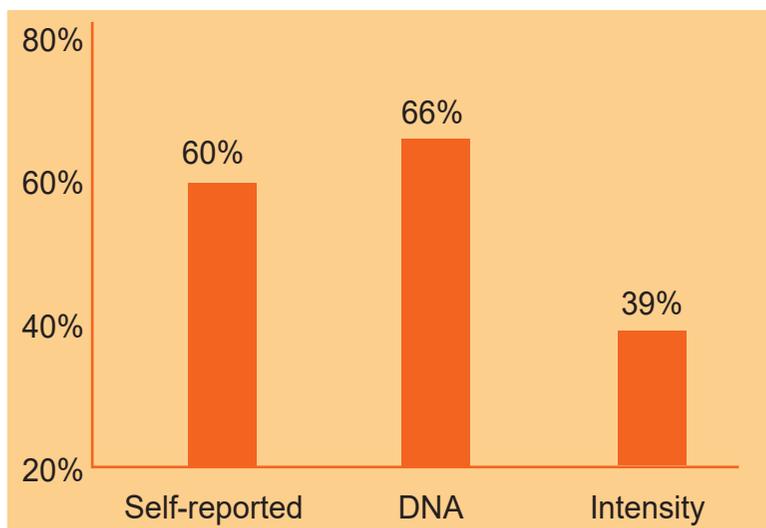
Understanding how and why farmers adopt improved varieties and their subsequent effects on productivity and poverty is

important for targeting and priority setting of technologies that are appropriate to the conditions of smallholders. IITA has successfully implemented a project entitled

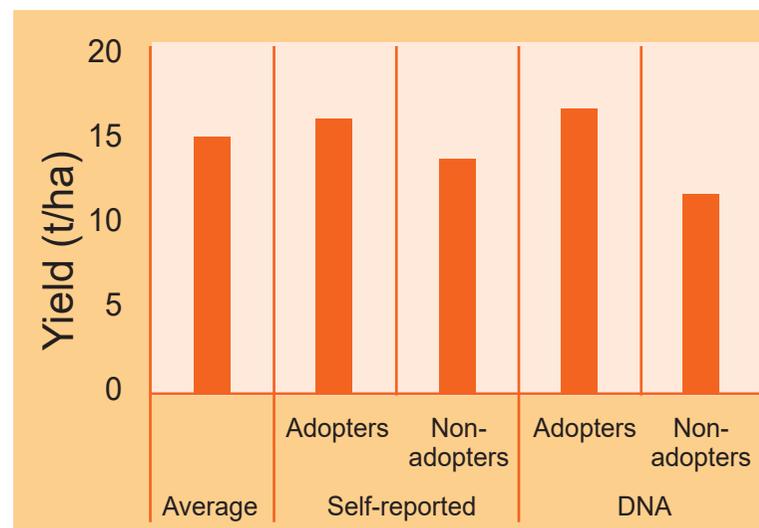
“Cassava monitoring survey (CMS) in Nigeria” that involved breeders, biotechnologists, bioinformaticians, economists, extensionists, agronomists, gender experts, and



Cassava Monitoring Survey study area



Adoption and intensification rate of improved cassava varieties in Nigeria



Cassava yield in Nigeria

postharvest specialists to document adoption rates of improved cassava varieties in Nigeria, a key condition to generate an impact. The CMS project covered 16 states that together account for more than 80% of the total cassava production in Nigeria, and hence is representative at national level.

Since the evidence on the poverty reduction effects of adoption of improved cassava varieties is only as good as its measurement, we used innovative data collection approaches to overcome measurement error-related inference issues. This project also introduced a new and innovative improved cassava variety tracking system using DNA-fingerprinting approach. Traditionally, adoption and its impacts on productivity and poverty have been estimated using self-reported adoption data. However, in the presence of weak variety maintenance and dysfunctional seed

certification system, measurement error in self-reported adoption data can be considerable, which leads to biased reporting of impacts on poverty reduction.

DNA fingerprinting offers a reliable method to accurately identify varieties grown by farmers and serves as a benchmark to measure the productivity and poverty reduction effects of adoption. Results from the CMS survey shows that about 60% of the farmers growing cassava have adopted improved cassava varieties. However, when adoption was measured using DNA-fingerprinting approach, it was found to be about 66%. Despite higher adoption rates, the intensification rate of improved cassava varieties was found to be about 39%, which is quite modest. Intensification rate of improved cassava varieties would have been higher if access to extension, availability of

planting material as well as access to input and output markets were enhanced.

A comparison between DNA-fingerprinting and household survey adoption data further showed that 42% of the respondents misreported their adoption status. In particular, about 28% of the farmers believed that they grow local varieties when they actually grow improved varieties. Similarly, about 13% of the households believed that they grow improved varieties when they actually grow local varieties.

Measuring productivity impacts

The graph shows average cassava yield in Nigeria using self-reported and DNA-fingerprinted adoption status. The average cassava yield in Nigeria is about 14.7 t/ha, with adopters reporting significantly higher yields than non-adopters, irrespective of the way adoption status is measured.



However, the yield difference between adopters and non-adopters is higher when adoption is measured by DNA-fingerprinting. This is so because the DNA-fingerprinting approach captures “genetic quality” more precisely. Using DNA-fingerprinted adoption data, we find that adoption of improved cassava varieties is associated with an 82% increase in cassava yields. When self-reported adoption data are used, that increase is only 60%. Thus, imprecise measurement of adoption status results in underestimation of the true productivity effects of improved cassava varieties by 18 percentage points. More accurate identification of improved varieties is key to generate robust evidence for prioritizing and justifying investment in the agricultural sector.

Impacts on poverty

How effective were productivity gains in reducing poverty? Despite large gains in productivity, the relationship between agricultural research and poverty reduction is not straightforward as benefits may not be accrued uniformly across different income groups. For example, adoption can be beneficial on average albeit ineffective in improving the income of the most vulnerable and poor farmers, who are often constrained by structural barriers that make improved technologies inaccessible and less profitable for them. Theoretically, adoption of improved cassava varieties may reduce poverty directly through productivity gains and indirectly through output, input, and labor market adjustments. By combining DNA-based adoption status with the individual- and market-level economic model, we found that adoption of improved cassava varieties contributed to reducing poverty by an estimated 4.6 percentage points, implying that 7.5 percent of the rural poor cassava producers (about 1.62 million individuals) have escaped poverty in 2015/16.

The poverty reduction impact of adoption would have been underestimated by 40% had we used traditional survey approaches instead of DNA fingerprinting. This suggests that more precise tracking of improved varieties is crucial to prioritize interventions and funding research in the agricultural sector. Further, we also found that adoption of improved cassava varieties has a heterogeneous impact. In particular, farmers who are more likely to be adopters are also likely to face higher input costs. Addressing structural and technical barriers that make adoption expensive for these groups of farmers is, therefore, important to maximize the poverty reduction effects of improved cassava varieties in Nigeria.

Edible insects: a neglected resource for food security in Africa



¹Christopher Mutungi, ²Francis Irungu, ¹Komi Fiaboe, ¹Abass Adebayo

Introduction

Insects are part of the diet for humans and domesticated animals in many African cultures. Insect farming has great potential to contribute to food security by increasing the essential nutrients—protein and micronutrients—in human and livestock diets. To this end, IITA scientists and partners reviewed and consolidated available evidence of postharvest technologies for edible insects in Africa (<https://cgspace.cgiar.org/handle/10568/93015>), identifying new research areas that can enhance the access to and consumption of edible insects as a resource for increasing food security and nutrient quality.



Edible mopane caterpillars are popularly consumed in Southern Africa countries, Photo by A. Abass, IITA

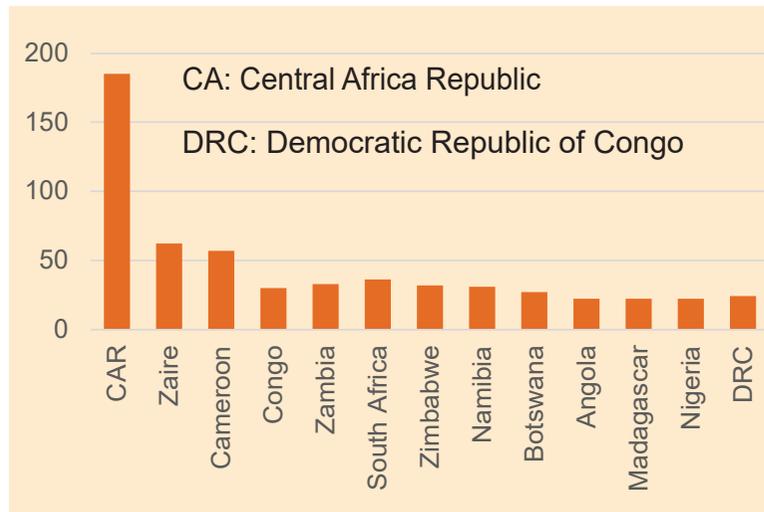


Figure 1. Consumption of edible insect species in Africa

Africa: a hotspot for edible insect biodiversity

Over 500 insect species are eaten by humans or used to feed animals in 34 African countries. The Central African region uses the highest number of insect species (256) followed by Southern (164), Eastern (100), and West Africa (91). At least 13 countries consume more than 20 insect species. The insects include caterpillars of butterfly and moth (30%), grasshoppers, locusts and crickets (29%), beetles (19%), and others such as termites, wasps, bees, ants, bugs, and flies (22%).

Insects as source of food and revenue

There is abundant evidence on the role of insects in the human diet and the economic conditions of communities. Fresh, fried, smoked, roasted, and dried insects are found in village markets and favorite species reach urban markets and restaurants. The consumption of insects helps in closing the gap in total protein intake in many communities. Insect consumption is seasonal and could be significantly high during the lean periods including before crop harvest, serving as food insurance and a source of revenue in many

rural areas. In Uganda, grasshoppers contribute about 500 g of protein in diets of consuming individuals annually. In the DRC, caterpillars constitute 40% of the total animal protein consumption of the population. It was estimated that the average household in Kinshasa consumed 300 g of caterpillars each year, translating to 96 metric tons of caterpillars consumed in the city in the 1990s.

Among the Gbaya people of Central African Republic, insect consumption accounts for 15% of the protein intake, while 95% of the population that lives in the forest zones was reported to depend on insects to meet their protein, fat, and micronutrient needs. In Zambia, caterpillars are the single most important source of nutrients during the lean season and constitute 40% of the specialties consumed by the Lala tribe during this period. In Zimbabwe, 90% of the population consumed insects and the practice contributed significantly to the prevention of protein malnutrition and kwashiorkor among the children of poor rural communities.

In terms of revenue generation, edible grasshoppers and moth caterpillars are sold at higher prices than beef in Uganda and Nigeria. The income from moth caterpillars in Botswana was estimated to be approximately 13% of total annual household revenue at the turn of the century. Cross-border trades in edible mopane worms was reported to employ over 30,000 people every season across Zambia, Botswana and South Africa, contributing about US\$85 million in annual sales. Thus, grasshoppers, termites, crickets, palm weevils, and other insects that are consumed across Africa every year represent an enormous overall trade value.

New opportunities

Improving processing and packaging

Traditionally, the harvested insects are processed by smoking, brining, frying, steaming, boiling, roasting, toasting, and drying, and are packaged in tins, plastic containers, baskets, or sacks. For safety reasons and the need for retention of the nutritional composition of processed insects, these indigenous processes require optimization. There is ample evidence that

during the indigenous processing practices, the insects may accumulate biological or chemical contaminants that are potentially hazardous and anti-nutritive.

Recent research on effective insect processing and packaging aim to minimize food hazards and increase shelf life (<https://doi.org/10.1016/j.foodres.2018.01.012>). There are indications that better hazard control and product upgrade or standardization can be achieved if indigenous processing practices are supported with quality assurance mechanisms by applying hygiene and safety management tools such as Good Manufacturing Practices (GMP) and Hazard Analysis Critical Control Point (HACCP). Further research is required to establish alternative processing techniques at the commercial level.

Developing new food and feed products

To derive benefits from edible insects on a large scale, new technologies for intensive insect rearing to replace harvesting from the wild require special attention. Nonetheless, some insect species are already being mass-produced in some parts of the world. The black soldier fly is farmed for animal feed whereas crickets, mealworms, silkworms, grasshoppers, and locusts are farmed for human or pet food. This selection is based on ease of mass production, nutritional content, and environmental implications.

There are prospects in developing new insect-based products such as nutrient-fortified food and feeds, and extracted products.



Indigenous processing and handling here: IITA scientist discusses with a local collector and a buyer mopane worm in Zambia. Notice the caterpillars drying on the ground in contact with soil, and the unhygienic handling and packaging materials. Abass Adebayo, IITA.



Youthful potential entrepreneurs learn hygienic processing of farmed house crickets in Kenya. Francis Irungu, IITA.

Opportunities also exist for small farmers to process intermediate products such as dried powders which can be delivered to food and feed factories as raw material for manufacturing value-added industrial products. Already, insect farming initiatives have taken off in Africa.

However, cost-effective mass-rearing techniques that provide consistent quantities need to be developed, and more value-addition options established.

The use of insects in the animal feed sector has received attention recently due to the rising cost of protein sources for feed formulation. In many African countries, poultry and fish enterprises are among the fastest growing agribusinesses. But the cost of feed is prohibitive, representing 60-70% of total production costs. Insects are natural feed for fish and poultry. Some ground-wheat meal for the manufacture of extruded fish feeds was accomplished <https://cgspace.cgiar.org/handle/10568/92542?show=full>.

Challenges

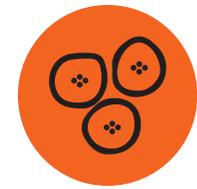
To increase consumption of edible insects beyond the traditional areas, some sociocultural issues need to be addressed. Negative perceptions about insect consumption which is dominant among people and cultures that traditionally do not consume them need to be overcome. The lack of legislative and regulatory frameworks to promote insect-use keeps the insect sector in a state of perpetual dormancy. Also, the lack of quality and safety standards and the absence of guidelines for handling other associated potential risks of insect collection and rearing is partly due to knowledge gaps. It is expected that these challenges will be overcome as more research data becomes available.

These highlights are expounded in a review article published in Critical Reviews in Food Science and Nutrition <https://doi.org/10.1080/10408398.2017.1365330>.

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Can pre-treatment processes improve the quality of fried chips?



Patchimaporn Udomkun¹, Bhundit Innawong², Emmanuel Njukwe¹

Fast food processing, the palatable taste of fried food, and considerable economic benefit make deep-fat frying one of the most popular cooking methods in the household kitchen, fastfood restaurant, street-food vendors, and industries. The sale of pre-cooked and ready-to-eat products such as chicken nugget, French fries, and potato chips, all of which are prepared by deep-frying process has dramatically increased in the western world and is rapidly expanding throughout the developing countries.

Frying involves submerging food in extremely hot oil (~160-180 °C) until it reaches a safe minimum internal temperature. When the food is deep-fried properly, it is endowed with an attractive flavor, golden-brown

pellicle (a skin or membrane on the surface of meat, fish, or poultry, which allow smoke to better adhere to the surface during the smoking process), and crisp texture. While deep-frying can give delicious results, many complex chemical reactions also occur in both the fried material and frying oil. Due to a high uptake of oil in deep-fried food, several studies have shown that consuming this product can be harmful to health as it can lead to coronary heart disease, diabetes, or hypertension. Moreover, a high accumulation of acrylamide – a chemical that can form in some foods during high-temperature cooking processes – in deep-fried food, especially in starchy-rich foods containing asparagine (amino acid) and reducing sugars, can potentially cause degenerative nerve changes via chronic oral intake (Parzefall, 2008), and introduce possible carcinogens to humans, classified in Group 2A by the International Agency for Research on Cancer (IARC) (Hsu et al., 2016).

