Building for better science

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Roots, Tubers and Bananas

Building for better science
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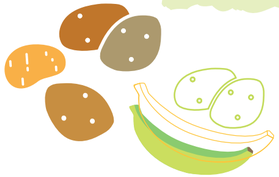


DASHBOARD

101 INNOVATIONS IDENTIFIED

Changes in development status for 40 innovations in 2019.

CAPACITY DEVELOPMENT ACTIVITIES

92,331 PARTICIPANTS
in short-term trainings and scaling activities.

95 TRAINEES
involved in academic programs (PhDs).

OUTCOME Case Facts

600,000 HOUSEHOLDS have adopted some BXW control practices. Adoption of these practices is higher among subsistence farmers.

USD 468 PER YEAR PER HA
is the average increased value of banana production for farmers using the entire BXW control package.

5 POLICIES AND REGULATIONS
in the agriculture and nutrition sector developed and adapted based on scientific evidence provided by RTB participants.

FOREWORD

In 2019, the CGIAR Research Program on Roots, Tubers and Bananas (RTB) continued to do great science and give serious attention to scaling, working with a diverse array of partners. This report, like last year's, is organized around five well-defined, high-impact flagship projects. The important topics of gender and youth are embedded across these flagship projects.

As you know we are entering a period of unprecedented change and uncertainty but also huge new opportunity. Institutionally we are actively engaged in the One CGIAR process which will lead to significant organisational and programmatic change. We are also grappling with the consequences of COVID-19 which began as a health crisis but will have enormous impacts on food systems. RTB crops with predominantly local value chains which are less vulnerable to global disturbances may play a key role in the response. Hence, we are presently considering how to build on our many assets, securing ongoing research but also pivoting to contribute in novel ways in this period of economic and social transformation. During a period of unprecedented change, RTB crops will continue to play a vital role in raising incomes, enhancing climate-resilience and improving nutrition and food security.

Some highlights this year include: spearheading the shift to demand-led breeding; using knowledge about metabolites for faster, better plant breeding; interactive conservation of native potato varieties and drawing lessons for other RTB crops; Nigerian farmers making money selling cassava seed of high yielding varieties; an impact study of how farmers benefit from managing a serious banana disease; using apps to diagnose crop health problems; optimizing extension methods to train young mothers about orange-fleshed sweetpotato; looking into the future to guide investment in root, tuber and banana crops; and showing how young agribusiness men and women are motivated by more than profits.

Across all the stories, RTB as a program adds value to the work of its collaborating centers and partners, building larger critical mass and contributing to the many successful outcomes and impacts in this report. Our aim is to build on recognised research excellence as we strive to ensure that the crucial, but still often neglected, RTB crops receive the recognition they deserve. We thank all our partners and donors whose outstanding contributions have made these achievements possible.

Barbara H. Wells
CIP Director General

Graham Thiele
RTB Program Director

RTB AT A GLANCE

The CGIAR Research Program on Roots, Tubers and Bananas (RTB) was launched in 2012 to harness the untapped potential of banana (including plantain), cassava, potato, sweetpotato, yam, and other root and tuber crops to improve food security, nutrition and livelihoods. RTB brings together the expertise and resources of five centers: the International Potato Center (CIP), which leads the program; Bioversity International; the International Center for Tropical Agriculture (CIAT); the International Institute of Tropical Agriculture (IITA); and the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), which represents several other French partners in the research program. The centers have teamed up to collaborate on common issues affecting RTB crops, mobilize complementary expertise and resources, avoid duplication of efforts, and create synergies.

This collaborative approach aims to increase the benefits of the centers' research and interventions for smallholder farmers, consumers, and other actors in root, tuber and banana agri-food systems. RTB consolidates research in five interdisciplinary flagship projects (FPs), described throughout this report. Each flagship has a dynamic leader based in one of the centers. Each flagship is composed of a set of interrelated research 'clusters' which have clear impact pathways through which RTB centers and their partners collaborate to achieve targeted outcomes. The areas of focus for each of the clusters were identified through an RTB assessment to determine the options with the greatest potential for impact.

The nested impact pathways at the cluster and flagship project levels are at the heart of the program's results-based management. A monitoring and evaluation system, aligned with the overall CGIAR performance management framework, has been developed and its implementation is facilitated through MEL, an online planning, monitoring, evaluation, and learning platform, collaboratively developed with several CRPs and centers. In 2019, RTB maintained collaboration with 319 partners, primarily national agricultural research organizations, academic and advanced research institutions, private companies and nongovernmental organizations (NGOs). These valuable partnerships have played an increasingly important role in this second phase as the program works to scale out the technologies and approaches developed under its flagships. RTB sought to accelerate the scaling of innovations linked with capacity development for partners, while ensuring that research benefits women and men alike and engages youth. Together, RTB and its broad network of partners are working to achieve the program's intermediate development outcomes – which are fully aligned with the Sustainable Development Goals – by 2022.

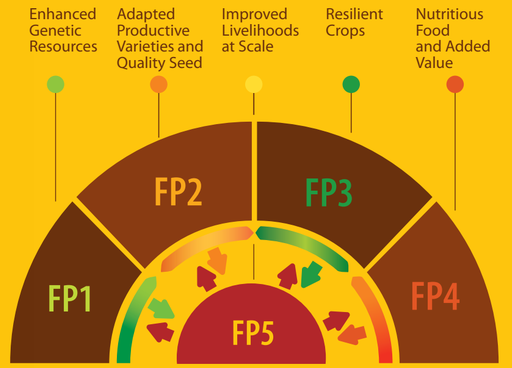
MORE THAN 300 MILLION PEOPLE below the poverty line in developing countries depend on root, tuber and banana crops for food

PROVIDE AROUND **15%** or more of the daily per capita calorie intake

RTB crops can significantly improve nutrition and food security

How we work

FP = Flagship Projects



Sustainable Development Goals

20 MILLION PEOPLE (50% women) increased their income

30,000 SMALL AND MEDIUM enterprises operating profitably in the seed and processing sectors

8 MILLION FARM households increased yield through the adoption of improved varieties and sustainable management practices

10 MILLION PEOPLE (50% women) have improved their diet quality

1.9 MILLION ha of current RTB crops production area converted to sustainable cropping systems

AT LEAST 2 MILLION HOUSEHOLDS have increased capacity to deal with climate risks and extremes

9,500 INDIVIDUALS (50% women) in partner organizations have improved capacities

AT LEAST 5 PARTNERSHIP and scaling models tested in a minimum of 5 target countries

Selected RTB Program targets (2022)

Flagship 1
Enhanced genetic resources

Flagship Project 1 (FP1) is developing leading-edge science for more efficient breeding of user-demanded root, tuber and banana varieties, while overcoming the limitations of conventional breeding for vegetatively propagated crops. Plant breeders across the RTB program are developing new genomic tools in collaboration with top universities and research centers around the globe. "FP1 is pleased to be a leader in the rapidly advancing field of genetic science," says Luis Augusto Becerra, FP1 leader and principal research scientist at CIAT.

Kennedy Masamba and Tiwonge Chadzala inspect OFSP vines in a screen house in Blantyre, Malawi. H. Rutherford (CIP)

Studying metabolites for faster, better plant breeding

Metabolites are the small molecules produced by living cells. Identifying the unique metabolic signature of plant tissues can help plant breeders quickly identify the desired traits in crop varieties. An exciting partnership with Royal Holloway University of London (RHUL) is conducting groundbreaking studies of the metabolites of cassava, potato, yams, sweetpotato, and bananas.

Plants produce thousands of small chemical compounds known as metabolites. Like a DNA fingerprint, which offers a portrait of a plant's genes and thus what it is capable of doing, a survey of the metabolites in a specific tissue, such as the leaves, can tell us what that tissue is doing, how it is responding to its changing environment and what might be happening in the roots or elsewhere in the plant.

Metabolites are the end result of genes switching on and off and directing all the complex workings of the cell. As a result, metabolomics (the study of the metabolites) offers insights into important genetic questions, fast-tracking through the layers of cellular regulation to deliver a functional printout of the genome. That is why RTB has invested in metabolomics, across all our major crops, working closely with RHUL. This long-term partnership that began in 2012 is now attracting significant international funding, and developing technologies that will soon be transferred to partners in other RTB flagship programs.

RHUL and RTB established protocols to extract and analyze plant metabolites, especially in young plants, to see if they would be good proxies for products in the mature plants – the roots, tubers and bananas. This remarkable progress has been documented in six publications, customized metabolite libraries and a database of the metabolomes of key crops produced over the last two years.

The analysis of the metabolites in leaves and tubers in different yam species highlighted the potential for predicting tuber composition from leaf profiles. In cassava, higher amylose (starch) content in the roots is indicated by particular leaf metabolites.

Leaf metabolites that are associated with high amylose are one example of a biomarker, something relatively easy to detect or measure that predicts the level of an important trait that may be more difficult to assay. Identifying these metabolites can help breeders to rapidly select improved crop varieties.

> Michael Friedmann, science officer with RTB, sees great potential. ***Breeders can use metabolomics to enhance the selection of parental lines and offspring that have unique chemical features, which make them resilient to climate change, or more resistant to pests and diseases, or make them more nutritious.***

A study of potatoes revealed nine metabolites that seem to be linked to plant responses to drought, suggesting probable pathways involved. Previous studies have shown these metabolites interfere with the ability of drought-tolerant plants to retain water from the soil or antioxidant mechanisms to protect from damage. In addition, these metabolites can be monitored by high-throughput techniques such as near-infrared spectroscopy (NIRS), thus allowing for many genotypes to be screened to study the metabolites' functional role in large genetic studies and to identify linked molecular markers. Therefore, future studies will enhance the discovery of drought-tolerant potato lines.

In cassava, research identified the metabolomes of one line that were resistant to thrips and another resistant to whitefly pests. For example, the cassava line susceptible to thrips had higher levels of the metabolites free catechin/epicatechin, which could indicate lower condensed tannin levels, thought to provide resistance to the pest. Likewise, disease-resistant banana lines also had specific metabolomes, with the line Calcutta 4, a parent usually used in crosses to confer resistance to various diseases, showing higher levels of the metabolites rutin, chlorogenic acid and caffeoyl-malate, which could be related to its resistance traits. The metabolomics study on the mechanisms associated with whitefly resistance in cassava suggested a strategy based on reinforcement of cell walls, with more lignification in the resistant line. Identifying such metabolites will make it easier for breeders to search through many more young plants to spot potential winners.

> ***The RTB scientific community strategically invested to build and integrate metabolomics. Today metabolomics is allowing researchers to look at natural variation while opening the possibility of faster trait discovery.*** Current work at the International Center for Tropical Agriculture (CIAT) elucidating the mechanism of whitefly resistance is a clear example of its potential, said Luis Augusto Becerra RTB, FP1 leader.

An important goal for breeders is to select for more nutritious crops, while ensuring that people will like and adopt the new varieties. Many metabolites are involved in the taste and smell of foods. A metabolomics study was linked to a sensory study in potato, that addressed various quality parameters such as potato flavor intensity, sweetness, savoriness, sourness, bitterness and mealiness, comparing breeding lines, landraces and wild potatoes. The metabolomic profiling identified 77 metabolites and showed differences between the different potato types. For example, breeding lines showed less starch degradation, thus sugars were released during cooking -- an important trait in breeding programs. The associations between metabolites and sensory properties are still being analyzed. Consequently, this work will provide guidelines for which metabolites to screen for after harvest, cold storage and cooking for product quality. Likewise, another study in sweetpotato showed that breeders can select even more nutritious sweetpotatoes by looking beyond the orange color, which is associated with pro-vitamin A content. Some carotenoids, such as mutachrome, supply less pro-vitamin A, while still producing an orange sweetpotato. Metabolomics gives sweetpotato breeders a robust way to decide which varieties will deliver the most vitamin A.

> ***Metabolomics as a technology will be key in quality trait assessment,*** said Paul Fraser of Royal Holloway - University of London. In combination with similar, cutting edge technologies and breeding populations it gives us a way to identify and validate alleles of interest.

For now, metabolomics work requires expensive laboratory equipment and trained staff, which means that the partnership with RHUL will continue to be important to breeders. However, equipment is becoming cheaper and RHUL is already training staff in partner countries; the hope is that in-country metabolomics centers will soon be available to local breeding programs.

This phase of RTB's research into metabolomics has already produced important results and points to promising new avenues to explore. It also established a strategic partnership between RTB and the metabolomics research group at RHUL, building on our complementarities. RTB teams have learned to design trials and prepare material for metabolite extractions, and RHUL gained experience working under the constraints of developing countries where some equipment may be lacking. This bodes well for extending and deepening this important partnership.

Farmers weeding their cassava fields in Uganda.
S. Fernandes (RTB)

Mapping the genes of wild bananas provides insights for disease resistance

Recent RTB-funded efforts are mapping the genes of bananas to breed varieties that are resistant to common diseases, as part of wider strategies to combat the diseases. All cultivated bananas are susceptible to banana *Xanthomonas* wilt disease (BXW), and many dessert bananas are susceptible to *Fusarium* wilt disease. However, some wild bananas are resistant to these diseases. Understanding the genes that defend plants from these diseases is a first step to breeding healthier, more productive banana varieties.

BXW is menacing banana and plantains across East Africa, where these crops are major staple foods. BXW is caused by a bacterium named *Xanthomonas campestris*. Most cultivated varieties of banana and plantain are susceptible to BXW. Fortunately, some varieties of a wild banana species, *Musa balbisiana*, are resistant to BXW, but their fruits are small, full of seeds and not edible. So, a key strategy for managing the disease would be to breed cultivated bananas with wild ones, bringing in the genes for disease resistance, but without dragging in unwanted genes that would compromise the fruit quality. The first step is to identify those bacteria-fighting genes.

Recent work funded by RTB has mapped these crucial genes for resistance, by comparing the wild banana, *Musa balbisiana*, with a cultivated variety, Pisang Awak, which is very susceptible to BXW. The project, led by Leena Tripathi at IITA, found about 30 stress-related genes that were differentially expressed in the wild banana in response to bacterial infection.

Within 12 hours of the pathogen attack, some of the resistance genes identify the invader, and other genes express responses to fight it off, for example by reinforcing the cell walls, inducing rapid calcium fluxes and oxidation bursts around the infection site. In other words, these genes activate the plant's basal defense (its innate, first line of protection against pathogens.). Other genes program the death of infected banana cells, robbing the disease of its toehold in the plant.

> ***This research project has mapped the candidate genes for resistance on the wild banana. Future plant breeders may be able to bring the traits for disease resistance from wild bananas to the cultivated ones that farmers grow in Africa by using modern biotechnological tools,*** says Tripathi.

In another area, is the *Fusarium* wilt disease, caused by the fungus *Fusarium oxysporum*, that is threatening the world's banana supply. Recently, a new form of the fungus, tropical race 4, has been spreading in Asia and has reached Africa and Latin America. Cavendish, the most widely grown banana variety, is very susceptible to tropical race 4. RTB has supported an alliance of researchers in Asia, Africa and Latin America to share knowledge and information to combat the disease. These researchers are helping to carry out surveillance on the spread of the disease, especially in Africa, by developing and implementing detection tools for the disease, and screening germplasm for resistance. Information and communication technology (ICT) tools are being developed to help identify the disease in farmers' fields.

Many commercial banana varieties are susceptible to *Fusarium* wilt, yet some wild bananas are resistant, including Pahang, a type of the wild species, *Musa acuminata*. So, research was carried out to understand the genetic basis of immunity of this hardy, wild banana.

This project, led by the Yunnan Academy of Agricultural Sciences and Bioversity International, has shed some light on candidate genes for *Fusarium* resistance. The *Fusarium* fungus is abundant in the soil, and commonly enters the plant through the roots. The wild banana fights off the disease by accumulating hydrogen peroxide in root cells, strengthening the cell walls and making secretions that inhibit spore formation and fungal growth.

> ***This work identified a few candidate genes in the wild banana species, which code for responses to Fusarium infection. This helps us to better understand the genetic basis for disease resistance in bananas,*** says Alberto Cenci, an expert in banana genetics at Bioversity International.

To find the genes that code for these responses, scientists compared expressed genes in the wild, resistant Pahang, with those of a susceptible commercial variety, "Brazilian." Before being infected with the pathogen, both banana varieties expressed differences in thousands of genes: Pahang expressed 3,867 genes at higher levels than those in Brazilian. However, Brazilian expressed 2,452 genes at higher levels than in Pahang. Since these differences were observed before infection, Pahang probably has many defense genes expressed all the time, which is called "constitutive defense." One day after infection, genes in the wild Pahang code for eight proteins to be produced, but this was not so for the susceptible Brazilian banana. Pahang has many resistance genes primed before infection, and then others which are induced by the infection, but faster than with Brazilian. So, the fungus can overcome the defenses of the susceptible variety, which seem to respond too little, too late.

The results obtained with BXW and *Fusarium* wilt are both examples of cutting-edge science being used to understand disease resistance in bananas and plantains, and to help plant breeders to produce new crop varieties that resist these diseases.

Better together - traders selling their bananas. Uganda. S. Fernandes (RTB)

Interactive conservation of native potato varieties, lessons for RTB crops

Interactive conservation of native potato varieties combines two types of conservation: *in situ* (on farm) and *ex situ* (in genebanks). Learning more about how rural communities grow valuable varietal diversity is helping researchers to understand and support *in situ* conservation, while improving farmers' livelihoods and nutrition.

Crop varieties can be conserved on farms (*in situ*) or in formal seed banks (*ex situ*), often at research centers. *Ex situ* conservation of roots, tubers and bananas is more work and costlier than storing the seeds of cereals and legumes, because vegetative seed (such as tubers and cuttings) must either be planted and grown every year or be frequently renewed using tissue culture. RTB has a lively community of researchers working across multiple crops on *in situ* conservation and exploring linkages with *ex situ*.

Participatory market chains build value for potato farmers and other actors along the chain. (CIP)

In situ conservation in the Andes is largely driven by farmers' multiple demands for diversity: superior taste and texture, cultural attachment to local varieties and managing the risk of crop loss in a harsh environment. Conserving seed on farm has the advantage of keeping it in the communities that grow the crops, where diversity can evolve in a context of farmer selection. *In situ* conservation is highly dynamic: varietal portfolios change over time as some varieties are lost and others are added.

Farmers maintain unique diversity which is not necessarily covered in genebanks. The ongoing evolution on farms is driven by selection, mutations, geneflow and farmer seed networks. In a complementary manner, *ex situ* collections and outside experts can backstop communities that wish to reintroduce lost native varieties. This is interactive conservation, linking *in situ* with *ex situ*.