Vacuum frying technology offers a better alternative in providing healthy and high-quality products to satisfy the expectations of fried food consumers. It is mostly used to preserve qualities of tropical fruits such as pineapple, mango, banana, avocado, and durian, apart from roots and tubers. Vacuum

frying is also a deep-fat frying process, which is carried out in a closed system, below the atmospheric pressure, substantially reducing the boiling point of water and, hence, the frying temperature (~60-70 °C). From the industrial point of view, vacuum frying has shown several advantages, such as lower oil content, lower acrylamide content, better preservation of natural color, flavors, and nutritional compounds, and better energy saving. Many Asian countries such as Indonesia, Thailand, Japan, and Vietnam are using the technology to produce highly nutritious snacks and vacuum-fried fruit can be added as ingredients to a variety of ready-to-eat breakfast cereals.

Apart from the advantage of consumers becoming aware of healthy lifestyles, vacuum frying has certain disadvantages, such as low efficiency especially with low-temperature frying, relatively high oil uptake in products, and quality attributes of fried products need to be improved. To overcome these problems, many processors seek ways to produce lower oil containing products. As a result, there have been strong incentives to introduce several pre-treatment methods that could produce foodstuffs with lower oil contents and with desirable sensory quality characteristics, such as coating with cellulose derivatives and/



or modified starches, dipping in osmotic solutions, or partial dehydration by heating process. However, studies on the use of pre-treatment as a partial dehydration process prior to vacuum frying are rather limited. This study was undertaken with Dr. Bhundit Innawong from the Department of Food Technology, Silpakorn University, Thailand, to investigate the effects of osmotic dehydration (sucrose and salt solutions), microwaving, and air-drying before frying on physical and chemical characteristics of vacuum and atmospheric-fried banana chips. The fryer apparatus is presented below (Figure 1).

To answer the question 'can pre-treatment processes improve the quality of fried banana chips?', the study confirmed that vacuum frying has been demonstrated as a highly promising processing technology enabling the production of safer crisps with improved quality values when compared to atmospheric frying. It was observed that pre-treatment process is a good technique, which can reduce moisture and oil uptake in both atmospheric and vacuum-fried banana chips. Vacuum-fried banana chips have better qualitative parameters resulting in a better-quality value for the pre-treated

fried product with less oil. Due to a lower frying temperature and limited oxygen access, pre-treatment process can also improve the color of banana chips (see Fig. 2). For sensory evaluation, consumers mostly preferred the osmo-dehydrated chips with sugar solution due to a desirable taste and color.

Study results showed that vacuum frying reduced oil uptake and retained high quality of products. This can contribute to design and optimizing frying technologies of starchy-rich foods.



Figure 1. The system for both atmospheric and vacuum frying processes.

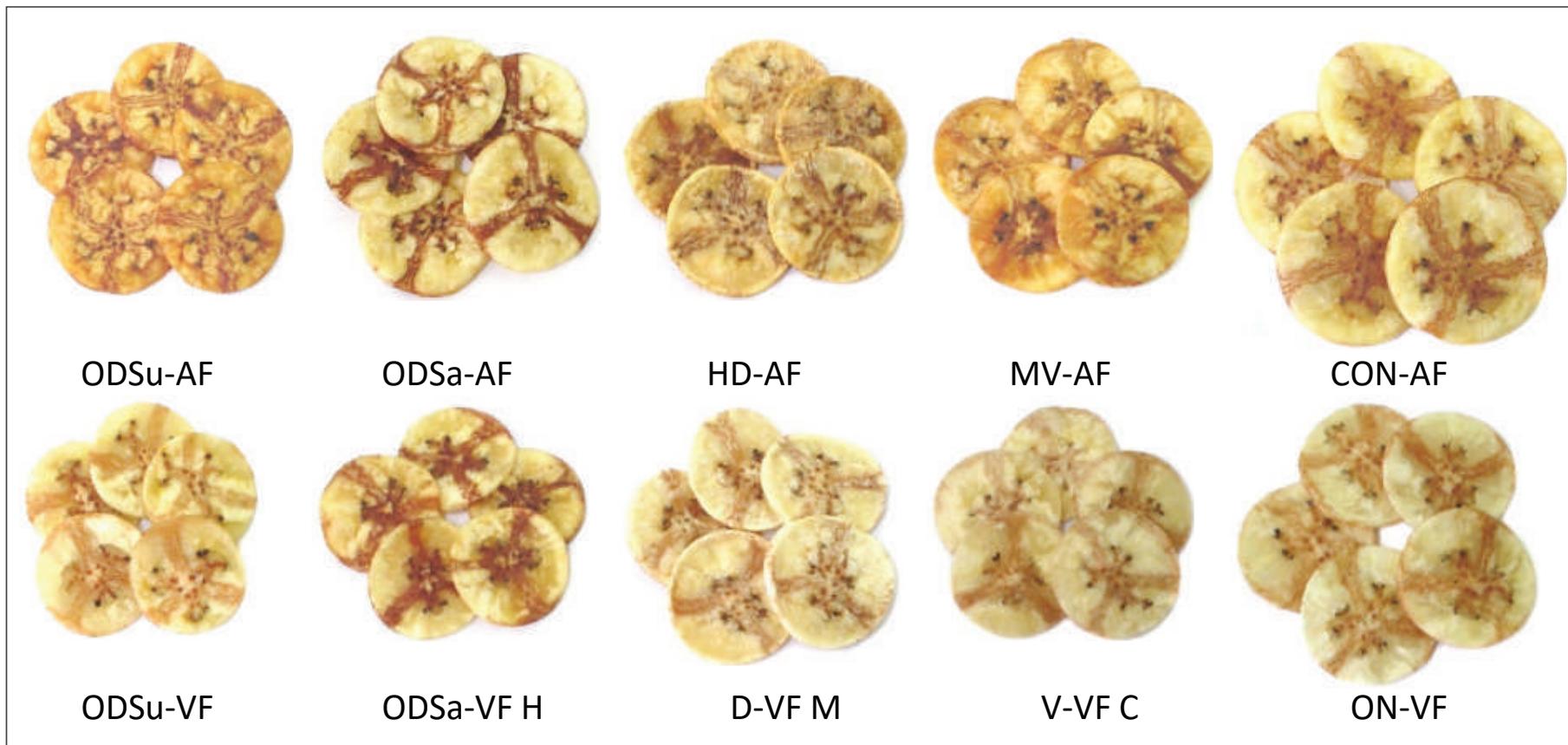


Figure 2. Physical characteristics of pre-treated banana chips fried under atmospheric (AF) and vacuum (VF) frying processes.
 *CON = Control (untreated), ODSu = Osmotic dehydration with 40°Brix sucrose solution, ODSa = Osmotic dehydration with 10% (w/w) salt solution, MV = Microwave, HD = Hot-air drying. In Udomkun P, Innawong B, 2018. Effect of pre-treatment processes on physicochemical aspects of vacuum fried banana chips. *Journal of Food Processing and Preservation* 42(8), <https://doi.org/10.1111/jfpp.13687>

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Identifying priorities for a global cassava research program based on potential economic and poverty impacts

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International cassava improvement research at IITA was initiated in the early 1970s with a focus on developing high-yielding varieties with resistance to major pests and diseases. In addition to breeding for high yield and resistance to major pests and diseases, cassava research involved developing biological control and integrated pest management options to reduce losses due to insect pests. The development of improved varieties and their delivery to national programs for testing under specific local conditions during the late 1970s and 1980s has led to the successful release of hundreds of high-yielding and disease-resistant varieties for adoption by farmers. The new varieties combine enhanced cassava mosaic disease (CMD) tolerance with preferred postharvest characteristics, wider agroecological adaptation, and 50-100% higher yields even without the use of fertilizer.

It is widely recognized that raising agricultural production to the levels needed to feed an increasing world population requires bigger public investments in research and development and widespread adoption of new technologies. Funding for national and international agricultural research, however, has declined in recent years. In this situation, priority setting has become increasingly important for allocating scarce research resources among competing needs to achieve greater impacts.

Table 1. Potential economic and poverty impacts of cassava research options.

Research and technology option	Economic benefits (US\$ million)	Rate of return (%)	Poverty reduction (millions)
High-yielding varieties with resistance to major diseases	1,189	57	1.00
High-yielding varieties with high dry matter and starch	2,143	71	1.27
High-yielding varieties with longer shelf life	1,167	44	0.84
High-yielding, drought-tolerant varieties and increased water-use efficiency	3,025	61	2.00
Sustainable crop and soil fertility management practices	8,284	210	2.66
Integrated pest and disease management practices, including resistant varieties	3,732	60	1.18
Efficient and massive high-quality planting material production and distribution systems	7,585	416	2.10
Processing technologies for value addition	3,345	120	0.92
Strategies to prevent introduction of exotic pests and diseases	1,529	71	0.11
High-yielding varieties tolerant to cold weather and frost	83	23	0.005

Systematic priority assessment has been conducted recently by combining scientists' views on the potential for addressing particular constraints through research and technology options with an economic assessment of the benefits that could arise from adoption of those technologies. Following its official launch in 2012, the CGIAR Research Program on Roots, Tubers and Bananas (RTB)

embarked on a strategic assessment of research priorities for banana, cassava, potato, sweet potato, and yam using partial equilibrium economic surplus models and poverty impact simulations. As part of this larger RTB effort, IITA led the priority assessment for global cassava research program based on the potential economic and poverty reduction impacts of cassava research and technology options.

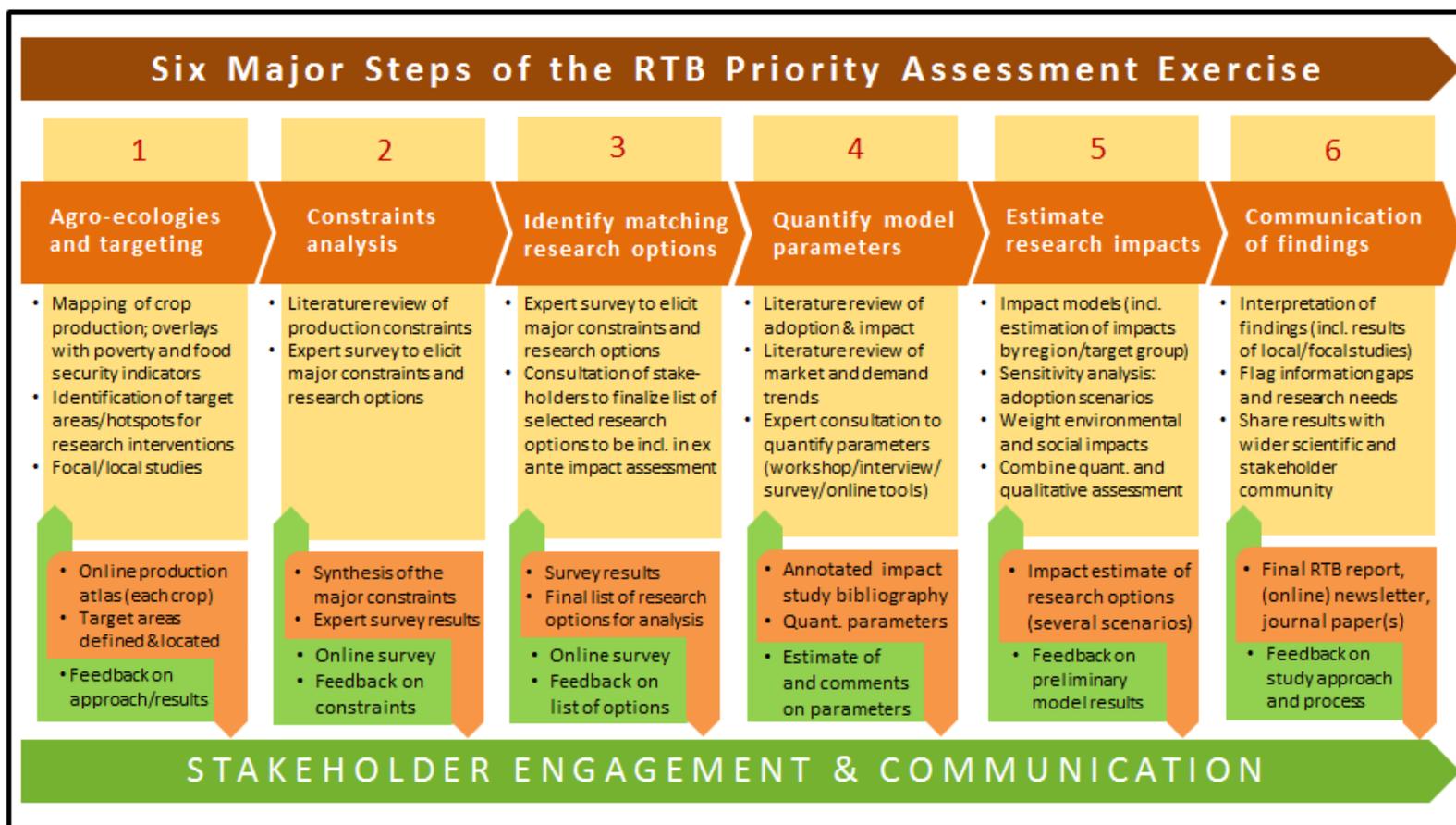


Figure 1. The six-step RTB priority assessment process.

RTB Priority Assessment Process

RTB used a systematic priority assessment procedure to identify where and how to focus the program's resources with a view to achieving the highest possible impacts on food security and poverty reduction. Scientists and stakeholders from across the global RTB community were engaged in a dialogue to increase the relevance and impacts of RTB research. This involved a dynamic, systematic and transparent approach that

included periodic revision and updating of research priorities involving six major steps. The steps are not necessarily consecutive, but complement one another to define RTB priorities in a way that incorporates the most current data and information and engages a wide array of stakeholders from the global RTB community.

The six-step process comprises the following:

(1) Mapping of agroecological zones, crop

production, poverty and food security indicators in to identify target areas where research is most needed; (2) Analysis of the key production constraints; (3) Identification of the most promising research options to address those constraints; (4) Quantification of impact model parameters; (5) Estimation of expected impacts under different adoption scenarios; and (6) Communication of results to stakeholders and the general public.



Pollinating yam flower. Photo by O. Adebayo.

Managing natural resources





Delivering technologies to farmers' organizations for sustainable cassava and maize production

Several cassava and maize genotypes have been developed by the IITA cassava breeding unit in Nigeria focused on improving root yields, starch content, resistance/tolerance for major pests and diseases, nutritional content (e.g., higher provitamin A content), and other characteristics desired by the cassava-based industry.

The deployment of these new varieties into Cameroon required a basic understanding of their performance (root yield and stability, nutritional quality of yellow-root genotypes, and response to pests and diseases) in relation to contrasting environments.

Selected varieties would then be disseminated through development projects like the Agricultural Investment and Market Development Project (PIDMA) in Cameroon.