One association of Peruvian potato guardian farmers, AGUAPAN, has organized themselves to act on their motivations, concerns and needs to conserve the native potato varieties that they love. The association is now expanding from 50 to 100 members and communities. Through private sector support, a direct benefit sharing scheme is run to support farming, health and education. This is encouraging the guardian farmers to care for Peru´s priceless heritage of native potato varieties.

A recent study of farm communities in Huancavelica and Pasco, Peru shows that diversity is changing. Since 1975-1985, native potatoes in these regions have continued to be grown, but climate change has pushed them to higher altitudes, 300 meters further up on average, and the native varieties are now found in a narrow band between 3,900 and 4,200 meters above sea level. These native potatoes cannot go much higher.

> "***The good news is that farmers are still conserving lots of native potatoes. Even commercial growers in Pasco still plant native varieties. But most native varieties are endangered,*** says Alejandra Arce, the leader of the study."

Group AGUAPAN, Peruvian potato guardian farmers. S. De Haan (CIP)

Farmers are growing widely-known commercial varieties, both native ones and those created by plant breeders. And Peruvian farmers are still growing dozens of floury local native varieties to eat at home, but most of these varieties are rare, and grown by just a few families. Some farmers also grow bitter varieties to make chuño, a freeze-dried potato consumed in the Andes since ancient times, but quickly becoming quite rare as food habits change and as a changing climate makes freezing temperatures less common.

While Pasco is a commercial potato-growing area; communities in Huancavelica plant potatoes mainly to eat at home, but also to sell. Potatoes contribute energy, iron, zinc, vitamin C and protein to local diets, but there is often a lack of dietary diversity. Half of the children under five are undernourished.

The farm families need better health care, and livelihood options that would allow them to access healthier diets with more meat, eggs, fruits and vegetables. The diversity hotspots must also become centers of prosperity for people to live and raise children if young farmers are going to continue to care for these irreplaceable varieties for future generations. Today's potato varieties will be crucial for helping tomorrow's farmers adapt to a changing world.

There are lessons here for the conservation of other root, tuber and banana crops in RTB and beyond. Conservation of treasured varieties need not be strictly *in situ* or in a formal genebank. Both strategies need to be brought together, in interactive conservation that helps farmers retain the varieties they need, while monitoring conservation and fostering the exchange of varieties so that both farmers and curators share materials to ensure their survival.

A genetic roadmap to bigger bunches of bananas

RTB has been supporting the development of genomic tools to accelerate breeding. One such approach, Genome Wide Association Study (GWAS), finds molecular markers for complex traits of agronomic and economic importance. Researchers have done the first study ever to map the genetic markers associated with high fruit yield in bananas. This will help speed up breeding programs, as researchers will be able to identify high-yielding hybrids before growing them out. Unproductive hybrids can be discarded early, allowing breeders to concentrate on finding the bananas with other promising traits as well.

Applying genomic approaches to develop molecular markers for complex traits such as yield can help increase the efficiency of RTB breeding programs. One of the main goals of many banana breeding programs is to increase the bunch weight of bananas (boosting yields). New research from IITA, the Institute of Experimental Botany (Czech Republic), and the Swedish University of Agricultural Sciences has applied genomic approaches to find the genetic markers associated with bunch weight in bananas. This can help eliminate many progenies earlier in the breeding program, allowing scientists to concentrate sooner on the more promising ones.

High yielding hybrid, with resistance to black Sigatoka and good fruit quality, bred by IITA and NARO in Uganda. B. Uwimana (IITA)

High-yielding Narita 10 hybrid, on the right, compared to its parents. B. Uwimana (IITA)

> *This is the first time ever that anyone has located the genomic loci associated with bunch weight and related traits, like the number and size of fruit,* says Moses Nyine, who led the study.

Geneticists have known since the 1960s that three genes control much of the variation of fruit size in bananas, but the location and mode of action of these genes remained unclear. This knowledge gap frustrated efforts for breeding disease resistance in bananas, because wild bananas are often disease-resistant, but they also bear just a few fruits, and small ones at that. So, crosses with wild bananas often resulted in resistant, but low yielding hybrids. As many as 90% of new hybrids had to be grown to maturity and then tediously discarded as breeders appraised the plants to discover which ones bore lots of fruit.

The team carried out a genome-wide association study (GWAS) of banana—a search for genetic markers linked to traits of interest, such as heavy bunches of fruit. The researchers compared 307 genotypes derived from East African highland bananas in three fields in Uganda, including two that were mulched and fertilized and one that was not (to help understand the role of environment in determining fruit yield).

The team found that bunch weight was highly heritable. After looking at over 27,000 genetic markers, 47 were found to be associated with bunch weight and its component traits (such as number of hands, and fruit size). These 47 markers were on 25 genomic loci on five chromosomes, but a single region on chromosome 3 probably bears most of the genes that affect bunch weight.

> *Our research suggests that fruit filling is under the control of a few genes, with major effects,* explains Nyine. *Future plant breeders will be able to select hybrids that have these genes, without growing out the whole plant. This will make it easier to concentrate on other desired traits, such as disease resistance and the ability to adapt to climate change.*

Flagship 2

Adapted productive varieties and quality seed

Flagship Project 2 (FP2) breeds better crop varieties and improves seed systems. FP2 sees that the crop varieties bred by RTB match the needs and preferences of farmers and consumers: men and women. FP2 also strengthens the seed systems that get these varieties into the hands of women and men farmers. "We are committed to bringing farmers into the breeding process. We are ensuring their demands for specific traits are incorporated into our breeding projects," says Maria Andrade, FP2 leader, plant breeder at CIP, and World Food Prize winner.

Farmers returning home with cassava stems they purchased through the market promotion with VSEs. S. Phelps (CRS)

Spearheading the shift to demand-led breeding

A revolution in the organization of plant breeding is sweeping the CGIAR. RTB is at the forefront, making sure that new approaches and tools fit our crops, including the complexities of breeding and the quality preferences of users. The introduction of product profiles is a key tool in this process. Market experts and social scientists including gender specialists, working closely with the breeders, consult with farmers, consumers, processors and other stakeholders to capture either new or existing traits that will successfully drive variety adoption. These specifications are written up as a prioritized list of traits called a "product profile," where the product being designed is a future crop variety. The product profile guides breeders in crop improvement and enables stakeholders and management to monitor progress towards delivering that variety.

A revolution is advancing the modernization of CGIAR public breeding programs to meet the twin challenges of climate change and growing populations. This requires increasing potential yields in a way that responds to market demands. Guided by the Excellence in Breeding Platform (EiB), this involves the more focused design of breeding products, better prioritization and mechanisms to manage breeding product pipelines, the use of genomics and other modern tools to accelerate breeding cycles, and digitization of breeding data to enhance accessibility and analysis (see BreeDBase story in Box). Moreover, breeding products must conform to farmer and consumer demands, which is the starting point for developing a new variety. RTB is at the forefront of this revolution, which is critical for our vegetatively propagated crops, with their complex genetic structures, making them more difficult to breed, and the need to incorporate key quality traits for consumer acceptance of new varieties.

Cu Thi Le Thuy with Alliance Bioversity-CIAT selects materials with potential resistance to cassava mosaic disease. G. Thiele (RTB)

Enhancing plant breeding through digitized data management

A modern breeding program requires digitized data to make effective breeding decisions. This also enables accessing and sharing breeding data. Today, breeding lines in the field are labeled with barcodes, and traits are described using standardized descriptors allowing for a drastic reduction in errors. Breeding programs can then aggregate data, follow trends over time and locations, and apply various tools of analysis, thus increasing effectiveness. BreeDBase is a comprehensive breeding management and analysis software, set up in collaboration with the Boyce Thomson Institute, for sweetpotato, cassava, banana, and yam.

BreeDBase can be used to design field layouts and collect data using android-based tablets to characterize the plants to help breeders select the most promising ones. BreeDBase can also store genetic information and correlate it with the eventual phenotypes (how the traits are actually expressed in the plants), enabling new breeding methods such as genomic selection. Digitization helps breeding programs to meet timelines, because it is faster to get the data for analysis and also because it is faster to prepare and organize trials. The time and labor saved also helps to keep costs down.

Since 2018, RTB breeders have used the software to manage data generated throughout all the steps of their breeding cycle. National agricultural research system (NARS) partners mainly from Africa, are also adopting the tool, and have entered hundreds of trials into its databases, creating valuable resources for breeders around the world. Future development of BreeDBase will take it towards greater compatibility with other bioinformatics systems, coordinated by CGIAR platform Excellence in Breeding (EiB) and Cornell University.

A key modernization step is the systematic introduction of the product profile tool, which is a prioritized list of traits that an upcoming variety must have, based closely on the drivers of variety adoption. In this manner, the new variety will be designed to meet a demand in a particular market that will make adoption of the variety more likely and hence have an impact on livelihoods. The product profile is jointly designed by the breeder together with market experts and social scientists, including gender specialists, through consultations with relevant stakeholders. Using product profiles at each stage of the breeding process also helps to focus breeding targets, monitor progress and allocate resources. Product profiles are organized like a table, to help chart the design of a new variety, building on the best practice of private seed companies.

Across the CGIAR, the Excellence in Breeding Platform (EiB) is helping breeding programs design their product profiles. So far, breeding teams in RTB have uploaded nearly 50 product profiles to the EiB online database. The table (right) shows a couple of examples. Each line is a variety under development that responds to a particular and important need of a given sector of farmers, processors, and/or consumers. After consultations, desired traits are listed in columns as basic traits of an existing variety, or "value added" traits needed in a future variety. A simplified example, showing a couple of traits, is given for draft product profiles for potato and for yam for specific agroecologies where particular popular local varieties are missing important traits. One key user trait is the poundability of the yam for traditional consumption recipes; this is a complex quality trait to breed for, and it needs to be retained as virus resistance is incorporated. Each proposed new variety has to outperform the local benchmark variety in each of the key traits.

However, vegetatively propagated crops such as roots, tubers and bananas are unlike other crops, so the standardized templates shared by the EiB need to be adjusted to better define and prioritize traits related to product quality, for example, poundability in yam. The RTB Breeding Community of Practice convenes RTB plant breeders, including NARS partner breeding programs, to review and improve product profiles. For example, sweetpotato breeder Solomon Afuape of the National Root Crops Research Institute (NRCRI) at Umudike, Nigeria, was looking to breed a new variety that was better than the popular variety Ex-Ibgariam, which had good quality traits, but did not have good virus resistance nor drought tolerance. In consultation with various stakeholders, including extension agents, food scientists and economists, Afuape was able to develop the product profile where the basic and value-added traits to be incorporated were refined and better defined. Therefore, the basic traits of the Ex-Ibgariam sweetpotato were outlined as good storability, attractive oblong shape and canopy closing by six to eight weeks. The value-added trait was prioritized to include drought tolerance, and an additional 10% more yield than Ex-Ibgariam under drought conditions.

> "*The point is that the people who develop targets for new varieties are not only breeders; they are also users and other stakeholders*, says Edward "Ted" Carey, a sweetpotato breeder with CIP in Ghana."

Moreover, RTB has led the Gender and Breeding Initiative where a tool to query if each trait in the product profile has a potential gender impact (positive or negative) was developed and is now being piloted together with the EiB in the adjustment of product profiles across the CGIAR.

As a next step in the breeding revolution, a hackathon is being planned by the RTB Breeding Community of Practice to share and improve product profiles and lessons about how to integrate stakeholder feedback.

EXAMPLE OF PRODUCT PROFILES FOR POTATO AND YAM FOR SPECIFIC AGROECOLOGICAL ZONES

	Agro-ecology zone	Basic trait	Value added trait: Trait	Value added trait: Benchmark variety	Value added trait: Change from benchmark
POTATO	Highland above 1,800m	1 Storability (over two weeks)	Dry matter	Kinigi	Greater than benchmark by 2%
		2 Red skin, cream flesh color	Late blight resistance	Kinigi	Greater than benchmark by 50%
YAM	Humid forest and derived southern Guinea Savannah	1 Pounding quality	Dry matter	Meccakusa or Hembakwase	Greater than benchmark by 5%
		2 Tuber flesh color	Yam mosaic virus tolerance	Meccakusa or Hembakwase	Equal to or less than benchmark severity score <2.5

Nigerian farmers make money by selling cassava seed of high yielding varieties

The demand for the seed of new cassava varieties is increasing in Nigeria. Until recently, there was no reliable supply of that seed partly because farmers were not used to buying it. As that is changing, village seed entrepreneurs (VSEs) have been organized to grow certified seed of high-yielding cassava varieties. Smallholder farmers, many of them women, are making money from this new seed business which is key to the sustainable adoption of new varieties.

In much of the world, new cassava fields are started by replanting cuttings from a mature plant, either from one's own field or from a neighbor's farm. In Nigeria this is starting to change, as new, high-yielding cassava varieties are increasingly becoming popular, spurred by growing demand to produce local foods like *gari* and *fufu*, partly to eat locally and partly for sale in the cities. The demand for improved varieties for industrial processing into starch and high-quality cassava flour is also increasing. What's been missing is a reliable provider of good quality seed of such varieties. Previously, campaigns would give stems away for free, but after the end of the project, the new varieties were no longer available. As the cassava market matures in Nigeria, the seed market is now expanding as farmers want a reliable supply of new varieties.

To respond to that demand, the VSEs in Benue State are turning cassava stems into a profitable business, as part of the Building an Economically Sustainable, Integrated Cassava seed System (BASICS) project, which is helping VSEs to establish their seed businesses. BASICS has planted 145 demonstration plots of seven improved varieties and two local check varieties for comparison. All the demo plots are clearly laid out and labeled, and the ones in Benue are planted next to main roads where everyone passing by can see the fields and their large, informative signs.

BASICS partner, Catholic Relief Services (CRS), helps the VSEs to promote the improved varieties at local markets, where hundreds of farmers visit on market days. A team of VSEs arrives at the market in a van, playing music, and dancing to draw a crowd. The VSEs show samples of large cassava roots, much bigger than those farmers are used to—and the big roots pique curiosity. VSEs distribute flyers and chat with curious farmers and explain where they may go to buy stems. Some of the farmers buy a sample of three stems, each one a meter long (enough to plant about 12 cassava plants) for 50 NGN (USD 0.14) or a bundle of 50 stems (enough to plant about 200 cassava plants on 165 square meters) for between 500 and 1000 NGN (USD 1.40 to USD 2.80). These small seed sales allow farmers to test the new varieties on their farms. Satisfied customers may contact VSEs later to buy more seed.

BASICS team field visit with VSEs. (RTB)

BASICS held 35 market day promotions in 2019, reaching over 30,000 people and sharing more than 60,000 flyers and posters. During these events, about 8,300 bundles of certified stems were sold at the markets.

To become seed producers, the VSEs must learn new skills, such as how to certify their seed, and how to produce more stems, by growing cassava plants closer together. The VSEs also must buy certified foundation seed and manage stem production. This investment pays off; some of the VSEs have been able to make USD 1,900 over two years from a one-hectare seed plot.

A VSE sells bundles of cassava stems as part of a market promotion by the BASICS program in Benue State, Nigeria. (CRS)

Although the VSEs are growing several improved varieties, demand is so high for one of them, "TME 419", that the entrepreneurs can't produce enough of these stems. The seed customers like TME 419 because it is high-yielding, and the stem is straight and tall (making it easy to transport), but it also has a catchy name. Merely by chance, 419 is also an infamous anti-fraud section of the Nigerian penal code. This helps customers to easily remember the number of this high-yielding cassava variety.

> One of the VSEs' customers, Ruben, explained, ***the VSE sold stems to me and I planted as instructed. The germination of 'sticks' (stem cuttings) of 419 was wonderful; growth was wonderful. If I told my neighbors, I feared they would cut my stems. I kept the thing quiet. Then the soil started cracking as the roots swelled. The roots were immense.***
>
> Many of the VSEs are women, and they are also making money from cassava stems. Cordelia Ortoho is a VSE who started growing certified cassava seed in 2016. ***I have been able to buy plots of land, feed my family, pay for school fees,*** she says. ***I sold 615 bundles worth USD 1,700 last year.***

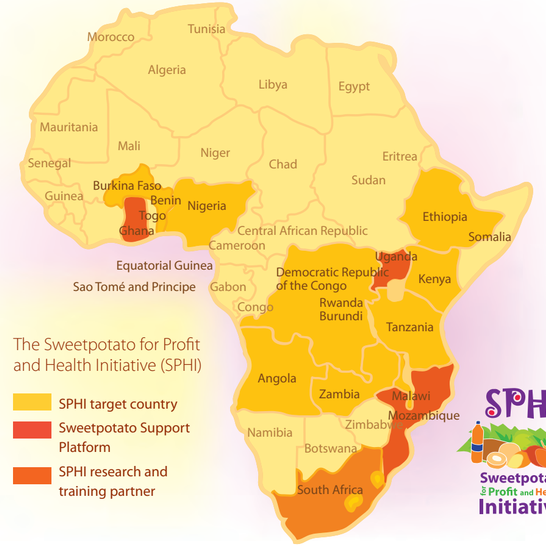
Putting in place seed businesses that make money augurs well for the sustainable adoption of new varieties that combine higher yields with the other key traits which farmers and processors need.

Woman sweetpotato farmer in Cote d'Ivoire proudly showing her harvest. (K. Dibi)

Multi-partner coalition drives adoption of improved sweetpotato by over six million African households

In 17 African countries, a coalition of 17 partners including R4D (research for development) organizations, major donors and RTB, joined together and supported the distribution and use of 150 improved sweetpotato varieties, including 100 orange ones, which have high levels of vitamin A. These varieties were distributed to at least 6.2 million farm households, reaching over 29 million people.

In 2009, a multi-partner coalition including R4D organizations, and major donors (and later joined by RTB) came together as the Sweetpotato for Profit and Health Initiative (SPHI) to promote the broader use of improved varieties of sweetpotato across Africa. The coalition, led by the International Potato Center (CIP), contributed to the release of 150 improved varieties of sweetpotato, including 100 orange-fleshed ones (OFSP), which have high levels of vitamin A. This is important for combating weakened immune systems, risk of blindness, childhood diseases such as diarrhea and other health problems that stem from vitamin A deficiency. Just one small cooked root of OFSP meets the daily vitamin A needs of a young child.



SPHI was a highly ambitious intervention which distributed new sweetpotato varieties to a massive group of low-income farmers over a large area. The varieties were bred specifically for improved nutrition, but also to resist pests, diseases, abiotic shocks and to be high yielding. The distribution was especially challenging because sweetpotatoes are vegetatively propagated. Farmers cannot be simply given a packet of seed, as with cereal grains or beans, for example. Partners involved in SPHI had to address a series of logistical challenges to get fresh cuttings to farmers in the villages. This meant establishing trained multipliers, who knew how to produce quality planting material by minimizing virus infestation.