PIDMA is a joint World Bank/Cameroon government operation that aims at transforming the low productivity and subsistence-oriented cassava, maize, and

sorghum subsectors into commercially oriented and competitive value chains that are inclusive of smallholder farmers, sustainable, and resilient to climate change, and create rural employment. IITA and PIDMA signed a partnership agreement to ensure that smallholder farmers benefit

from gender-equitable interventions. The aim is to provide eligible smallholder cooperatives with technologies for sustainable production such as improved pre-foundation and foundation cassava seedlings and maize (including biofortified varieties) with the following characteristics:



Maize selection by producer in the Far North here: Photo by IITA

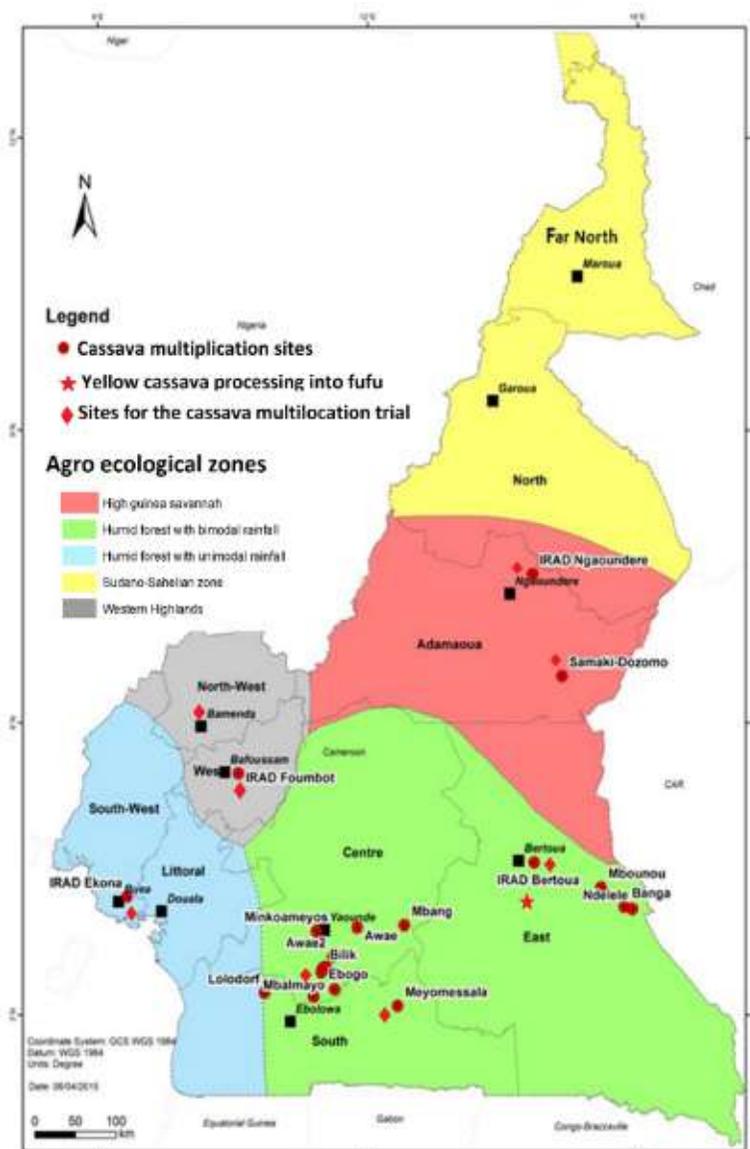


Figure 1. Distribution of improved cassava multiplication sites in Cameroon, PIDMA project

high yielding, disease-resistant, and adapted to targeted production zones.

The project aims to improve the competitiveness of maize, sorghum, and cassava value chains and the access of beneficiary farmers' groups (including women and youths who are direct beneficiaries) to value chain finance and quality food. This is achieved by addressing challenges related to low productivity of cassava and maize landraces, vitamin A deficiency yield loss caused by emerging pests and diseases, and low soil fertility.

The project is implemented in collaboration with PIDMA, Institute of Agricultural Research for Development (IRAD)-Cameroon, and the Ministry of Agriculture and Rural Development (MINADER).

Successes recorded include the introduction of 17 cassava and 13 maize genotypes from IITA-Ibadan which were evaluated in multilocation trials conducted with the national research institute IRAD (Fig. 1). Figure 1. Distribution of improved cassava multiplication sites in Cameroon, PIDMA project

From the trials, five cassava genotypes that had an average fresh root yield between 25 and 30 t/ha in four agroecologies¹, and two maize genotypes with yield between 2.5 and 3.5 t/ha in two agroecologies were selected. Average fresh cassava root yield for the 17 improved varieties over two cropping seasons was 26.9 ± 0.98 t/ha against 16.65 ± 1.23 t/ha for the best local variety (Fig 2). In 2018, 4,395,000 cassava cuttings and 8 t of improved maize seeds of the selected genotypes (including biofortified varieties) were delivered to 37 farmer groups. The cumulative number of improved basic cassava cuttings supplied by IITA to the project for subsequent multiplication into certified seeds is estimated at 8,525,000. Cassava yields in PIDMA cooperatives increased from eight t/ha in 2014 (baseline study) to 21.75 t/ha,

¹Fotso Kuate et al. 2018. AMMI analysis of cassava response to contrasting environments: case study of genotype by environment effect on pests and diseases, root yield, and carotenoids content in Cameroon. Euphytica 214:155



Transport and distribution of Improved cassava cuttings: Photo by IITA

against an expected project target value of 20 t/ha (108.8%). Maize yield increased from 1.5 t/ha to 3.8 t/ha against an expected target value of 4 t/ha (95%).

With the nutrition component, biofortified cassava genotypes were selected for having mean total carotenoid content in fresh yellow roots reaching 10.96 µg/g with genotype I070593. In collaboration with CIRAD, the processing of this yellow cassava into a local cassava-based food (*fufu*) was successfully conducted in the east

region where vitamin A deficiency is among the highest² in the country.

Field surveys and trials were carried out to advise the project on emergent pests and diseases, and soil fertility management in maize and cassava production systems. Results showed (1) various strains of the cassava mosaic virus was mapped in different cassava production basins and in cooperative farms, with lower incidence recorded for improved varieties (9%) compared to local varieties (79%); (2) none

^{<2>}WFP Cameroon Country Brief, May 2018

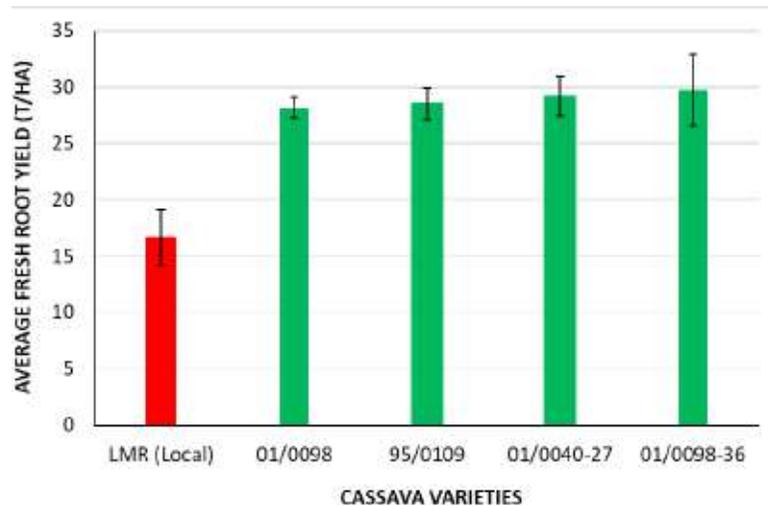


Figure 2. Average yield of four top improved cassava vs the best local variety over two cropping seasons in four agroecological zones in Cameroon.

of the samples collected was tested positive for the cassava brown streak disease; (3) the distribution of the fall armyworm was mapped in the country with the identification of strains and host plants³; (4) five booklets and five brochures on sustainable cassava and maize production and integrated pest management were developed and distributed to cooperatives.

Further research could be conducted on the Provitamin A (PVA) cassava introduced in rural communities to (1) evaluate the effect of



cassava pests and diseases on PVA content, (2) assess the effect of processing technologies on PVA retention, and (3) understand the drivers of adoption of PVA cassava among farming households.

Woman drying yellow cassava for fufu in the East region here. Photo by CIRAD

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Fotso Kuate et al. 2018. AMMI analysis of cassava response to contrasting environments: case study of genotype by environment effect on pests and diseases, root yield, and carotenoids content in Cameroon. *Euphytica* 214:155

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Akilimo: Taking cassava agronomy advice to scale

David Ngome and Pieter Pypers

The ACAI agronomy advice tool, Akilimo, was built to provide optimized and economically beneficial recommendations tailored to the biophysical and socioeconomic situation of cassava growers.

ACAI extension agents carrying out a yield assessment exercise on a trial field in Oyo state in Nigeria. (Photo: D. Ngome, IITA)

The tool considers planting and harvest dates, local soil data, weather

conditions, prices of available fertilizers, cost of land preparation operations, prices of cassava root produce, cropping objectives, risk attitude, and the investment capacity of the farmer.

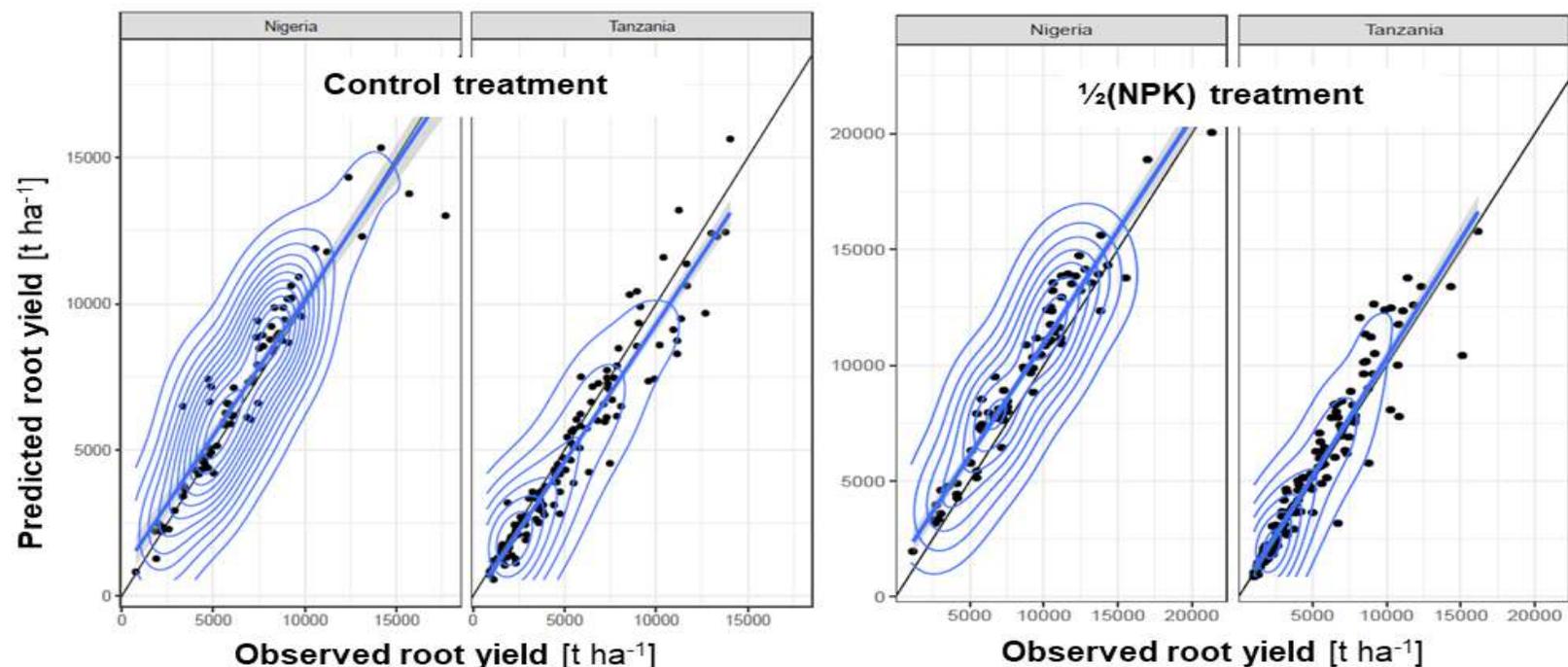
ACAI has been conducting trials in Nigeria and Tanzania in collaboration with national research and development partners to find out how agronomic technologies affect the performance of cassava under different growing conditions. Results showed large variations in response to the variables, indicating the need for tailored recommendations for fertilizer regime, tillage operations, weed management, and advice on overall investments in a cassava cropping system.

Process based crop models and machine learning

To provide tailored recommendations, ACAI has developed an integrated system using machine learning techniques coupled with process-based crop models. To determine fertilizer recommendations, the ACAI team has combined the Light Interception and Utilization model (LINTUL), the Decision Support System for Agrotechnology Transfer (DSSAT), the Quantitative Evaluation of the Fertility of Tropical Soils model (QUEFTS), and economic optimizer algorithms to calibrate the recommendations. The mechanisms put in place determine the soil nutrient supply capacity, yield potential, nutrient-limited yield, and fertilizer rates required to acquire a target yield maximizing net revenue by combining observations from field trials, available GIS data, weather data, and the farmers' ability to invest in fertilizer.

Using the QUEFTS model, the soil NPK supply was accurately predicted using the observed yield response in the Nutrient Omissions Trials. At these locations, the relationship between apparent soil nutrient supply and soil properties obtained from GIS





QUEFTS: The graph showing how well ACAI can predict cassava root yield based on apparent soil nutrient supply using a calibrated QUEFTS model.

layers from the International Soil Reference and Information Centre ([ISRIC](#)) was modeled using machine learning techniques. These models in turn were used to predict the soil NPK supply for the entire target intervention area. These soil properties can sufficiently explain the regional level soil variation. To explain soil variation at short range, however, the GIS layers need to be complemented with a local scale soil fertility indicator.

The use of common local soil fertility indicators, such as local soil name, soil depth/color, cropping history, perception of soil fertility, cropping history, manure/fertilizer use, etc., are not sufficiently generic as their predictive ability depends on the local context. Such

indicators are therefore challenging to use in a standardized way. Within ACAI, current yield was found to be the best generic fertility indicator to adjust the soil nutrient supply at a regional scale to local soil conditions. This process forms a significant part of the research that has gone into developing the prediction engine.

Akilimo: Tailored cassava agronomy advice at scale

Akilimo is an all-in-one agronomic advisory tool that can be used to help intensify cassava farming and increase root and starch yields for cassava growers. The tool is currently providing tailored recommendations packaged in Interactive Voice Response, a smart mobile phone application and printable maps and guides. ACAI is in the process of developing

AKILIMO:

developing and delivering tailored agronomy recommendations to cassava growers

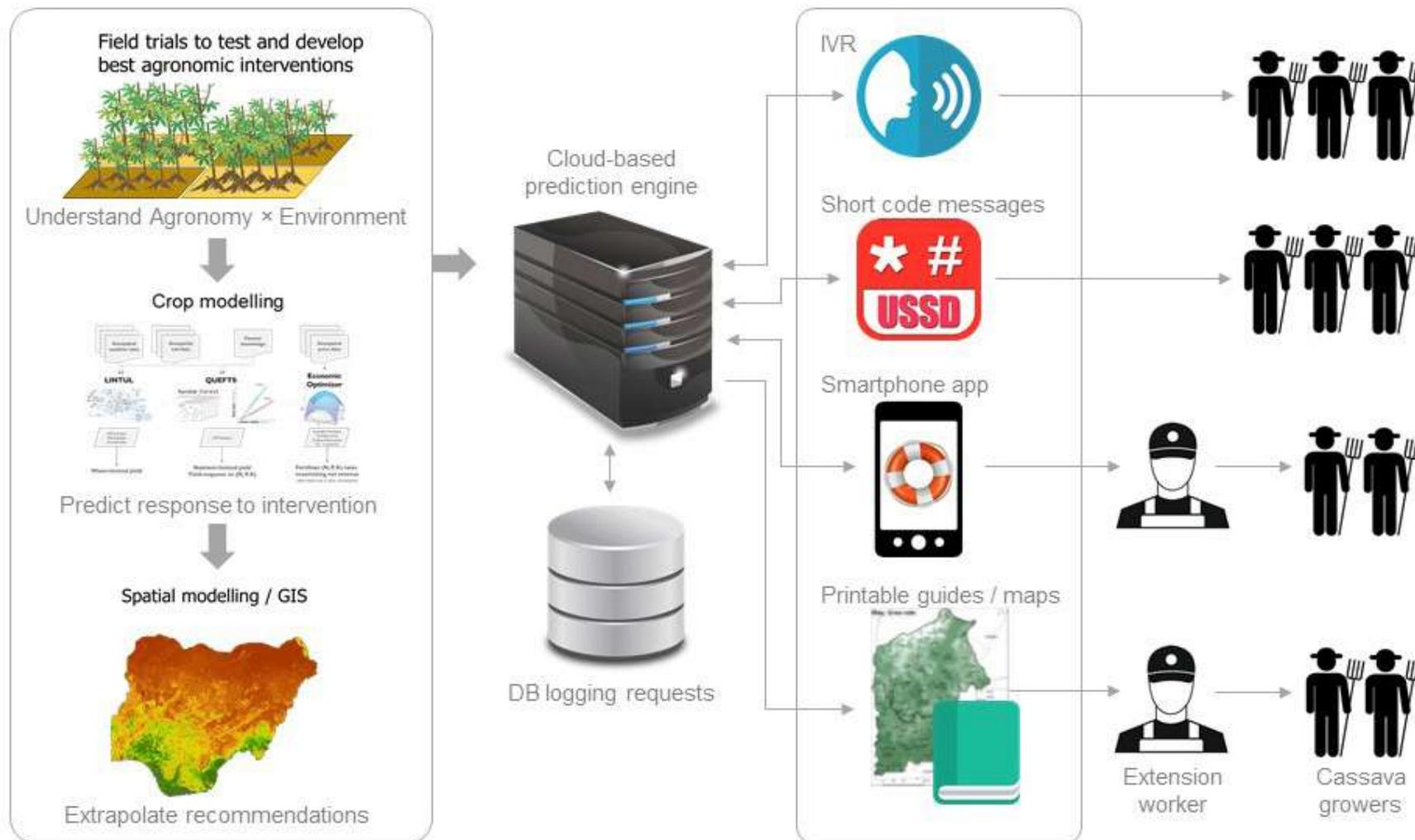


Diagram showing the process of generating recommendations in the Akilimo Cassava agronomy advice tool back-end.

infrastructure for short code formats as well as partnering with companies that offer integrated dissemination platforms like eSOKO and Viamo.