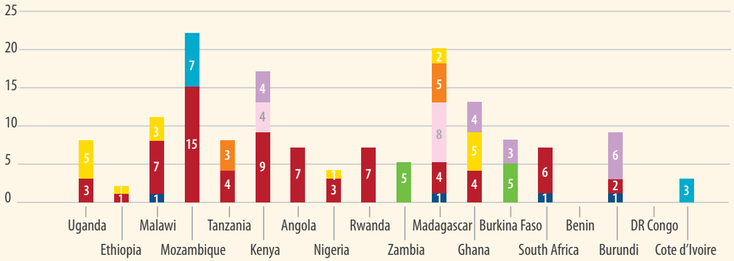
In all, the coalition set up 1,030 decentralized vine multipliers, farmers who could produce and sell vines to neighboring villagers. An ingenious phone survey took advantage of the recent, wide acceptance of cell phones across Africa to reach out to the vine multipliers. Although they were now largely free of project support, 76% of the vine multipliers contacted reported that they were still producing sweetpotato vines for other rural households. The survey also enabled plant breeders to follow which varieties are the most demanded over time.

The coalition tracked how the improved varieties were distributed across the continent. 6.2 million households (which included about 29 million people) received vines of the new sweetpotato varieties in 18 countries: Angola, Benin, Burkina Faso, Burundi, Cote d'Ivoire, Ethiopia, Ghana, Kenya, Madagascar, Malawi, Mozambique, Nigeria, Rwanda, South Africa, Tanzania, Uganda and Zambia.

> ***"The coalition wasn't content to just distribute the vines. The partners set up a monitoring system to keep track of the farmers who benefitted. For example, between mid-2018 to mid-2019, two-thirds of the 251,199 farmers who received vines directly from the project were women,*** explains Julius Okello, of CIP.

This success with SPHI is a model that can be followed by future efforts to distribute vegetatively propagated crops across a vast area and to use a monitoring system to keep track of the farmers who benefited.

SWEETPOTATO VARIETIES
RELEASED IN SPHI TARGET COUNTRIES, 2009-JULY 2019



TOTAL VARIETIES RELEASED 2009-2019 162

Source: Compilation from breeder reports from various countries

- 2009
- 2010-2013
- 2014
- Jan-July 2015
- July 2015-June 2016
- July 2016-June 2017
- July 2017-June 2018
- July 2018-July 2019

An innovative app facilitates seed certification and creates a market for cassava seed of improved varieties

IITA scientists developed an app, the Cassava Seed Tracker, to e-certify seed fields. The app allows farmers to locate a seed producer and buy high quality, virus-free seed of improved varieties. In this way buyers can be sure of getting stems of the variety they want, as mix-ups of varieties are common in the informal seed system. The Seed Tracker can be used on a smart phone to collect and organize seed production information, making it easier for regulatory institutions to register producers, certify seed fields, monitor seed quality, location, variety, and availability. Seed producers can find expert advice on quality seed production, and information to help buy and sell certified seed. Seed Tracker allows real-time information exchange between producers, regulators and buyers, saving time and money. The National Agricultural Seed Council (NASC) of Nigeria has adopted it, replacing cumbersome paper forms that later needed to be transcribed, and the Tanzania Official Seed Certification Institute (TOSCI) has started pilot testing, to make seed certification more efficient, accessible and cost-effective.

Cassava seed entrepreneur, Antonia, working with her IT-savvy son on entering seed business data into SeedTracker. J. Yabeja (IITA)

Flagship 3

Resilient roots, tubers and bananas

Flagship Project 3 (FP3) develops the strategies needed to keep root, tuber and banana crops healthy and productive. "FP3 is making sure that farmers have the most up-to-date tools to control crop pests and diseases and maximize productivity," explains James Legg, FP3 leader. These efforts include new assay methods for seed-borne diseases, and a suite of apps to help diagnose crop pests and diseases and to give farmers information to manage those plant health problems.

The mobile app 'Nuru' used by farmers to diagnose crop diseases in the field. (IITA)

Smarter farming: using apps to diagnose crop health problems

New apps are now being tested with thousands of farmers in Africa, South Asia and the Andes to diagnose the pests and diseases of cassava, banana and potato crops. These decision tools can be used with a smartphone, and some also have a hand-held, printed version. Some apps use artificial intelligence, developed through machine learning, to recognize major disease symptoms and pest damage, and to give advice on controlling the pest. The printed charts use information provided by the farmer to help decide on specific management recommendations.

Information and communication technologies (ICT), such as apps, can help extensionists and farmers to produce food more efficiently, and to be more resilient in the face of risks, such as pests and diseases. The RTB team involving IITA, Bioversity International, CIAT and CIP are inspiring each other to create new apps and to improve recently developed ones to help farmers diagnose plant health problems and to decide on the best ways to manage them. There is an effort to make the apps interoperable and the data they collect easily shared. This will allow for a global tracking and monitoring system that will work in real-time and could make information collected by farmers, extensionists and scientists available to support decision making in the field and also at the policy level.

A team from Penn State University, CIP, IITA and RTB have won the Inspire Challenge Award (from the CGIAR Platform for Big Data in Agriculture) for their app called PlantVillage Nuru (Swahili for "light"). Nuru uses machine learning and Google's open source TensorFlow software to recognize symptoms of leaf damage caused by diseases and pests. Nuru can recognize cassava brown streak disease (CBSD), cassava mosaic disease (CMD) and cassava green mite damage (CGM), as well as the healthy leaf condition.

> "*Partnerships were really important in the development and piloting of this app,* says James Legg, who is RTB's FP3 leader, and ***this is where working with our flagship team has been so vital, as it fosters strong cooperation between CGIAR scientists, while also encouraging the development of new initiatives with external partners, such as Penn State.***"

To use Nuru, you start up the app in your android phone, point the phone's camera at a cassava leaf in the field, and Nuru will identify the condition in a matter of seconds. It's like having a plant doctor in your pocket.

> *You wave your phone over a specific leaf, and if it has a symptom, a box will pop up saying 'you have this problem.' When you get a diagnosis, you learn about the best management practices,* explains Amanda Ramcharan, who was part of the Penn State team.

Nuru has been downloaded from the Play Store more than 1,000 times and users have generated more than 16,000 reports from 60 countries—adding to the app's database of images.

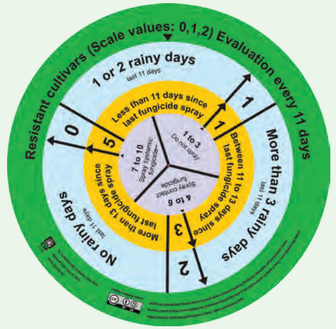
Self Help Africa, an NGO, is testing Nuru with 28,000 farmers in seven counties of Kenya. Nuru is still undergoing improvement, and its accuracy is much higher with severe symptoms than with mild ones. Making further improvements to the app is important, because farmers can manage disease better if they diagnose it early, spotting mild symptoms. Improved accuracy is a challenge, especially since viral disease symptoms can be difficult to distinguish, but Nuru is improving quickly. The RTB teams involved are working to extend the use of the app to potato and potentially other crops. In addition to Nuru, the teams are working on other decision support tools for farmers to diagnose plant health.

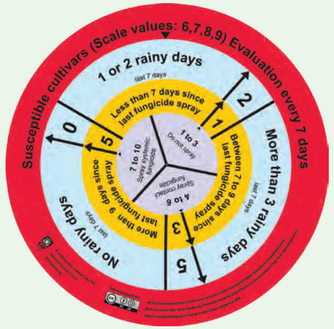
A new app called Tumaini ("hope" in Swahili) is used on a smartphone to diagnose major diseases of banana, including Xanthomonas wilt, Fusarium wilt and black Sigatoka. Farmers who have tested Tumaini in Colombia, Democratic Republic of Congo, India, Benin, China and Uganda have found the app to be 90% accurate.

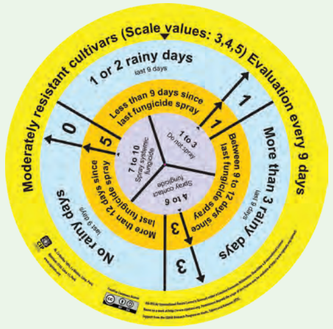
> *The increasing popularity of smartphones and recent advances with digital imaging made possible by deep learning allow Tumaini to diagnose banana diseases,* says Michael Selvaraj, who led the research team at Alliance Bioversity-CIAT.

THE SET OF WHEELS (JUEGO DE RUEDAS, IN SPANISH) IS AN AFFORDABLE AND PRACTICAL APP,

DEVELOPED BY CIP TO IMPROVE MANAGEMENT OF LATE BLIGHT IN POTATOES.







To make a diagnosis with Tumaini, you take a photo of the plant symptoms with your phone. The app saves your photo to improve future diagnoses. Tumaini gives the user management options, even without an internet connection.

The Set of Wheels (Juego de Ruedas, in Spanish) is an affordable and practical app, developed by CIP improve management of late blight in potatoes. It helps farmers to decide when to spray fungicides and what to spray. There is also an offline version that includes a red cardboard wheel for potato varieties that are susceptible to late blight, a yellow wheel for moderately susceptible varieties, and a green wheel for resistant ones. Each wheel is a simple chart, which indicates whether to spray with a contact fungicide, a systemic fungicide, or to apply nothing, based on the frequency of recent rains and the time since the last fungicide application. The wheels help farmers use less fungicide, while effectively managing late blight. Farmers are now using it in Peru and Ecuador, with trials planned elsewhere.

> *The good performance of the Juego de Ruedas for late blight management indicates the value of integrating some of the factors driving disease severity in the decision-making process of using fungicides. This is especially important in areas with poor access to internet and weather data,* says plant pathologist Jorge Andrade-Piedra at CIP.

Diagnosing crop health problems and deciding how to manage them has always been one of a farmers' biggest challenges. Recent advances in information and communication technology promise to help farmers make smarter decisions.

Smartphone apps allow farmers to crowdsource information for more timely interventions. E. Yvonne

Farmers increase profit by managing a serious banana disease

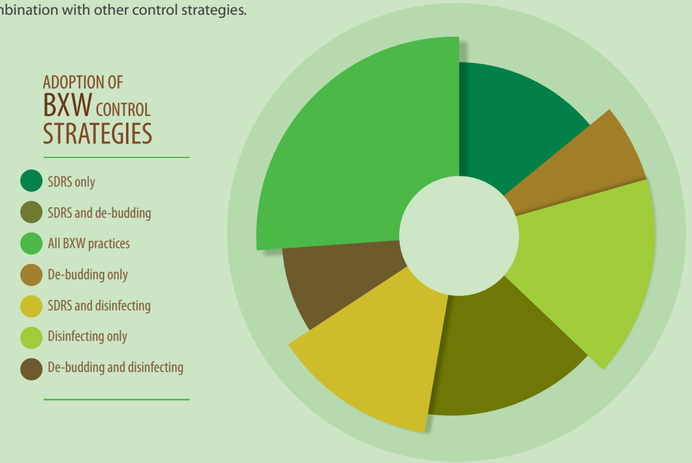
Farmers in East Africa are adopting practices to control banana *Xanthomonas wilt* (BXW). Adoption is highest on subsistence farmers. Benefits are higher on larger farms. Women who receive training in BXW control are more likely to adopt these profitable, disease-control techniques.

Banana *Xanthomonas wilt* (BXW) is rapidly spreading westwards from East Africa to the plantain belt of West and Central Africa. So, understanding how farmers adopt technology to combat the disease is crucial for protecting the banana and plantain crops. Research by Walter Ocimati and colleagues at Wageningen University and Bioversity International in 13 villages in the DR Congo shows that bananas were the most important crop before BXW struck. Now only one village ranks bananas as their top crop, and farmers are reluctantly replacing bananas and plantains with other crops.

Farmers in Uganda were known to be adopting technologies that came from RTB research to control BXW including: 1) removing the male flower bud that attracts the bees and other insects that vector the bacteria, 2) single diseased stem removal (removing a sick stem, but not the whole banana mat), and 3) disinfecting metal tools with fire or a sodium hypochlorite solution to keep from spreading the disease to healthy plants. Enoch Kikulwe (Bioversity International) and colleagues conducted a large, quantitative survey of 1,224 farmers in Uganda. This was the first proper adoption survey of BXW control practices with information about numbers of adopters, practices adopted and estimates of benefits linked to these changes in behavior.

Application of the novel SDSR technique to control BXW: a woman in eastern DR Congo cuts a diseased stem at soil level. B. Van Schagen (Alliance Bioversity-CIAT).

The study used advanced statistical methods to estimate adoption and the underlying contributory variables for the three BXW control methods. As the following graph shows, 70% of adopters took up cutting of single diseased stems, either alone or in combination with other control strategies.



Training boosts the adoption of control measures, especially if bananas are an important crop to the household. Over half (55%) of the sampled farmers received training on BXW control. Nevertheless, 69% of the farmers who adopted the whole BXW control package had received training (while 31% adopted without training). Training women farmers increased the likelihood that the household would adopt all three control methods by nine percentage points.

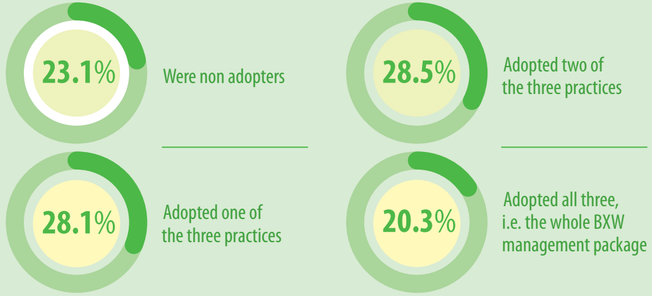
A third of the farmers (33%) produced bananas at the subsistence level, and these farmers were more likely to adopt all of the control practices.

> *Higher adoption by subsistence farmers could be due to the centrality of their crop to their livelihoods, or the relative ease of adopting the practices on their smaller acreage,* says Enoch Kikulwe. Farmers who also work off-farm are less likely to adopt BXW control practices.

Non-adopters earned the least from their banana production, as adopting BXW control measures reduced the disease incidence and increased banana yields and sales. Adopting all three control practices was more profitable than using one or two. Adoption of the whole control package helped to prevent the BXW disease and increased the value of surveyed farmers' banana production by USD 468 per ha, while adopting two practices improved that value by USD 348 per ha.

A solid understanding of the technologies helps farmers to improve their income more than other farmers who were not trained, even those who adopted the whole package. Farmers trained in BXW earned an average of 176% more when they adopted all three practices, while untrained adopters of all three practices earned only 113% more. Uganda has about 800,000 banana- growing households. Extrapolating the results of the survey, perhaps 600,000 households have adopted some of the BXW control strategies.

OF THE FARMERS SURVEYED:



Farmer training in BXW control in eastern DR Congo, as part of out-scaling disease control to affected banana production regions in east and central Africa. B. Van Schagen (Alliance Bioversity-CIAT)

Meanwhile, other projects in RTB continue to find new ways to share information about managing BXW in East Africa. A collaboration involving the GREAT project (Gender-Responsive Researchers Equipped for Agricultural Transformation) found that smallholders in Burundi are poorly informed about BXW, limiting their ability to manage the disease. Francois Iradukunda and colleagues at Bioversity International found that men do most of the work with the banana crop and they handle the sales, while women manage plantains grown to eat at home. Men are also more likely to attend trainings. Men and women alike see bananas as a men's crop, further constraining female participation in BXW control. Increasing women's access to BXW management would probably increase adoption and benefits, especially in households where more of the plantains are eaten at home, and not sold.

From 2015 to 2018, the AMASHIGA development program, led by Bioversity International, taught four farmer learning groups in Burundi to manage BXW by single diseased stem removal (SDSR). Removing just the diseased stem is effective, and it takes much less work than removing a whole diseased mat of bananas. In one year, the incidence of BXW in the four sites declined from 15% to less than 1%. Bioversity International is now scaling out this technique by training 230 extension agents who are teaching 60 farmers each (13,800 households) in Muyinga Province, Burundi, using fact sheets, radio and video, as part of the Broadening the Scaling of BXW Management project, which is also part of AMASHIGA.

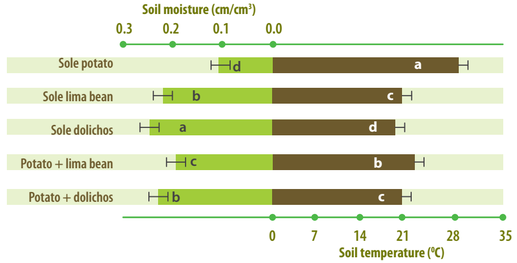
A woman reads a flyer as part of efforts to increase the uptake of the SDSR technique. B. Van Schagen (Alliance Bioversity-CIAT)

Potatoes and legumes: better together

Legumes can be intercropped with potatoes to help manage soil erosion. In addition, a legume intercrop boosts the overall productivity of the land, while helping to improve soil moisture and soil fertility.

In East Africa, potatoes are an important crop for consumers and for highland farmers, helping to improve the livelihoods of rural families. Potato fields usually depend on intensive tillage, contributing to erosion on fragile soils, particularly on slopes. Farmers are also starting to plant potatoes at somewhat lower altitudes where heat and drought are problems. Here, low yields and erosion are exacerbated by the warmer, dryer climate, and by more erratic rainfall. Yet with a growing population, people need to use land more intensively and in a sustainable manner.

FIGURE 1: SOIL TEMPERATURE AND SOIL WATER CONTENT MEASURED UNDER DIFFERENT CROPPING SYSTEMS IN LOWER MIDLAND



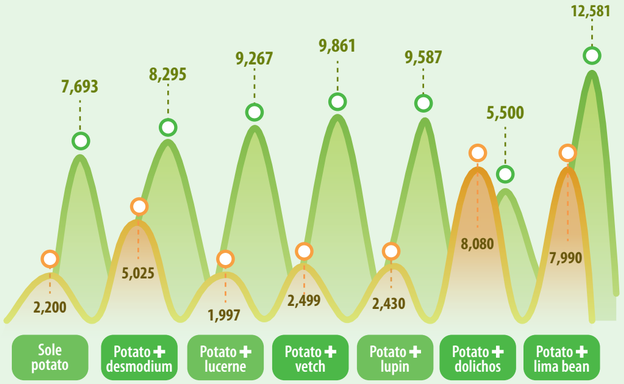
A CIP team is developing a practical solution to improve soil conservation in the East African highlands by intercropping potatoes with legumes. The legumes grow a thick canopy of leaves, which covers the soil, shading and cooling it, thus increasing soil moisture (see Figure 1). This helps the potato crop in warmer areas. When cropped on steeper land, the thick canopy reduces damage from hard rainfall and protects the soil from erosion caused by runoff. And by adding a legume crop, farmers get more food from the same area of land than if only potatoes were grown. With the added value of the edible legume grains, intercropping can increase the value of the harvest by the equivalent of three to fifteen tons of potatoes per hectare, if the right legume species is used for the field's agroecological zone. Legume intercropping can increase the net returns in the highlands by up to USD 4,880 per hectare and by up to USD 5,880 per hectare in the lower midlands (see Figure 2).