Akilimo combines initial use cases into a set of recommendation suited to the needs of the end user based on the input data and information requested. An extension agent will enter essential data inputs responding to a set of user-friendly questions into the *Akilimo* front-end application. The prediction engine running on a central server than receives a request and calculates the recommendation based on the received input data and sends out the advice by SMS, email, or directly within the application.

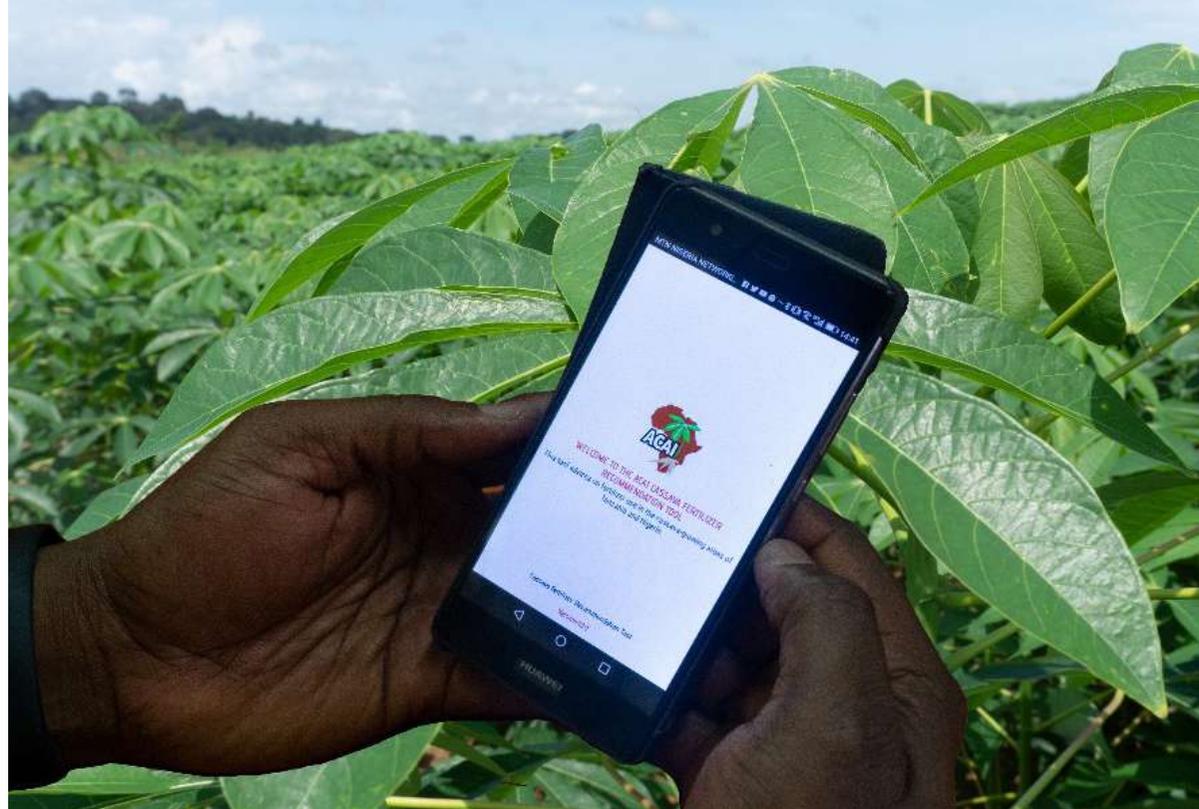
Akilimo formats

Akilimo is being integrated in the following formats: Smartphone app; Paper-based tools: flyers, manuals, lookup tables and maps; Interactive Voice Response (IVR); and Unstructured Supplementary Service Data (USSD).

The **Smartphone App** can be downloaded from Google app store. The app collects user-defined variables like location, land area, etc., asking questions in a stepwise manner. It interacts with the prediction engine on the server to provide recommendations directly on the smartphone or via SMS or email.

The **Paper-Based Tools** summarize the recommendations made using most logical values for input variables and present them using tables and maps. The paper-based tools are highly simplified versions providing simple best recommendations based on a limited set of input variables. For fertilizer recommendations, for example, best recommendations on a hectare basis are provided for each planting month per state or local government area (LGA).

The **USSD** approach requires the user to dial in a code which will let users answer several questions to define their location, resources, and other conditions and as in the smartphone



app it interacts with the prediction engine to provide tailored recommendation via SMS. It is more versatile and site-specific than paper-based tools, but less so than the smartphone app. The USSD approach is highly favored by farmers who have simple feature phones and who wish to access the recommendations directly, without additional support from an extension worker.

The **IVR** method presents the same questions as in the smartphone app and USSD but in IVR, users can listen to the questions and select the answer from the provided choices.

One of the major challenges to improve the accuracy of the recommendations is the quality of the price data both for the fertilizers and the cassava roots. ACAI is exploring partnerships

ACAI Akilimo is already operating as a smart mobile phone application with recommendations for fertilizer regimes, cropping systems and investment cost, and yield prediction.



ITA senior agronomist and ACAI project coordinator for East Africa Dr. Veronica NE Uzokwe speaking with a farmer in Mtwara, Southern Zone Tanzania.

with various organizations providing digital market information as well as price mapping to provide meaningful default values.

Future steps include validating *Akilimo* both functionally—verifying whether the recommendations outperform current practices in the

field, and architecturally—evaluating the user friendliness and how the tool can best fit within the dissemination strategy of development partners. ACAI is actively seeking interest from secondary partners to further test and scale the use of the *Akilimo* innovation.

Affordable and efficient maize fertilizers for Nigeria



Maize is the third most important food crop in Nigeria in terms of production after cassava and yam, with 31% used for feed and 12% for processing. The demand for maize increases annually due to urbanization and population growth (FAO, 2013).

Although Nigeria produces over 7 million metric tons of maize per year, grain yield is low, leading to a deficit in total production. Poor soil fertility is a major constraint in the predominantly maize production areas of the Nigerian savannas. Fertilizer application is widespread and is required to increase maize production. The most commonly used fertilizer is NPK 15-15-15, the suitability of which is much debated for maize. Poor response to fertilizer application is an important constraint in expanding commercial maize production.

The OCP-Africa fertilizer company in Morocco funded a project in 2017-2018 to develop affordable and efficient fertilizers to sustainably increase maize yields in



Nigeria. The project is the largest in IITA that is funded by a commercial private organization. IITA collaborates with the Africa Soil Information Service (AfSIS) and

with national partners Bayero University Kano (BUK), Institute of Agricultural Research (IAR), Zaria and National Agricultural Extension Research and Liaison

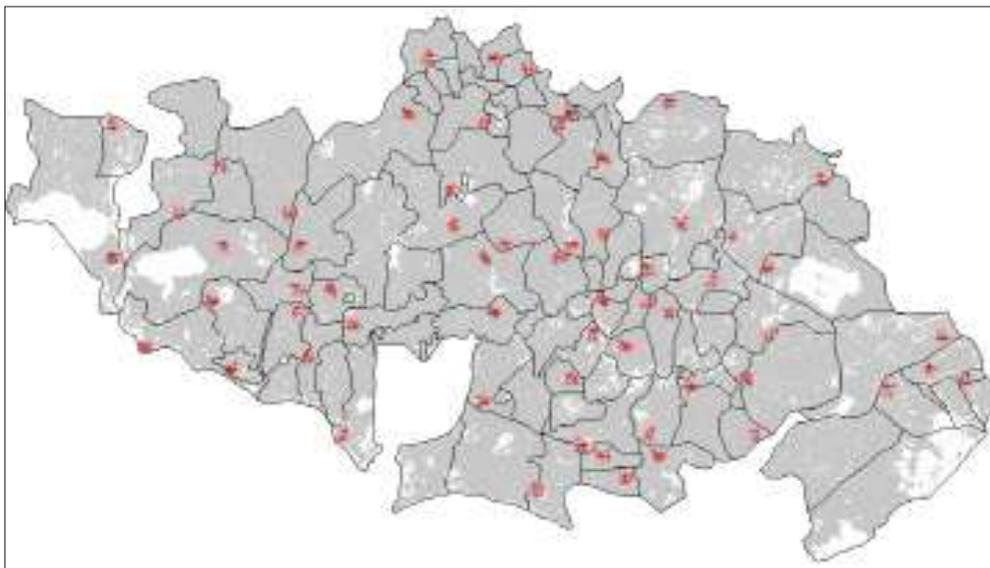


Figure 1. The maize belt of Nigeria and distribution of the 3000 sampling point locations.

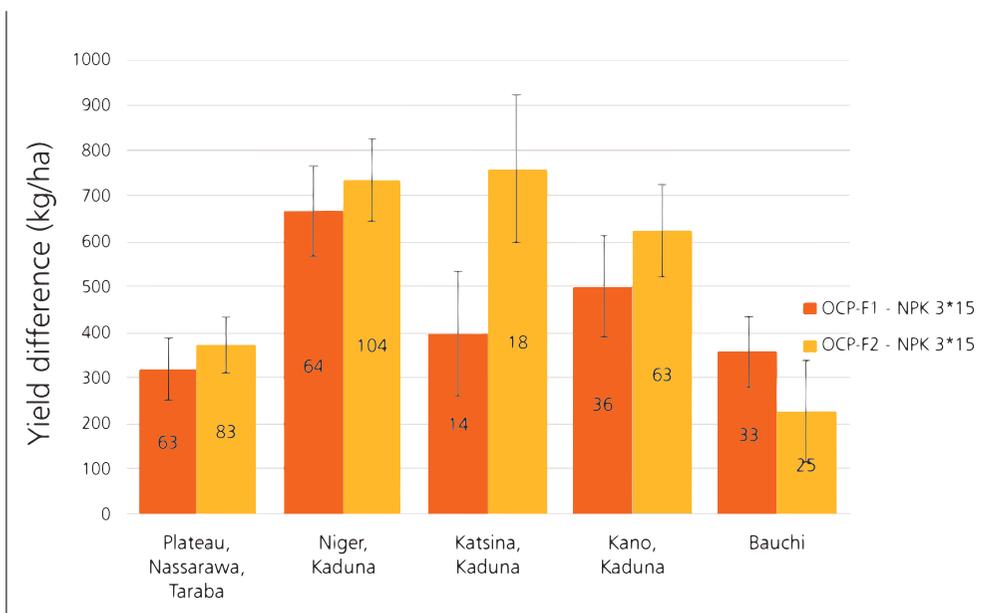


Figure 2. Average yield increase for OCP-F1 and OCP-F2 fertilizers compared to NPK-triple-15 for the different regions within the maize belt serviced by the various teams. Error bars indicated standard error of the mean, numbers in the bars indicate the number of observations.

Services (NAERLS); and with the Agricultural Development Programs (ADPs) of the relevant Local Government Areas (LGAs) for implementation. The project covers the whole maize belt of Nigeria, which measures around 225,000 square kilometers (Fig. 1). Developing new fertilizer formulations relevant for the area required characterization of the soils of the maize belt in terms of limiting nutrients, development and production of new fertilizers, and validation of new formulations in many trials across the area.

Soil characterization was done by collecting top- and subsoil samples from 3000 randomly selected locations following a hierarchical sampling design with 60 'sentinel' sites, representing an area of 10 by 10 km, within cultivated land. Ten clusters, each covering an area of 1 km², were randomly selected, with 5 sampling plots for each cluster. For each plot a composite soil sample was taken covering a 100-m² plot. The soil samples were analyzed to determine soil organic carbon, total N, Mehlich-3 P, K, S, Ca, Mg, Mn, Zn, B, pH, ECEC, and texture. The soil limiting nutrients were identified and based on these new fertilizer formulations were produced in Morocco and shipped to Nigeria and distributed to various locations where the validation trials were established. Two new fertilizer formulations were developed and tested. Both fertilizers contained elements (in varying percentages) that are generally limiting.

About 1,322 suitable locations were randomly selected from the 3,000 soil sampling locations for the establishment of the trials. The project successfully established 872 trials in 2017. The treatments consisted of a nonfertilized control, an NPK15-15-15 treatment, and two treatments for the two new OCP fertilizers. The application rate was the same for each of the fertilizer plots, viz., three bags of the NPK fertilizer for basal application and two bags of urea for topdressing to give a comparable amount of N applied, ranging from 62 to 68.5 kg N/ha but varying amounts of P and K and including S, Zn, and B in case of the OCP fertilizers.

Both OCP fertilizers performed significantly better than the NPK triple 15, with an average yield increase ranging from 4% to 12% for OCP-F1 depending on the region. The average yield increase for OCP-F2 varied between 6% and 27%. However, the performance of the two OCP fertilizers contrasted for individual sites. If the OCP fertilizer that



performs best for each individual site is considered, the average yield for OCP-F1 increased from 14% to 23%, and for OCP-F2 from 14% to 44%, depending on the region and team that implemented the trials.

The highest average yield increase for OCP-F2 compared to NPK-triple-15 was obtained for the Katsina-Kaduna region with an increase of 750 kg/ha on average. The Niger-Kaduna region showed the highest average yield increase for OCP-F1, about 670 kg/ha on average. Average attainable yield levels with the application rate used in the trials are 4.55 t/ha except for the Kano-Kaduna region where this was found to be around 6 t/ha. The two formulations were therefore superior to the widely available NPK 15:15:15 widely used in Nigeria.

A Nutrient Expert (NE) Tool developed by the project Taking Agronomy to Scale in Africa (TAMASA) was used to make site-specific fertilizer recommendations of nutrients using the new formulations developed by OCP. In 2018, the OCP, based on its School Lab Program, provided over 1,260 NE recommendations to farmers across 72 communities (12 LGAs) in Kaduna State, Nigeria. The program is leveraging the activities carried out in TAMASA for developing an NE tool for the Nigerian savanna.

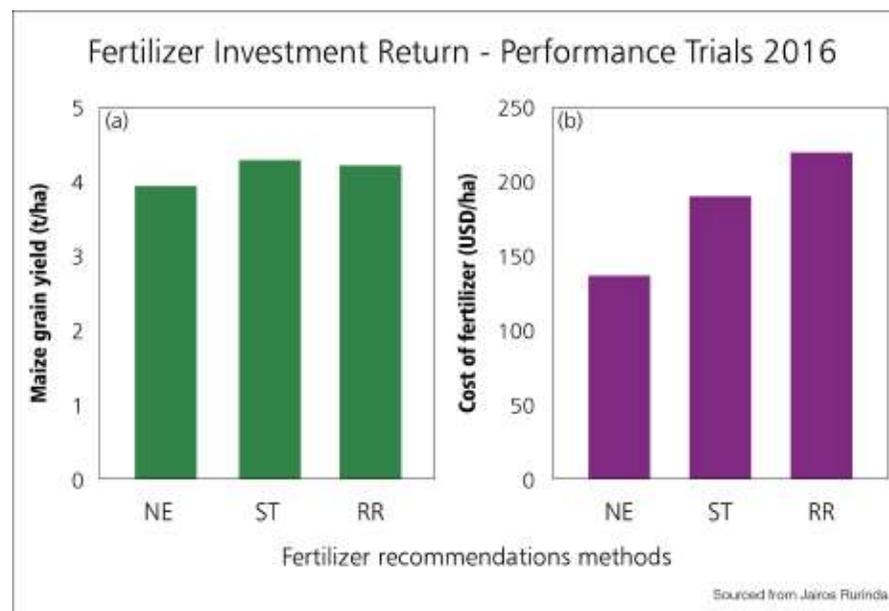


Figure 3. Grain yield and cost of fertilizer input associated with the alternative fertilizer recommendations. Data from performance trials of 2016.



Figure 4. Maximum and average yield and margin realized with recommendations from Nutrient Expert and FFP; results from the evaluation of NE by SG2000.



N2Africa: Improving Africa's smallholder legume farmers wellbeing through productivity enhancing technologies

Paul M. Dontsop Nguetzet, Theresa Ampadu-Boakye, Fred Kanampiu, David Ngome, and Bernard Vanlauwe

*Soybean field
at harvest stage
during Brown Field
Day at Marama
Hawul LGA, Borno
State, Nigeria, 2018.*

Food security, nutrition, lowering the risk of climate change, and increasing soil fertility are critical challenges that concern many African countries now and in future. In addition, producing food in a sustainable manner is important in agriculture and food systems.

In this regard, legume crops could play an important role because of their multipurpose nature. They are a good source of high-quality food and feed, they contribute to reducing emission of greenhouse gases, and they allow the sequestration of carbon in soils. Legumes also have socioeconomic benefits and perform well in conservation, intercropping, and rotation systems, which are very important

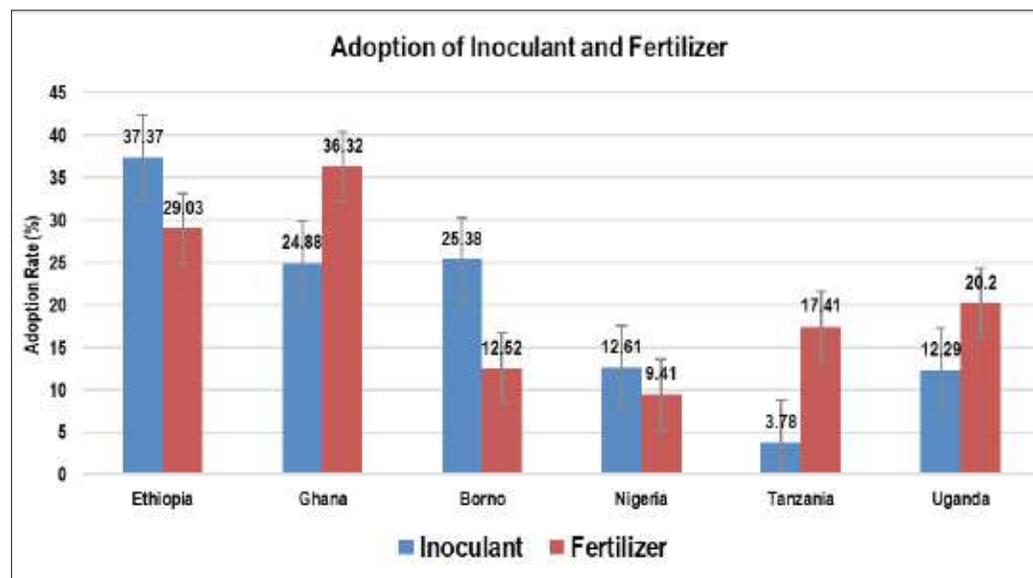




in developing countries with low access to inputs and low-yielding farming systems. In addition, legume crops fix atmospheric nitrogen, release in the soil high-quality organic matter, and facilitate soil nutrients' circulation and water retention as well as playing an important role in integrated soil fertility management (ISFM). Based on these multiple functions, farmers' adoption of ISFM-technologies is expected to play an important role in achieving better growth in the agricultural sector.

Against this background, since 2009, N2Africa through well-established public-private partnerships (PPP) had been disseminating a set of legume technologies including improved legume seeds varieties, fertilizers, inoculant (such as NoduMax), and agronomic practices aimed at increasing legume productivity, crop income, food security/household nutrition as well as promoting gender empowerment. After more than 5 years of project implementation, a study was conducted in several countries including Ethiopia, Ghana, Nigeria, and Tanzania to assess the level of awareness/exposure, adoption of legume technologies, and the impact of adoption on legume productivity and crop income.

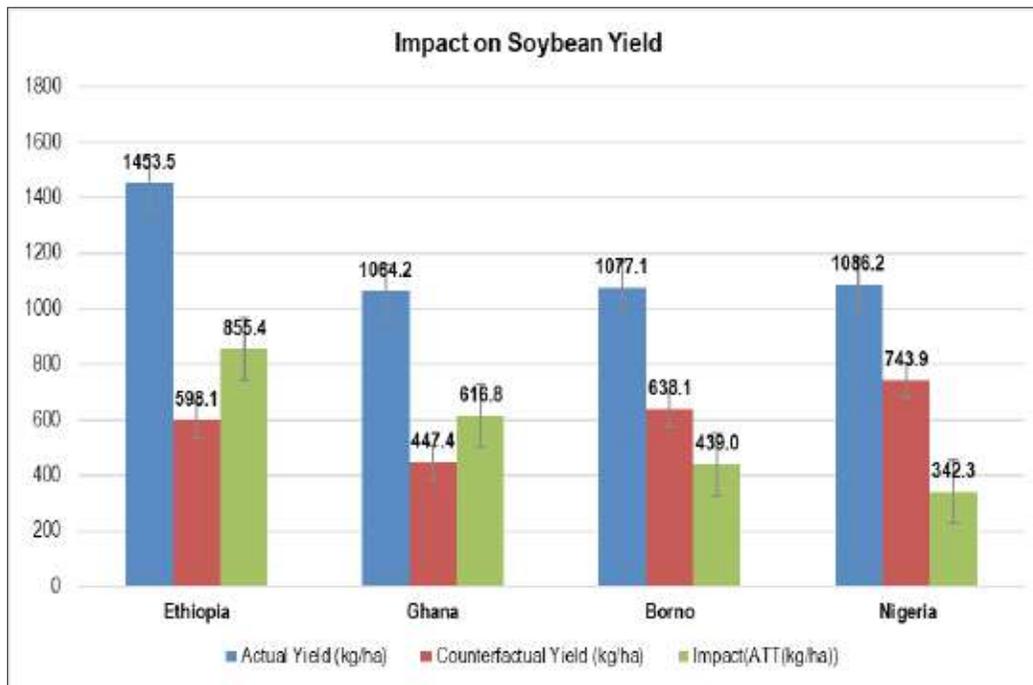
N2Africa is a "research-in-development" project focused on putting nitrogen fixation to work for smallholder farmers



growing legume crops in Africa. It is led by Wageningen University and Research and funded by the Bill & Melinda Gates Foundation, with IITA and ILRI as main implementing partners. The project is implemented in 11 countries across Africa including DR Congo, Ethiopia; Ghana; Kenya; Malawi, Mozambique, Nigeria; Rwanda, Tanzania, Uganda and Zimbabwe, referred to as core countries. The project aimed to contribute to increasing biological nitrogen fixation and productivity of grain legumes among African smallholder farmers to enhance soil fertility, improve household

nutrition, and increase their income levels.

During its implementation, N2Africa established public-private partnerships to enable African smallholder farmers to benefit from symbiotic N₂-fixation by grain legumes through effective production technologies including inoculants and fertilizers adapted to local settings. Yield was enhanced in the major legume growing areas in each target country using the ISFM package plus inoculant such as NoduMax, legume fix, etc. The story focuses on Ethiopia, Ghana, (Borno) Nigeria, Tanzania, and Uganda.



A total of 61,401 beneficiaries have been trained since 2014, 36% of them female. Implementation of project activities was done through establishment of 43 partnership arrangements in 2018 of which 67% addressed input markets, and 61% output markets. For this study, 3,744 legume farmers households were interviewed across the four countries as follows: Ethiopia, 744 (19.8%); Ghana, 603 (16.1%); Borno, Nigeria, 599 (16.0%); Nigeria, 595

(15.9%); Tanzania, 609 (16.3%); and, Uganda 594 (15.9%). Female-headed households represented about 21% of the total sample.

In Ethiopia the major legumes adopted¹ were chickpea and soybean, with adoption rates of 63% and 35%, respectively. In Ghana improved varieties of cowpea (Apagbaala, Kirkhouse, Padituya, Songotra, Wang kae, and Zaayura), groundnut (Chinese, SAMNUT

21 to 23), and soybean (Afayak, Jenguma, Soungpungu, TGX 1835-10E, TGX 1904-6F) were well adopted by legume farmers at 44%, 34%, and 56%, respectively. Similarly, the same improved varieties were enthusiastically adopted by more than 52% of farmers in Borno and more than 65% in Nigeria as a whole. In Tanzania, improved varieties of bush bean (Jesca Lyamungu 90, Njano uyole) and soybean (SC Samba, SC Semeki, UY Soya 1 to 4, Uyole Soya 2) were adopted by farmers at 39% and 24%, respectively.

In addition to improved legume germplasm, 29% and 37% of Ethiopian farmers, respectively, adopted fertilizer and inoculant in their farms. In Ghana, 36% of the farmers adopted legume fertilizers, whereas 25% adopted inoculant. Similarly, in Borno State, 13% of the farmers adopted fertilizer and 25% adopted inoculant. The rate of adoption of legume fertilizer was 9% in Nigeria, 17% in Tanzania, and 20% in Uganda. That of inoculant was 13% in Nigeria, 4% in Tanzania, and 12% in Uganda.

Farmers also simultaneously combined improved varieties and other inputs such as fertilizer and inoculant, with 34% of farmers in Ethiopia, 31% in Ghana, 25% in Borno, 17% in Uganda, 12% in Nigeria, and 8% in Tanzania. In addition, at the time of the survey (2018 cropping season), about 26% of those who were

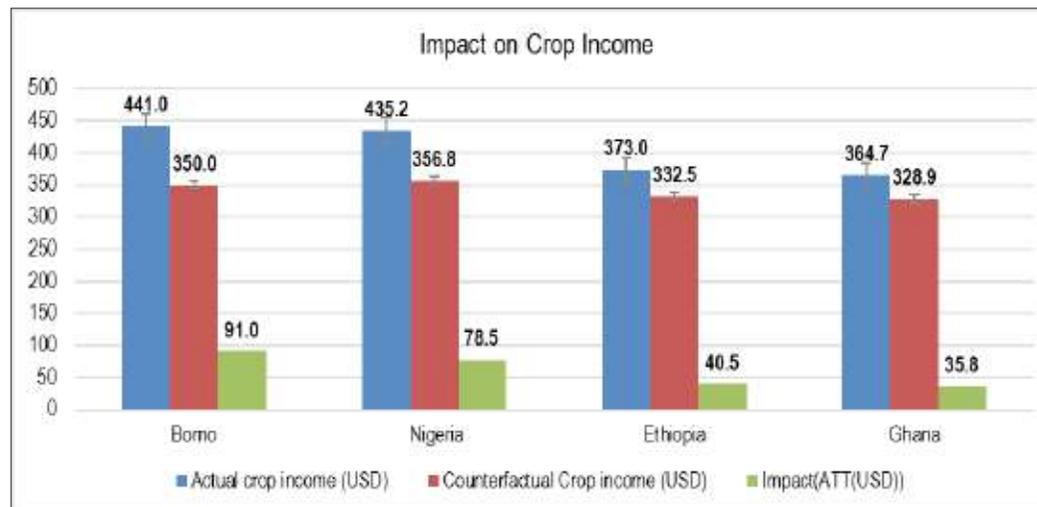
¹Adopters of those technologies were farmers who use an improved legume variety together with at least two other inputs out of inorganic fertilizer, inoculant and agronomic practices.



combining the technologies were still using the technologies in Ethiopia, 20% in Ghana and Borno, and less than 20% in the remaining countries.

Adoption of N2Africa technologies had a positive and significant impact on the quantity of soybean harvested per hectare by smallholder farmers across all the countries. In Ethiopia, the expected soybean yield for households that used N2Africa technologies was 1453.5 kg/ha while in the counterfactual case, farmers who used N2Africa technologies would have obtained a yield of 598.1 kg/ha had they decided not to use them. Consequently, the use of N2Africa technologies had increased soybean yield by 855.4 kg/ha. In other countries, the expected soybean yield for households that used N2Africa technologies was 1064.2 kg/ha in Ghana, 1077.1 kg/ha in Borno, and 1086.2 kg/ha in Nigeria. In the counterfactual case, they would have obtained 447.4 kg/ha in Ghana, 638.1 kg/ha in Borno, and 743.9 kg/ha in Nigeria had they not decided to use those technologies. Hence, use of N2Africa technologies had positively and significantly increased soybean yield by 616.8 kg/ha in Ghana, 439.0 kg/ha in Borno, and 342.3 kg/ha in Nigeria.

Similarly, increased soybean yield contributed to a significant increase in the level of income received from crop



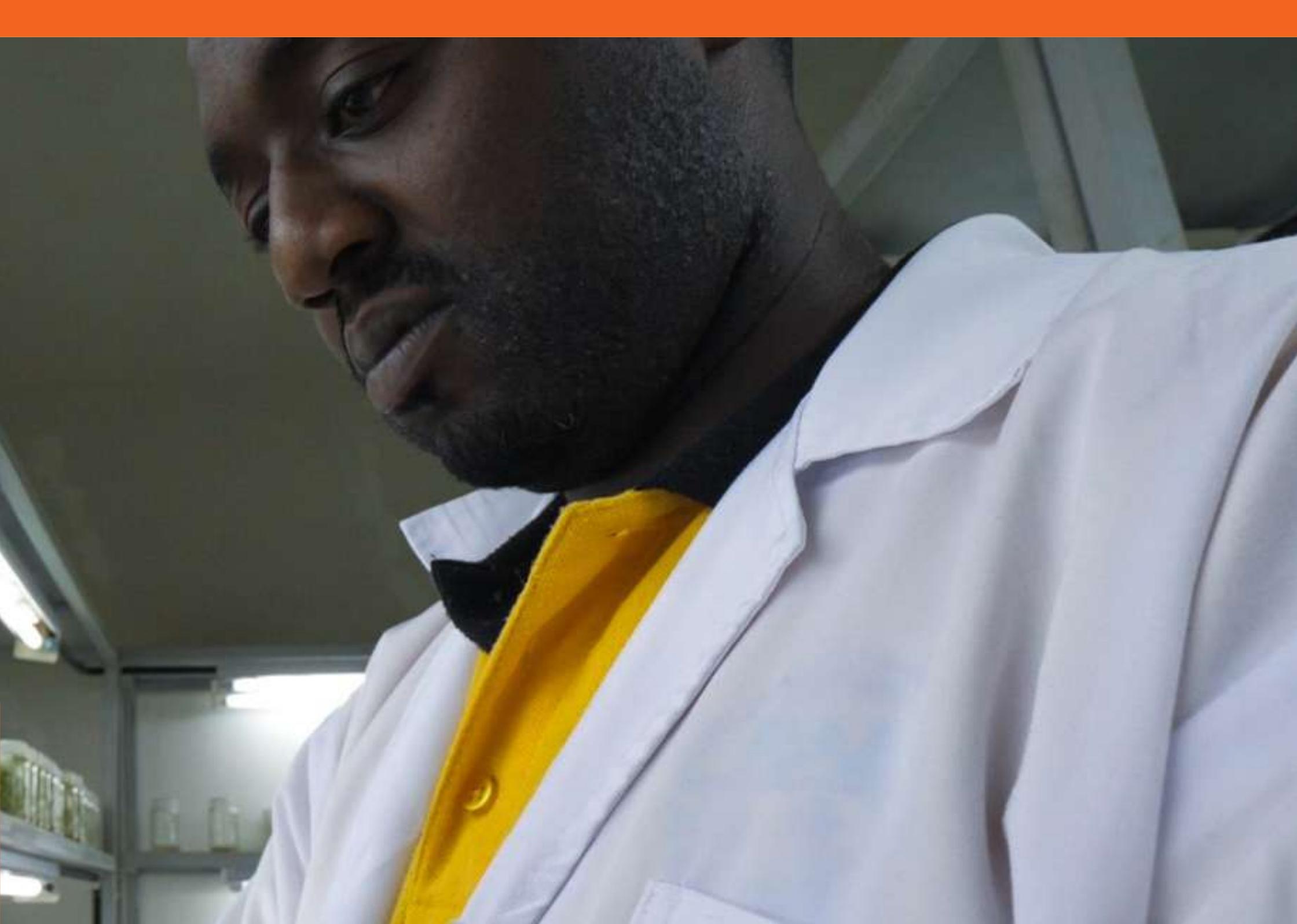
sales. The expected income from crop sale by user households was \$441.0 in Ethiopia, \$435.2 in Ghana, \$373.0 in Borno and \$364.7 in Nigeria. Had they decided not to use the technologies, they would have obtained the \$373 in Ethiopia, \$365 in Ghana, \$441 in Borno, and \$435 in Nigeria, respectively. Therefore, use of N2Africa technologies increased income from crop sale by \$40.5 in Ethiopia, \$35.8 in Ghana, \$91 in Borno, and \$79 in Nigeria.