So, choosing the right legume depends on the altitude, maturity dates and the soil of each area. Figuring out the right planting distances for potatoes and legumes, as well as staggering the planting dates, can enhance soil fertility and modify the microclimate of the plants with little loss of yield. One of the most promising legumes for the drier midlands is lablab (or dolichos), a high-yielding crop that produces more biomass than the others tested. Vetch, lupin, lima bean and lucerne (or alfalfa) also showed great potential to control soil erosion in the highlands and to improve potato yields.

Total plant growth in an intercropped plot is higher than the biomass produced by potatoes alone. The legume roots also go deeper, as much as a meter, versus just 30 centimeters or so for potatoes. Long roots allow legumes to lift moisture from deeper underground. Planting legumes also increases the nitrogen content in the soil which might help reduce the need for nitrogen fertilizer.

After harvest, the crop stubble is incorporated back into the earth, returning phosphorous, nitrogen and other nutrients to the soil. This also increases organic matter and makes the soil more porous (so it will hold more water and allow roots to grow more easily).

FIGURE 2. NET RETURNS (USD/HA) OF POTATO-LEGUME INTERCROPPING IN LOWER MIDLAND AND UPPER HIGHLAND



> *Legume intercropping is a wise investment in the future*, says Shadrack Nyawade, one of the researchers on the team. ***Every year, intercropping builds the soil a little more, while monocropping degrades it.***

Potato-legume intercropping can fulfill important roles in helping smallholder farmers adapt to climate change by controlling soil erosion in the highlands. Intercropping also keeps soil cooler, while retaining moisture and nutrients in the drier, lower midlands. Legume intercropping is ideal for smallholders, as the innovation requires little investment. With a handful of legume seed, and an eye to the future, farmers can try intercropping and sustain it.

Flagship 4

Nutritious food and value added

Flagship Project 4 (FP4) harnesses the nutritional potential of roots, tubers and bananas, sustainably expanding their use and adding value through post-harvest innovation. "At FP4 we want to understand the end users themselves and what is important to them in terms of post-harvest quality to drive innovation. This can guide breeders so they can make the varieties that people will want to grow and use," says Tawanda Muzhingi, FP4 leader and food scientist at CIP.

Emily grows and supplies OFSP to Organi Ltd., a sweetpotato purée manufacturer in Kenya. S. Quinn (CIP)

Tasty, healthier food made from roots, tubers and bananas: getting to the bottom of consumer preferences

Across tropical Asia, Africa and Latin America, many foods are traditionally processed from roots, tubers and bananas. These crops can continue to play a vital role in food security if they can gain more access to urban markets, including restaurants and food processing industries emerging across these regions. Root, tuber and banana flours and purees can be substituted for some of the imported wheat flour, to reduce the cost and to improve the flavor and the nutritional value of novel processed products. New methods are now being used to discern sensory and physicochemical properties of new, manufactured foods, and to understand what consumers really want.

OFSP puree technology demonstration workshop. N. Ronoh (CIP-SSA)

New baked products using OSFP puree. S. Quinn (CIP)

Roots, tubers and bananas are vital crops for food security, especially for the poor, in much of Africa, Asia and Latin America. For centuries, roots, tubers and bananas have been processed into food products. Many people have also begun to eat manufactured foods made from white flour. Millions of people can enjoy better nutrition if food processors can substitute roots, tubers and bananas for some of the imported wheat flour that is now used in baked products. Food scientists are developing new recipes and testing them with consumers to design healthier foods that consumers want to eat.

In several studies, food scientists evaluated prepared food such as fritters (fried flour dough) in Zambia, chin chin (a crisp pastry) in Nigeria, as well as sponge-cakes and cookies. New ingredients tested included plantain flour, tigernut, watermelon rind, groundnut, black pepper and cinnamon. In all cases, various mixes of different flours made from cassava, plantain, groundnut and other crops were used to prepare these foods.

Panels of consumers tasted different versions of each food and ranked them (for example, on a scale of 1 to 5) on various sensory characteristics such as appearance, aroma, texture in the mouth, taste, crispiness and overall acceptability. Statistics were used to determine which characteristics (for example, taste and aroma) contributed the most to the overall acceptability of the new products. These were compared with physical and nutritional properties, such as percentage of protein, fiber, carbohydrates, ash, fat, and sugar. For example, foods that absorb less cooking oil are judged to be crunchier and tastier. In each case, consumers accepted the pastries made from new ingredients. Researchers were able to refine these evaluations, to identify which blends of healthy ingredients consumers preferred the most.

In Benin, RTB researchers bringing together a team of food technologists from CIRAD, CIAT and Université d'Abomey Calavi studied *gari* (a traditional flour-like foodstuff made from cassava) to determine how consumers would react to gari enriched with oil. This was the first sensory profiling study of *gari* conducted in Benin and the first in Africa to go beyond general descriptors like appearance and taste. Nine traditional, and three enriched *garis* were profiled using 15 descriptors. All 12 *garis* were evaluated dry and mixed with water.

The nine traditional garis, produced in different regions, varied widely in terms of the amount of roasting, drying and sifting during processing. Consequently, there was wide variability in particle size, particle heterogeneity, water absorption and sour taste, as well as in physiochemical characteristics, such as degree of starch gelatinization, lactic acid and vitamin A. The three enriched types of *gari* were blended with soybean oil, palm oil, or both.

Eighteen panelists were carefully trained to use 15 different descriptors based on color, odor, texture and taste. The samples were tested three times each, over nine sessions, using a sophisticated scoring device: panel members put a mark for each descriptor on a 100 mm linear scale. The panelists perceived the three enriched kinds of *gari* as different from the traditional ones mainly in their color and odor, while their swelling capacity, texture while chewing and light sour taste were similar. This helps pave the way for making enriched *gari* that consumers will want to buy.

Work on developing tasty products from orange-fleshed sweetpotato which meet consumer and manufacturers' preferences is well advanced. In East Africa, the sweetpotato has already been adapted for use in bakeries. In Kenya, major retailers have adopted OFSP puree as a wheat flour substitute in baked and fried products. However, the informal sector, such as small bakeries and street vendors, have no access to cold storage, so to include them CIP developed a shelf-stable puree with preservatives wich lasts for 3 months.

Taken together, these experiences with different crops show that the first step is to create healthy recipes for roots, tubers and banana with attributes that consumers really want. Then, these recipes can be adapted for use by the value chains, including food manufacturers.

Nissa Madura works in her sweetpotato field in Concepcion, Philippines. (CIP)

FoodSTART+ project. Farmer business school participants. S.Fajardo (CIP)

Farmers learn to run successful small businesses

Farmer Business Schools have been adopted by national development programs, funded by the International Fund for Agricultural Development (IFAD) in three Asian countries. The results were encouraging: some 3,500 farmers have been trained, about three-fourths women. They have learned new business skills, how to work together, and have developed new products to market.

The International Potato Center (CIP) developed the Farmer Business School (FBS) in the early 2010s. The FBS builds on the Participatory Market Chain Approach (also developed by CIP) for fostering innovations in root and tuber value chains. The FBS also adapts ideas from the Farmer Field School (FFS), where groups of farmers learn to use integrated pest management in the field. The FBS strengthens farmers' capacity to respond to emerging market opportunities.

The FBS has an appropriate gender balance between men and women farmers. Small groups of 20 to 25 farmers learn about each other and how to work as a team. Through a facilitated process, they visit markets, learn about opportunities for new products or other innovations. They meet buyers, extensionists, suppliers and other support service providers. The groups prepare a business plan and develop their innovative products or marketing techniques, which they launch at a publicized event to potential customers and supporters.

After the success of FBS in Indonesia, IFAD invested in CIP's FoodSTART (Food Security Through Asian Root and Tuber Crops) initiative to scale FBS through IFAD investment projects in Asia and to help farmers become more savvy entrepreneurs in dynamic value chains for roots, tubers and other commodities.
In the first phase of FoodSTART, CIP established a collaboration with the International Center for Tropical Agriculture (CIAT), within RTB, and partnered with the Second Cordillera Highland Agricultural Resource Management Project (CHARMP2) in the Philippines.

The Farmer Business Schools in the Philippines worked so well that the EU joined with IFAD to fund a second phase of FoodSTART (Food Resilience Through Root and Tuber Crops in Upland and Coastal Communities of the Asia-Pacific, or FoodSTART+) to support additional FBSs in India, Indonesia and the Philippines.

The FBS curriculum includes climate change and gender perspectives and is now helping farmers to build enterprises based on nutritious products are fried. Farmers can use the FBS with any commodity, not just roots and tubers. For example, the Bureau of Fisheries and Aquatic Resources has used Business Schools to develop not just sweetpotato and cassava products such as chips, jams, candies, and juice, but also bottled mussels, fish crackers, seaweed noodles, dried fish, and many other products.

Almost 3,500 farmers (76% women) have completed the FBS. These graduates, often working in groups, have established over 130 small enterprises in India, Indonesia, and the Philippines. More than 100 outcome stories were collected with farmers sharing how the business experience had improved their lives.