Findings show that users of N2Africa technologies were better off than the non-users in terms of soybean yield and income received from crop sale. Majority of farmers

that were exposed to those technologies eventually used them. However, the current level of awareness and adoption suggest the need for efforts geared toward dissemination and sensitization campaigns in all countries to close the information gap. In this regard, any intervention that will help increase the level of awareness will also contribute to adoption. Therefore, PPPs developed through this project should be maintained and encouraged to ensure wider dissemination of technologies. In addition, it was also shown that if given the opportunity, women that adopt N2Africa technologies will benefit more than the men. Hence, activities for promoting these technologies should be gender friendly.



Improving crops





Stress resilient maize Varieties for African farmers

Abebe Menkir, Baffour Badu-Apraku, A Tahirou Abdoulaye, Melaku Gedil, and Silvestro Meseke

Maize has emerged in the last three decades as an important food security and income generating crop for millions of people in sub-Saharan Africa (SSA). Despite its importance, the average maize grain yields are still low in farmers' fields in the region due to constant exposure to recurrent drought, parasitic weeds (primarily *Striga hermonthica*), diseases, insect pests, inappropriate crop management practices, inadequate input use, and institutional factors.

The Drought Tolerant Maize for Africa (DTMA) project was launched in 2006 to reduce vulnerability and improve food security through the development of maize hybrids and open-pollinated varieties (OPVs) with stable yields and enhanced tolerance for drought, resistance to *Striga* and major diseases prevalent in Eastern, Southern, and Western Africa.

The DTMA Project financed by the Bill & Melinda Gates Foundation and the Howard G. Buffet Foundation (HGBF) was run in three phases (2006-2015). It was jointly

implemented by the International Center for Maize and Wheat Improvement (CIMMYT) and IITA in partnership with the national agricultural research and extension systems



Maize field in Nigeria. Photo by Clement Ono-Raphael, IITA.



(NARES), private seed companies, community based organizations (CBOs), nongovernmental organizations (NGOs), and universities in 13 target countries across Africa, including Ethiopia, Kenya, Tanzania, Uganda, Angola, Malawi, Mozambique, Zambia, Zimbabwe, Benin, Ghana, Mali, and Nigeria. The first two phases of this project focused primarily on product development, testing, registration, and release through building of the required partnerships with both public and private sector institutions while strengthening their capacity to promote and deploy stress resilient products to farmers. The third phase placed strong emphasis not only on the development of better stress resilient OPVs and hybrids but also facilitated the production of quality seeds, promotion, and delivery of released OPVs and hybrids to African farmers. The Stress Tolerant Maize for Africa (STMA) project followed the DTMA project in 2016 with continued funding from the Gates Foundation and USAID to develop varieties with combined multiple stress tolerance and enhanced productivity that can effectively respond to emerging and future production challenges for outscaling.

The two projects catalyzed the release of 254 new stress resilient maize hybrids and OPVs in target countries across Africa between 2007 and 2017. Of these, IITA in collaboration with its national and private sector partners in Benin Republic, Ghana, Mali, and Nigeria released 44 hybrids and 54 varieties of extra-early-, early-, intermediate- and late-maturity combining tolerance for drought with resistance to *Striga* in West Africa. These OPVs and hybrids have

high levels of resistance to diseases in the major agroecologies and produced 20% to 30% more grain yields than the current farmer-grown improved OPVs or commercial hybrid checks across stressful and favorable field conditions in the target countries. Most of the released stress resilient maize varieties have been commercialized in the target countries. SeedCo and Premier Seeds Nigeria Ltd. each accessed two multiple-stress resilient hybrids directly from IITA and registered them with

their trade names. Although other small and medium size seed companies in Nigeria and other countries in West Africa were encouraged to access specific hybrids for registration and release under their names, most preferred to access large quantities of seeds of parents of released hybrids from the NARS as well as IITA for certified seed production due to limited resource endowment (land, capital, facilities) and technical capacity (skilled staff) to coordinate the production and maintenance





of breeder and foundation seeds of parents of hybrids.

Considering the diversity of production environments prevalent in the various countries in West and Central Africa, IITA has announced allocation of specific hybrids (exclusive licenses) to each seed company or national partner in Nigeria and other countries in West Africa to help the small and medium size national seed companies stay competitive and market attractive maize hybrids that guarantee sales to farmers. IITA believes that providing exclusive licenses for specific hybrids will promote branding and sales of good quality hybrid seeds with diverse genetic backgrounds in specific target production zones to help maintain genetic diversity for minimizing potential yield losses resulting from unexpected climate extremes as well as disease and pest outbreaks.

The largest area occupied by the stress resilient varieties in 2013 was in Nigeria (>23%) followed by Benin (22%). In 2015, a stress tolerant variety (SAMMAZ15) alone was planted to an estimated area exceeding 100,000 ha in Nigeria. The DTMA project also worked with public and private sector partners and produced approximately 52,000 metric tons (MT) of seed of the stress

resilient OPVs and hybrids in 2014 alone. The STMA project had a target of producing and disseminating an additional 50,000 MT seeds of multiple stress tolerant OPVs and hybrids in eight target countries in sub-Saharan Africa in 2019. In West Africa alone, IITA's national partners and seed companies have already produced a total of 115,816 MT seed of stress resilient OPVs and hybrids under DTMA and STMA from 2007 to 2017. These covered nearly 5.8 million ha of land and benefited millions of farmers. This was driven by IITA's involvement in constantly supplying breeder seeds of released varieties and parents of hybrids to the NARS and private seed companies under the two projects. Significant investments have also been made under these projects in training technical and management staff of national partners and seed companies to strengthen their capacity to produce and market good quality seeds of stress resilient OPVs and hybrids to a greater number of farmers in West Africa.

The DTMA and STMA projects have established effective product pipelines integrating cutting-edge phenotyping and molecular tools that contributed to the development of several promising stress resilient varieties and hybrids awaiting release and commercialization.

Therefore, increased investment in strengthening the public and private sectors would still be needed to speed up the uptake and commercialization of new multiple stress resilient OPVs and hybrids that can help achieve higher yield gains in farmers' fields. The new multiple stress tolerant maize OPVs and hybrids available to farmers will have significant impact on productivity at the farm level largely due to their better response to fertilizer and favorable growing environments and resilience under stressful production conditions. Results of an ex-post impact assessment study in Nigeria showed that adoption of drought tolerant maize varieties increased maize productivity by 32% and per capita expenditure by 22%, reduced exposure to farming risk among adopters by 64%, and reduced poverty among adopters by 8%. The production of stress resilient varieties has thus increased food supply and helped to overcome chronic food insecurity among the most vulnerable groups in West Africa. Nonetheless, increased investment in a vibrant and well-functioning seed sector is still needed in the subregion to promote the production and spread of new multiple stress-tolerant OPVs and hybrids to increase farmers' incomes, reduce food prices for consumers, and improve the profitability and sustainability of the seed industry.



Application of genome editing for improving banana



Leena Tripathi, IITA-Kenya

Banana is a major staple food crop feeding more than 500 million people in tropical and subtropical countries. Its production is seriously affected by several factors, specifically stresses such as declining soil fertility, narrow genetic diversity in germplasm, and inadequate availability of clean planting material among smallholder farmers. Diseases and pests are a major factor limiting yields worldwide.

Production is mainly reduced by many bacterial, fungal, and viral pathogens, mainly *Xanthomonas campestris* pv. *musacearum* (Xcm) causing banana Xanthomonas wilt (BXW), *Ralstonia solanacearum* causing moko and bugtok disease, *Ralstonia syzygii* subsp. *celesensis* causing blood disease, *Pseudocercospora fijiensis*, *P. musae*, and *P. eumusae* causing black Sigatoka, yellow Sigatoka, and leaf spot disease, respectively, *Fusarium oxysporum* f. sp. *cubense* causing fusarium wilt (commonly known as panama disease), and viruses such as *banana bunchy top virus* (BBTV)



and *banana streak virus* (BSV), and pests like nematodes and weevils.

There is a huge yield gap in banana production in areas where several of these pathogens and pests



occur together. Therefore, improved varieties need to be developed with multiple and durable resistance to pathogens and pests. Modern breeding tools such as genome editing can be applied to improve banana, complementing traditional breeding. CRISPR/Cas9

Figure 1. Genome-edited banana. (a) Non-edited plant, (b) Gene edited plant with mutations in PDS gene disrupting its function and causing albinism. [Source: Tripathi et al. 2019a]



has emerged as a potent editing tool that can be used efficiently to induce targeted mutations in the genomes of plant species to produce improved varieties. This technology has been successfully applied in many organisms including several plant species.

At IITA, researchers have established a genome editing tool for banana using *phytoene desaturase* (*PDS*) gene as a marker as mutations disrupting *PDS* causing albinism and dwarfing of plants (Figure 1, Tripathi et al., 2019a). Establishment of CRISPR/Cas9 system has paved the way for applying genome editing for improving banana varieties resistant to diseases and pests and tolerant of abiotic stresses.

Recently, we have applied CRISPR/Cas9 based genome editing to knock out the endogenous *banana streak virus* (eBSV) integrated in the B genome of *Musa* spp., overcoming a major challenge in banana breeding. BSV is a plant pathogenic badnavirus of the family *Caulimoviridae*, affecting banana production. It was first identified in West Africa in 1958 and is now reported in most banana and plantain growing countries. Like other badnaviruses, BSV sequences integrate into the genome of *Musa* spp. BSV is a complex of different viruses belonging to the pararetroviruses (PRVs) and classified as endogenous pararetroviruses (EPRVs) when they are integrated into a host genome. The EPRVs of BSV in banana are known as endogenous BSV (eBSV). The eBSV sequences are integrated in the B genome derived from *Musa balbisiana*.

Many economically important subgroups of banana, such as plantain (AAB), an important staple food in Africa, contain at least one B genome. When the banana plants are stressed, the eBSV recombines

to produce a functional episomal viral genome and infectious viral particles and as a result the plant develops disease symptoms. The major epidemics caused by BSV are not due to natural transmission through insect vectors or through use of infected planting materials, but rather due to activation of integrated virus under stress conditions such as unfavorable conditions, *in vitro* culture for propagation, and hybridization through conventional breeding. Consequently, BSV is considered a major constraint in banana breeding programs, restricting the use of the diploid progenitor *M. balbisiana* or its derivants carrying a B genome as parents for introgression of desirable agronomic traits. It also restricts germplasm movement of genotypes with the B genome worldwide due to this potential activation of eBSV into the episomal infectious form. Therefore, it is crucial to design a strategy to irreversibly silence the latent eBSV in the B genome. IITA scientists in collaboration with University of California, Davis, USA applied CRISPR/Cas9-based genome editing technology to inactivate eBSV strain Obino l'Ewai (eBSOLV) sequences in the host plantain genome (Tripathi et al. 2019b).

The CRISPR/Cas9 reagents targeting the virus genome were delivered to embryogenic cells of plantain cultivar 'Gonja Manjaya', a false horn plantain, and complete plants were regenerated. The regenerated plants were validated by PCR analysis and Sanger sequencing of the targeted sites. The genome-edited plants and wild type control plants, developed from the same embryogenic cell line, were found to be phenotypically similar with no growth abnormalities. The regenerated genome-edited events of 'Gonja Manjaya' showed mutations in the targeted sites with the potential to prevent proper transcription or/and translation into



functional viral proteins. The genome-edited plants along with control nonedited plants were evaluated under the glasshouse for activation of eBSOLV into infectious virus under water stress conditions. Seventy-five percent (6/8) of the edited events remained asymptomatic compared to the nonedited control plants under water stress conditions, confirming inactivation of eBSV and reversal of its ability to be converted into infectious viral particles.

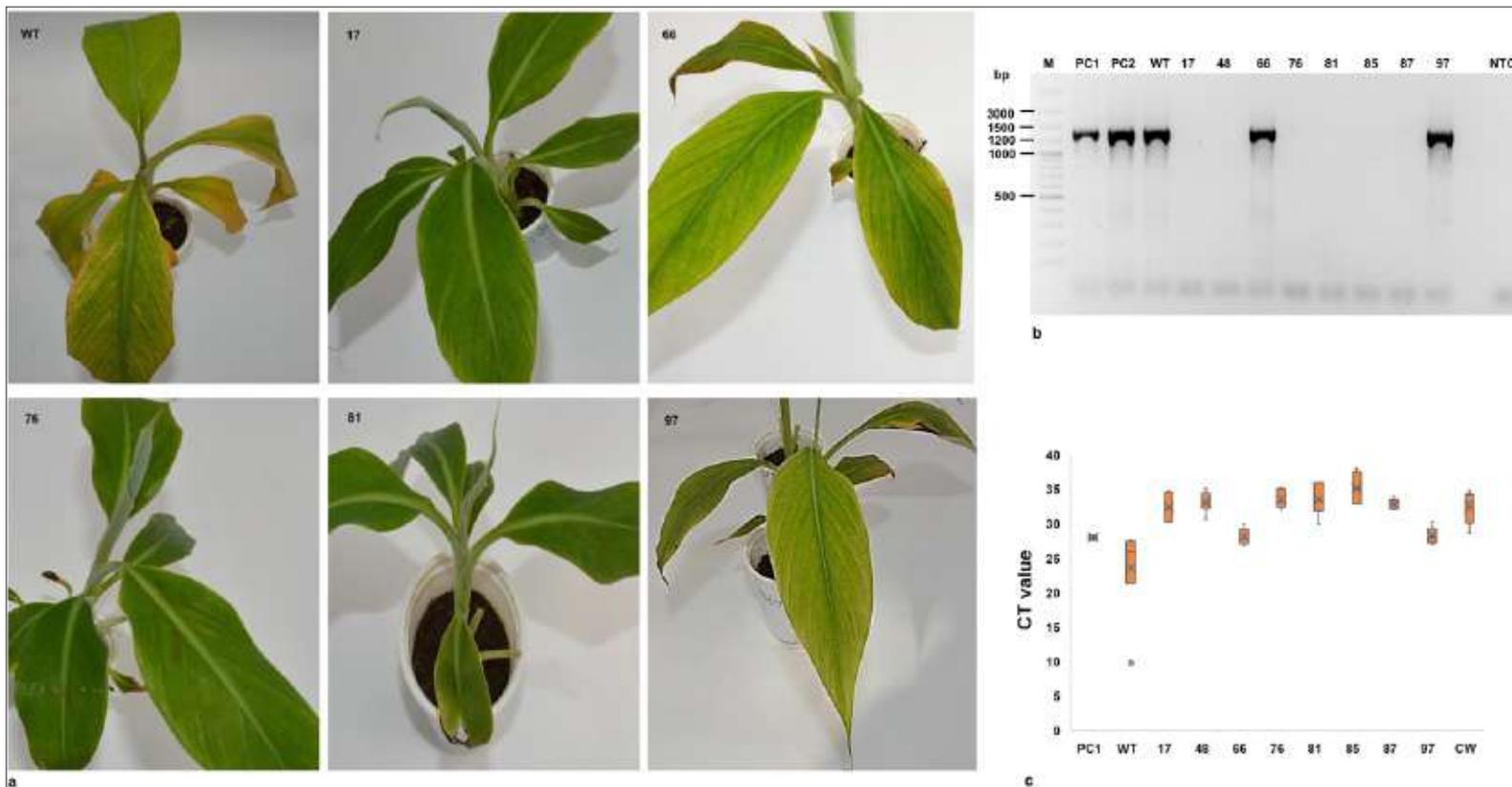


Figure 2. Evaluation of genome-edited and wild type non-edited control plants of 'Gonja Manjaya' for induction of BSV symptoms under water stress conditions. (a) Pictures of asymptomatic genome edited plants (17, 76, and 81), symptomatic edited plants (66 and 97) and wild type control plants (WT). (b) PCR diagnostic to detect activation of episomal BSOLV in genome edited and control plants under water stress conditions. (c) qPCR analysis to detect episomal BSOLV in genome edited and control plants under water stress conditions. [Source: Tripathi et al. 2019b]

Disease symptoms such as broken or continuous streaks of yellow, chlorotic, black or brown color on the leaf appeared in all the wild type control plants tested, as would be expected if there was activation of eBSOLV into episomal infectious BSOLV. However, six out of eight genome-edited events tested remained asymptomatic and the remaining two events showed only moderate symptoms (Fig. 2). The

presence of the infectious episomal form of BSOLV was confirmed by PCR and qPCR analysis.

This is the first report to demonstrate the knockout of integrated endogenous DNA sequences of the pararetrovirus in a host plant genome. We have demonstrated that CRISPR/Cas9 based targeted mutagenesis can permanently inactivate

endogenous eBSV and presents a promising model for inactivating other endogenous viral genomes. This study paves the way for editing banana germplasm with B genome(s) that can be used as one or both parents in the breeding programs. This is a particularly important strategy for both improving plantains and enabling global dissemination of the resulting hybrids with improved B genome.

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Selfless Malawian cassava farmer finds joy in community food security

Pheneas Ntawuruhunga

Research development issues or challenges addressed

Malawi is a landlocked and densely populated country with a population of more than 17.2 million, corresponding to 145 inhabitants per km², compared with the average 34 per km² inhabitants for sub-Saharan Africa (UNPD 2015). The percentage of persons falling below the poverty line is 50.7%. Rural poverty remains much higher (56.6%) than urban poverty (17.3%) (NSO 2012).

Levels of malnutrition also remain high, with 62% of children under 5 stunted, 12% wasted, and 31% underweight, while 47% remain vitamin A deficient and 63% have anemia (NSO 2012; IFPRI 2015).

The dependents of regular humanitarian assistance due to periodic floods and droughts were estimated to reach over



two million in 2015/16 (up from 300,000 in previous years).

Unfortunately, weak coping mechanisms remain for the resilience of local livelihoods. Meanwhile the agriculture sector accounts for 34% of the total GDP, higher than in most eastern and southern Africa countries. Maize takes up over 80% of land under smallholder cultivation, thus the

government has prioritized crop diversification in recent policies (GoM/NSO, 2010). The government also recognized the need to invest in potential synergies between the nutrition and agriculture sectors to achieve the goals of food and nutrition security in the country. Root and tuber crops (RTC) are well established in Malawi's food systems, which, with appropriate investments, can further contribute to these development goals.



Cassava is the most important root crop and a major staple second to maize in Malawi, supporting over 30% of the lakeshore population in Nkhatakota, Nkhata-bay, Rumphu and Karonga districts as their primary staple food. It is a very important source of income and food security for poor households due to its ability to produce reasonable yield under adverse environmental conditions under which other crops fail.

The goal of Root and Tuber Crops for Agricultural Transformation in Malawi (RTC-ACTION MALAWI): Cassava Component is to contribute to food security, nutrition, incomes, and employment in Malawi. The project aims to strengthen potato, sweetpotato, and cassava value chains within the context of a more productive, climate-resilient, and diversified agricultural sector. The specific objectives of the project are:

- Increased productivity, climate resilience, and nutritional value of RTC production systems
- Increased revenues, consumer orientation, and nutrition outcomes of RTC value chains, and
- Effective policies and strengthened capacities for continued development of RTC

Within the 4-year project, around 160,000 households are expected to adopt improved technologies and practices, with 500,000 consumers to benefit from nutritious RTC foods. The RTC-ACTION project will achieve significant increases in productivity and revenues among 25,000 RTC smallholder farmers, and improved diet quality for over 80,000 women and 60,000 under-five children.

The cassava component is implemented in Lilongwe East and West, Kasungu, Nkhatabay, Nzimba South and North, and Mangochi, targeting 40,000 beneficiaries.

The project is being implemented through partnership with the International Potato Center (CIP) as coordinating agency, IITA, Department of Agricultural Research Services (DARS), Department of Agriculture Extension Services (DAES), and Lilongwe University of Agriculture and Natural Resources; nongovernmental organizations and other local organizations; commercial partners; farmers and community groups. It is funded by Irish Aid.

Malawian small-scale farmers are happy

After years struggling to get a decent harvest from growing cassava varieties that were highly susceptible to yield-sapping diseases, Velium Levion sought guidance from DARS experts. They made him a beneficiary of the RTC-ACTION project which is disseminating pathogen-free planting materials of four improved varieties (Sagonja, Mbundumali, Sauti, and Mpale) in the targeted Districts. He received 100 bundles of Mpale in 2018 as a seed multiplier. Although initially skeptical, Levion discovered that this odd-looking, brown-stemmed variety was both sweet and high yielding. Levion invited his neighbors to taste the roots, who liked it. This stirred a huge demand for Mpale planting materials and as the sole supplier in his community, Levion could not meet the demand. He gave away 100 bundles for free to about 100 fellow farmers and reserved 144 bundles for himself. He

sold 207 bundles that earned him a cash bonus of US\$340. He also sold some roots for cash, but much of the root harvest was used in exchange for labor on his farm (food for work).

Through the RTC-ACTION project Levion has also received training in best production practices for quality planting material. He has now increased the area under Mpale and has also been certified as a seed producer of high-quality planting material through the RTC-ACTION project which paid for his registration costs with the Seed Services Unit. Levion is now the source of Mpale seed in Lilongwe and is looking forward to making more money from the current crop.

Levion will be used as a reference point for other farmers and seed multipliers in the other project areas. In two years, the RTC-ACTION project has already distributed improved cassava varieties to 20,000 farmer-beneficiaries. Mpale was officially released by DARS in 2011 as a sweet, high yielding variety (30 t/ha) with high dry matter content. It showed more resistance to mosaic disease than Mbundumali. It has dry matter content, is mealy when cooked, and makes good 'kondowole' (fermented) flour, a locally prized delicacy. However, Mpale should only be grown in regions where there is low pressure from cassava brown streak disease, such as Lilongwe district.

Farmers Levion and his wife Dorothy Chalowerera have seven children and hail from Mkwinda village, Traditional Authority Chadza in Lilongwe District and have worked with DARS on cassava since 2017.

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Farmers Emmanuel Misago and wife Seraphine in their plot in Burundi. Photo by P. Lepoint, Bioversity International.

Making crops healthy





Healthy vegetable seedling systems lead to increased yields, lower pest and disease incidence and reduced pesticide reliance

Danny Coyne, Laura Cortada, and Joseph Kisitu

Everywhere across the globe, children are always encouraged to eat their vegetables for a healthy diet, as fresh vegetables play an important role in nutrition. In sub-Saharan Africa (SSA), peri-urban vegetable farming can be quite lucrative. Surging rural-urban migration is resulting in rapid urbanization, requiring ever greater supplies of fresh food, especially nutritious but perishable vegetables.

Vegetables, such as capsicum pepper and tomatoes, are particularly affected by pests and diseases. Their production, therefore, tends to attract more pesticide use than most other crops in the region. Given the often poor awareness of farmers regarding pesticide use and safety, we need to ask ourselves how healthy the vegetables we get in the market are.



The answer can be alarming, with weekly pesticide sprays repeatedly administered by farmers who have little understanding of what, why, or how they need to apply such toxic chemicals. (Fig. 1). Vegetable growers

intensively and continuously cultivate small land areas (often <0.2 ha), which magnifies pest and disease problems, a major cause of crop loss and poor productivity. Applying synthetic pesticides is a common coping

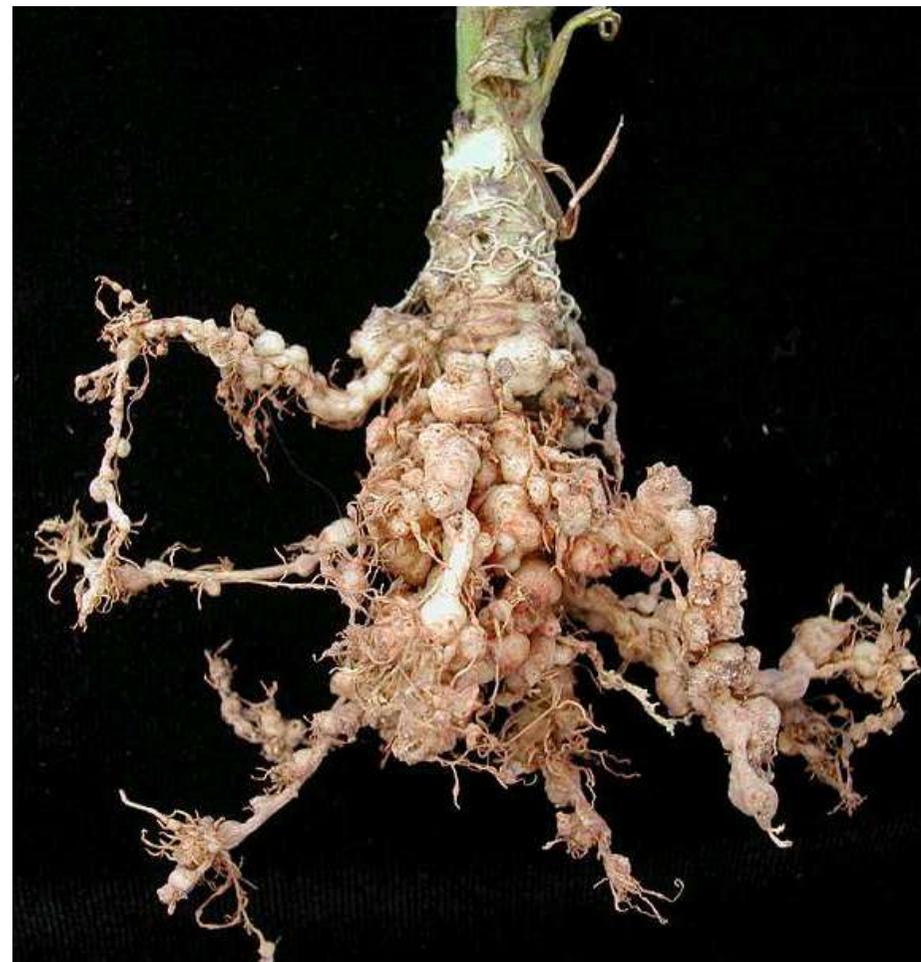
strategy, threatening the health of farmers, consumers, and the environment. Local regulatory frameworks for pesticide use are often difficult to enforce, allowing the entry and use of hazardous pesticides, including those that are banned elsewhere.

Over the past 5-6 years, together with our various partners, we have led activities in East Africa towards reducing pest and disease incidence and consequently reliance on pesticides on pepper and tomatoes. The platform for this has been the introduction and demonstration of healthy seedlings. In addition, good agronomic practices (GAPs) have been promoted, varieties assessed for disease resistance, biological control agents (BCA) evaluated, and farmers' awareness of the correct use of pesticides improved. Healthy seedlings formed the basis of this work, with the hypothesis that healthy seedlings would be less prone to infection. Underscoring this theory was that reducing nematode infection in particular would render seedlings better able to cope with the pest and disease onslaught experienced by vegetable farmers. Nematodes, especially root-knot nematodes (*Meloidogyne* spp.), plague vegetable production but they are unseen and often overlooked, affecting the roots (Fig. 2). Early infection with root-knot nematodes (RKNs) can significantly impair growth and health of plants. We compared healthy seedlings prepared in the screenhouse with farmer seedlings, and then further compared resistant varieties, better practices, including appropriate but expensive pesticides and

microbial biological control products from our partner ReallPM. This work was conducted in Ethiopia, Kenya, Madagascar, Tanzania, and Uganda under a number of donor-funded projects.

What we found was eye-opening! By simply introducing the use of healthy seedlings, we could effectively double farmers' yields of tomato and pepper. Healthy seedlings germinated better, survived better, grew into stronger, more resilient, bigger plants that gave much higher yields of fruits. For example, germination was on average 40-50% better in healthy conditions in seedling trays than for traditional farmers' practice using the same source of seeds. This immediately provides 40-50% more plants for farmers. Healthy seedlings consistently led to higher yields of about 50%, but the value of using healthy seedlings was highlighted when combined with GAPs, which in general doubled yields.

The farmers were happy with the results (Fig. 3). Farmers reported that tomatoes and peppers from healthy seedlings were generally larger, looked better, and consequently were more appealing and preferred by traders and markets. Furthermore, a key factor for farmers was that their tomatoes and peppers could be harvested earlier than those from farmers' practice, entering the market sooner and commanding higher prices at times; harvests were better synchronized as well, reducing the financial and labor burden of transporting to local markets. A particularly outstanding finding, however, related to the use of pesticides.



When using healthy seedlings and implementing GAPs, together with sound advice, pesticide applications were reduced by 75%-- i.e., four times lower than conventional farmers' practice (3.5 L/ha compared with 15.5 L/ha).



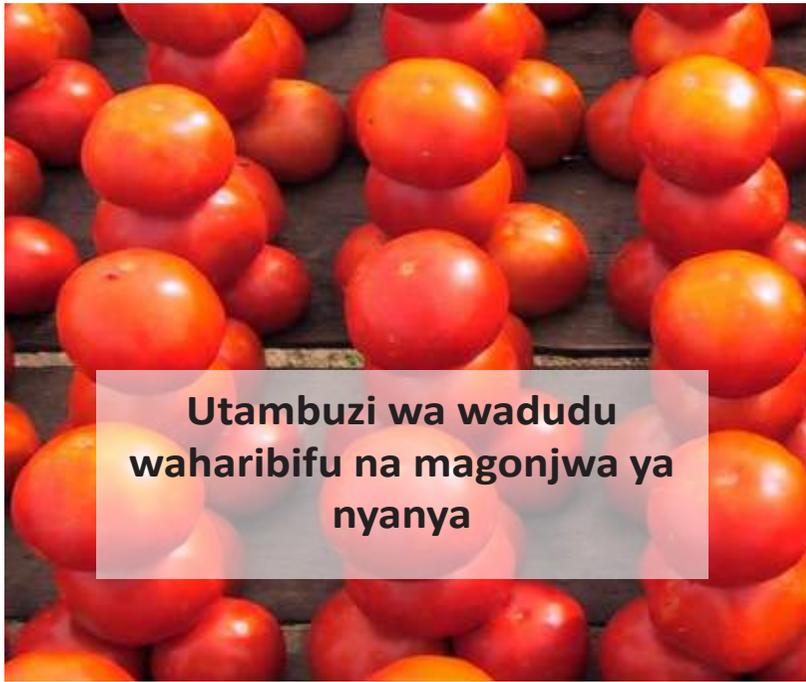
In general, prior to the project training, farmers had a limited understanding of pesticide use in terms of which were most suitable, which should be used for which diseases/pests and in

their ability to correctly identify causal agents of disease and pest symptoms. We found that most farmers gained much of their information on pesticide products from the shop/storekeeper,

who were not particularly expert in relating disease and pest symptoms to a product. The production of a pictorial pest and disease guide as part of the training was very well received by farmers and agricultural staff (Fig. 4). A defining factor for selection of pesticide products tended to relate to cost, and the cheapest at that.

Prior to using healthy seedlings and receiving training farmers were spraying pesticides indiscriminately on a calendar basis (usually every week) that constituted misuse and overuse of pesticides. By using healthy seedlings and implementing GAPs, the pest and disease incidence and damage were generally reduced. This was particularly notable for RKN infection, which, in turn helped to reduce additional disease infections. Although farmers were applying four times more pesticides than in the improved practice plots, pest and disease levels and damage were still higher for farmers' practice. Cheap pesticides do not necessarily lead to savings and can turn out to be expensive when they do not work. In 2018, three BCAs to manage soil-borne pests/diseases researched in this project passed the registration process by the Ministry of Agriculture in Uganda (MAAIF) for commercialization.

This work has led to improving the safety and health of vegetable farming practices in the intensive peri-urban production systems in East Africa. Increasing yields, reducing reliance on chemical pesticides, and introducing safer alternatives benefit farmers, consumers, the public, and the environment. We now need to extend the knowledge of using healthy seedlings and other improved practices to improve



**Utambuzi wa wadudu
waharibifu na magonjwa ya
nyanya**



vegetable farming at scale and ensure that we all eat healthy vegetables.

Projects and Donors

Federal Ministry for Economic Cooperation and Development (BMZ); Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Local Focus: safe and effective pest and crop

management strategies to strengthen the vegetable value chain in the humid tropics. 2013-2015

Federal Ministry of Finance (MoF) of the Republic of Austria; Austrian Development Agency (ADA): Healthy seedling systems for safer, more productive vegetables in East Africa. 2015-2018

U.S. Agency for International Development (USAID): Feed the Future. Integrating vegetables into maize-based systems for enhanced nutrition and income generation. 2013-2015



Private sector partner demonstrates use of a weeder. Photo by A. Adetunji, IITA.

Training and Seminars

Types of training



	Group		Staff development		Use of facilities		Visiting scientist/ Individual		Internship	
	M	F	M	F	M	F	M	F	M	F
Intakes	11,358	6,343	71	50	3	3	10	3	251	274
Total	27,678				6		13		525	

Group training

A total of 189 group training were conducted covering Cassava Production, Agribusiness, Agronomy, Business Plan, Aflatoxin Management, Postharvest, Plant Breeding, Integrated Pest Management, R Statistical Programming, Data Collection, Experimental Design etc. with participants (56% male and 44% female) in 12 countries (Benin, DRC, Ghana, Kenya, Malawi, Mali, Netherlands, Nigeria, Rwanda, Tanzania, Uganda, and Zambia).

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

Table 1. Number of training workshops, 2018.

Country	Training organized (no.)	Male (no.)	Female (no.)	Total (no.)
Burundi	10	311	60	371
DRC	3	71	58	129
Ethiopia	1	13	4	17
Ghana	5	108	31	139
Kenya	10	230	164	394
Liberia	13	164	95	259
Malawi	15	10020	9747	19,767
Mozambique	2	28	4	32
Nigeria	100	2783	1557	4,340
Rwanda	3	37	20	57
Tanzania	22	1585	485	2,070
Uganda	5	46	20	66
Total	189	15,396	12,245	27,641

External group training (fee based)

Five fee-based training were organized with 67 participants (45 males and 22 females).

Table 2. Training implemented and number of participants.

Training title	Participants (no.)	Gender distribution (no.)	
		Male	Female
Cassava and Banana production and processing	10	7	3
Novel Techniques for Weed Management in Cassava Farming Systems	13	13	0
Geographical Information System Training Course for Agricultural Research in Africa	4	4	0
Hands-on Molecular Biology Techniques Training	25	11	14
Statistics and Statistical Computing Methods Using SAS Training	15	10	5

Internship

A total number of 525 interns were recruited: 120 graduate interns (44 male & 76 female) at five IITA locations (Kenya, Nigeria, Rwanda, Tanzania, and Uganda), 354 IT/SIWES (178 male & 176 female) from 27 higher institutions across Nigeria, and two batches of NYSC with a total number of 51 (29 male & 22 female). IT/SIWES and NYSC are interns applicable in Nigeria only. Tables 3 and 4 / Figures 2 and 3 show the distribution of graduate interns across IITA locations and IT/SIWES interns.

Table 3. Graduate interns, by location.

Country	Male (no.)	Female (no.)	Total (no.)
Kenya	2	1	3
Nigeria	39	68	107
Rwanda	2	2	4
Tanzania	1	0	1
Uganda	0	5	5
Total	44	76	120

Table 4. IT/SIWES interns, Nigeria.

Category	Male (no.)	Female (no.)	Total (no.)
IT/SIWES	178	176	354
NYSC	29	22	51
Total	207	198	405

Talent Grant

A total of 12 awards were given

Units	No./%	Hubs	No.	Male	Female	Type	
Research (R4D)	7 (59%)	Western Africa (58%)	7	4	3	Individual	11
HR/Admin	2 (17%)	Eastern Africa (17%)	2	1	1	Group	1
CDO	1 (8%)	Central Africa (8%)	1	1	0		
HOSTRAS	1 (8%)	Southern Africa (17%)	2	1	0		
ICT	1 (8%)			7	4		
Total	12		12				12







Knowledge managers in IITA organize knowledge products for open access. Photo by E. Onasanya, IITA.

Publications

Publications

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Plantain and banana market in Ikire, Nigeria. Photo by O. Adebayo, IITA.

Our Finances and Supporters

Funding overview



Omoshalewa Sholola

Funding for 2018 was US\$87.673 million, of which 99.74% came from CRP and Non-CRP funding windows and 0.26% from other sources. Expenditures were US\$87.254 million (net of indirect costs recovery of US\$9.218 million) of which 88.1% was used for program expenses and 11.9% for management and general expenses.

The governments and agencies that provided the largest share of our funding in 2017 and 2018 are shown in Figure 1 (top 10 donors).

IITA's 2018 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.complementing traditional breeding. CRISPR/Cas9

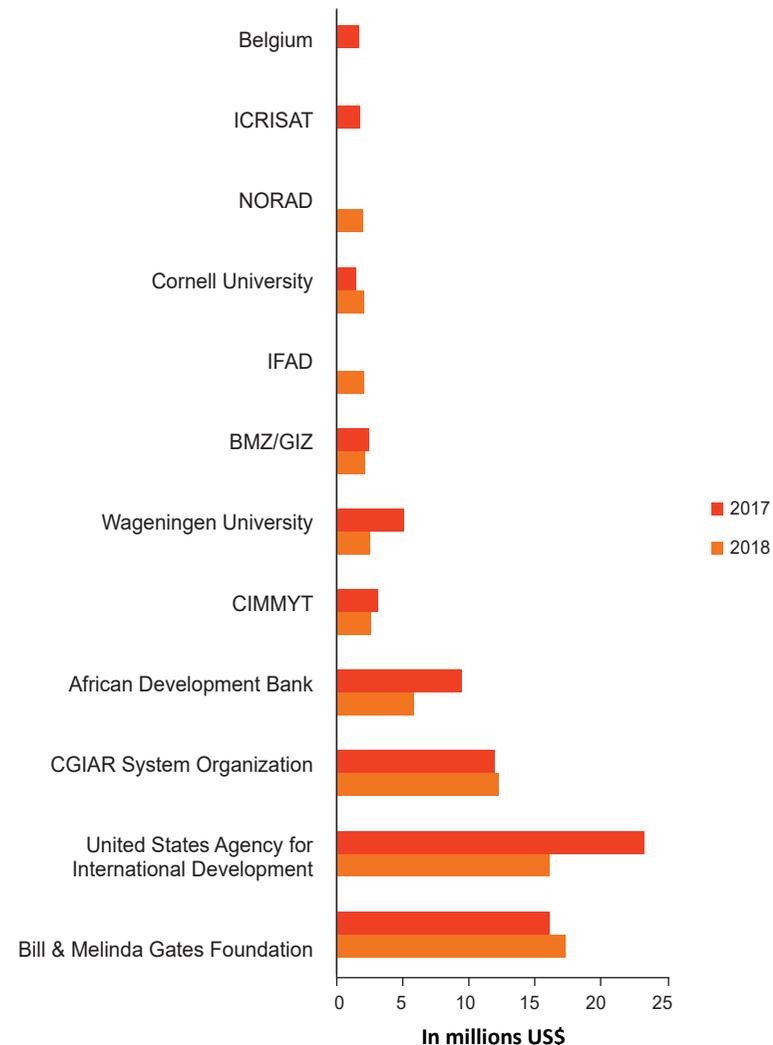


Figure 1. Funding: top 10 donors, 2017 and 2018

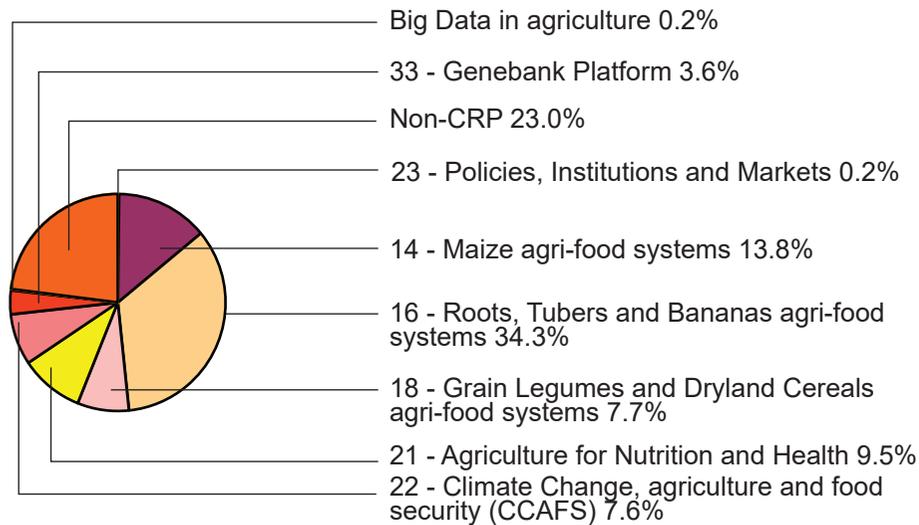


Fig 2: 2018 Investment by CRP and Non-CRP Funding Windows - Expenditure

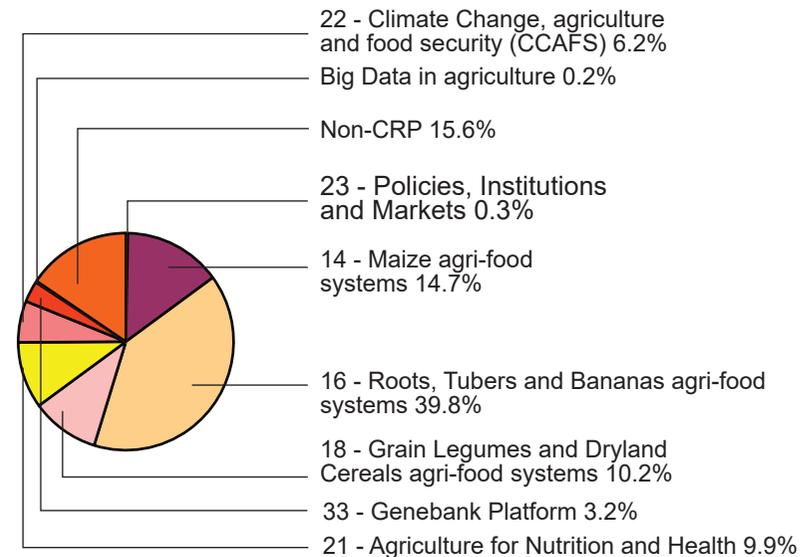


Fig 3: 2018 Investment by CRP and Non-CRP Funding Windows - Expenditure

Table 1. 2018 Investment by CRP and Non-CRP Funding Windows

CRP / Non-CRP	Budget (\$'000)			Actual Expenses (\$'000)		
	W1/W2	Window 3 / Bilateral Proj.	Total	W1/W2	Window 3 / Bilateral Proj.	Total
23 - Policies, Institutions and Markets	176	-	176	176	74	250
14 - Maize agri-food systems	1,761	12,044	13,805	1,761	11,044	12,805
16 - Roots, Tubers and Bananas agri-food systems	5,110	29,181	34,291	4,834	29,892	34,726
18 - Grain Legumes and Dryland Cereals agri-food systems	941	6,778	7,719	941	7,964	8,905
21 - Agriculture for Nutrition and Health	1,657	7,869	9,526	1,657	7,006	8,663
22 - Climate Change, agriculture and food security (CCAFS)	477	7,141	7,618	435	4,958	5,393
33 - Genebank Platform	2,599	976	3,575	2,455	299	2,754
Big Data in agriculture	161	-	161	161	18	179
CRP / Platform	12,882	63,989	76,871	12,420	61,255	73,675
Non-CRP	-	22,981	22,981	-	13,579	13,579
	12,882	86,970	99,852	12,420	74,834	87,254

Table 2. Performance Indicators: Financial Health

	2017	2018
Short-term Solvency (or Liquidity)	37.1 days	40.9 days
Long-term Financial Stability (Adequacy of Reserves)	25.1 days	30.9 days
Indirect Cost Rates	18.2%	16.0%
Cash Management on Restricted Operations	1.11	1.30
Audit Opinion	Unqualified / Clean Bill of Financial Health	

Table 3. List of IITA Investors

	2017	2018
IITA Investors	(expressed in US\$ Thousands)	
African Development Bank	9,571	5,883
ANADARKO	-	601
AGRA	285	
Austria	574	304
Belgium	1,746	676
Bill & Melinda Gates Foundation	16,314	17,503
BMZ/GIZ	2,494	2,219
Burundi	274	778
Cameroon	-	1,519
Canada	643	-
CGIAR System Organization	12,086	12,420
Chemonics	144	6
Chevron Nigeria Limited	205	101
CIRAD	-	154
Commission of the European Communities	56	224
CORAF/WECARD	252	-
Cornell University	1,480	2,118
Deloitte Consulting LLP	792	577
Democratic Republic of Congo	537	420
Development Aid from People to People in Zambia	128	
Donald Danforth Plant Science Centre	286	332
Florida Atlantic University (FAU)	-	339
Food and Agriculture Organization	335	159
Food for the Hungry International	97	-
France	330	-
<i>Friedrich-Alexander-University Erlangen-Nuremberg</i>	323	-
Ghana	409	101
Global Crop Diversity Trust	778	183
International Crop Research Institute for the Semi-Arid Tropics	1,817	1,215
International Centre for Tropical Agriculture	1,330	1,247
International Food Policy Research Institute	777	565
International Fund for Agricultural Development	928	2,136
International Livestock Research Institute	800	496

	2017	2018
IITA Investors	(expressed in US\$ Thousands)	
International Maize and Wheat Improvement Centre	3,147	2,617
International Potato Centre	1,012	1,296
Ireland	143	590
Japan	745	544
Leventis Foundation	72	65
Liberia	1,164	463
Meridian Institute	45	2
Michigan State University	164	145
MoFA Sudan	-	410
National Agricultural Research Organization	508	379
Natural Resources Institute	113	228
Netherlands	1,200	392
Nigeria	901	1,099
NORAD	-	2,022
OCP S.A., Morocco	122	8
<i>Programme Integre de Rehabilitation de l'agriculture dans la Province du Maniema</i>	110	-
Purdue University	364	204
Queens University Belfast	278	341
Queensland University of Technology	591	398
Saint Louis University (SLU)	-	303
Sweden	27	86
Tanzania	537	557
United States Agency for International Development	23,487	16,245
University of California	73	33
University of Illinois	251	112
University of Florida	-	174
University of Lausanne	203	139
Wageningen University	5,109	2,544
World Bank	777	23
Miscellaneous Projects	1,906	3,750
Grand Total	98,840	87,445



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IITA-DRC (Bukavu) research facilities. Photo by M. NSimire, IITA.

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