FoodSTART+ Farmer business school participants preparing their highly nutritious products. S. Fajardo (CIP)

> *"Thanks to FBS we have learned how to keep records of our expenses and calculate the profit and loss statements from our potato cultivation. It has benefited us so much that we now know how to price our products and understand what the buyers want. For instance, through the FBS, we have realized that there is huge demand for organic seed potato in the market and this gives us hope. But as the traders we have met have told us, we need to improve our packaging*, says Sarlin Mawphlang a FBS graduate in Wahlyngkien, Meghalaya, India."

The farmers also said their groups had become better organized. Individuals and groups improved their business skills. Farmers forged better links with local markets. Gender equity was promoted, and new food security and income opportunities emerged as production, processing and marketing techniques improved.

Gender responsiveness in Farmer Business Schools

The Farmer Business Schools (FBS) is a participatory approach to provide technical assistance and support to smallholder farmers to improve their income and livelihood opportunities. In Asia, the approach has been adapted to ensure gender responsiveness, by including women, diagnosing their needs, and helping them to start group businesses. Experiences show that value chain development can contribute to gender equitable access to resources and benefits from innovations linked to roots, tubers and bananas.

In Bohol, in the Philippines, the FoodSTART+ project created six FBS groups, with more participation from women. It was the first time for many women to learn about business and they gained the confidence to start a new business activity independently.

In Meghalaya, India, FoodSTART+ established six FBSs with 110 women and 55 men. Men offered labor, experience and connections. Women contributed leadership skills to produce organic potatoes and organic cassava flour. One group of women began to sell cassava snacks in a local market.

In Assam, India, a baseline survey characterized opportunities for women and men in the potato value-chain. The study found that women's participation in the potato value-chain is concentrated in post-harvest activities. In a future FBS, the project will take into account this gender norm and facilitate women's participation in post-harvest activities such as storage development, processing and packaging.

FoodSTART+ project. Farmer business school participants. S. Fajardo (CIP)

Leading the family banana farm. Uganda. S. Fernandes (RTB)

Which extension methods work best? Teaching young mothers about orange-fleshed sweetpotato

To grow nutritious orange-fleshed sweetpotato, women need vine cuttings for re-planting, as well as motivating information about the root's nutritional value. Young mothers in Kenya were more likely to keep growing these nutritious sweetpotato varieties at least one year after initial planting, depending on how they learned about the crop. The most effective teaching methods were practical sessions at open days, radio talk shows and personal contact with trusted local farmers who were experts at growing and sharing sweetpotato vines. Other extension methods were not effective.

Farmers packing quality sweetpotato seed after purchase in Nungwe, Tanzania. K. Ogero (CIP)

In the Homa Bay area of western Kenya, CIP collaborated with the local government to share orange-fleshed sweetpotato (OFSP) vine cuttings and agronomic and nutritional information with pregnant women and mothers of children under five. Getting their hands on the cuttings gave women the ability to plant OFSP, while the information motivated them to do so.

The planting material was distributed by decentralized vine multipliers (DVMs), respected, local farmers trained to produce high quality vines. The DVMs supplied the women with one or two varieties of OFSP, while sharing some neighborly advice on how to nurture the crop.

This OFSP sweetpotato farmer in Kitgum, Uganda, earns extra income selling roots and vines for planting. V. Atakos (CIP)

Information was packaged in other ways as well. Some women received nutrition talks, counselling and cooking demonstrations by community health volunteers (local women who had been trained by extension workers). At "open day" events expert agronomists provided hands-on guidance in sweetpotato cultivation, including planting practices, length of vine cuttings, spacing of plants, keeping vines during the dry season, weeds, pests and diseases, timing of harvest, and post-harvest.

The open days contrasted with "field days," which were less intense and less structured. Participants of field days toured sweetpotato demonstration plots with agronomists who explained how to grow and manage the crop and then answered questions. FM radio stations also broadcast talk shows in local languages on OFSP discussing nutrition and the prevalence of vitamin A deficiency.

One year after receiving the vines, 537 women were interviewed to see if they were still planting the new sweetpotatoes. Of 372 surveyed women who received one variety during the short rainy season (preferred for planting sweetpotatoes in this part of Kenya), three out of four were still planting OFSP, while only about one out of three who received vines in the long rainy season were still doing so. Women who had low-lying wetlands could more easily keep the crop alive over the dry season, and they were more likely to plant the new varieties a year after receiving them.

So, agronomy mattered, but so did the way information was shared. Listening to radio talk shows, attending open days and collecting vines directly from a DVM (and not from another farmer), all influenced women to continue to plant OFSP a year later. Other methods had no effect, including contact with a community health volunteer, or attending field days.

> "*Not all extension methods are equal. Convincing information may come in the form of a well-prepared open day, an engaging talk show in the local language, or as a bit of mentoring from a DVM who is a neighbor and a farmer,* says CIP's Julius Okello, who led the extension study. These insights should benefit many extension programs, not just those that share information on good nutrition practices and sweetpotatoes."

Flagship 5
Improved livelihoods at scale

Flagship Project 5 (FP5) helps take innovations to scale. RTB is researching the best ways to engage African youth in agribusiness, considering how gender influences innovation and developing foresight models to anticipate the research and development needs of the future. "We are working to overcome the bottlenecks to adoption and to ensure that different groups of farmers are able to access and use RTB innovations at scale," says Marc Schut, FP5 leader and senior innovation and scaling scientist with IITA and WUR.

Looking into the future to guide investment in root, tuber and banana crops

With changing climates, demands on agriculture are also increasing. Root, tuber and banana crops will continue to be important across the developing world, in particular in Africa, where the population is expected to rise faster and for longer than on other continents. The crops of the future will need to be higher yielding, pest and disease resistant, and adapted to new climates. A collaboration among researchers of the RTB and the CGIAR Research Program on Policies, Institutions, and Markets (PIM) used foresight analysis to show that root, tuber and banana crops can contribute to food security in the world's poorest regions if research and development (R&D) investments in those crops is increased.

Tigist Masresra, technical assistant, Highland Maize Breeding Program Ambo Research Center, Ethiopia, 2015.

The population of Africa is expected to double by 2050, and the continent is heavily reliant on root, tuber and banana crops for food security and livelihoods. With global temperatures set to exceed a 2°C increase by 2100, world crop production may fall unless there is R&D to reverse declining yields and to help farmers to adapt to new climates. Agriculture is changing in other ways as well, with more farming being done by women, with rural youth leaving for the cities, greater pressure on farmland and the new food preferences of the emerging middle class. Potato production is expected to rise in India and China, and more bananas may be grown in Latin America. In Africa, root, tuber and banana crops will be key food staples for the next generation. The systemic interaction of these changes will demand sophisticated models to guide research soon.

> ***Innovative holistic breeding strategies will need to be developed to embrace the full pipeline from trait discovery to varietal deployment and seed system development***, says Philip Thornton, a modeler with the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Modelling and other forms of foresight analysis will be crucial to identify plant breeding and other research needs for the future.

Root, tuber and bananas crops may prove more climate resistant than other crops, but climate change will create new niches for pests and move their ecological frontiers. Plant breeding and other strategies to manage pests and diseases will be crucial for future food production.

Athanasios Petsakos of CIP, and colleagues at the Global Futures and Strategic Foresight project (GFSF) of the PIM have modelled the results on crop productivity (including supply, demand and yield) under different investment scenarios of the future, noting that there is already less investment and research in roots, tubers and bananas than in cereals, pulses and other crops.

The GFSF modeled the future of these crops based on projected population and economic growth and climate change. The modeling showed that the investments in market access, such as

Farmers often grow sweetpotato alongside banana and cassava in Uganda. S. Fernandes (RTB)

Bean breeding at CIAT in Kawanda, Uganda. N. Palmer (Alliance Bioversity-CIAT)

Bean diversity helps farmers tackle climate change. G. Smith (Alliance Bioversity-CIAT)

improved infrastructure, would not contribute significantly to greater yield or supply of roots, tubers and bananas. Targeting crop productivity, especially through plant breeding, will alleviate production constraints and strengthen the future role of root, tuber and banana crops more than investing in marketing and infrastructure.

With no future changes in investment strategies (that is, business-as-usual), by 2050 the production of roots, tubers and bananas will reach 1,400 million tons, a global increase of almost 50% over 2010, with the greatest increase coming from developing countries in Latin America, Africa and Asia. Investment in agricultural research would lead to additional increases of 25 to 50% in the global supply of roots, tubers and bananas by 2050.

Regional investment would help to improve trade balances and improve food security for each continent.

> ***Investments that aim at increasing productivity in regions which are expected to face high population pressures, like sub-Saharan Africa and South Asia, can serve to efficiently target increasing supply and reducing dependency from imports***, says Petsakos.

This foresight analysis shows that roots, tubers and bananas will be important in the future for feeding people in the world's poorest regions, and for creating positive impacts on food security, making African countries self-sufficient in food production and reducing the risks of volatile price changes. Root, tuber and banana crops are generally climate resilient and nutritious, making them key for reducing malnutrition and poverty in a warmer world, with an increasing population. A sound way to ensure that the full potential of root, tuber and banana crops is achieved is to increase investment in research now.

Young agribusiness men and women
are motivated by more than profits

When it comes to starting a business, money is not everything. African youth are attracted to agribusiness if there is money to be made, but profit is not the only motive. Young people are also interested in work that confers high status, and they are more likely to stay in the countryside it if is equipped with roads, electricity and running water.

In a recent article Mastewal Yami and colleagues at the IITA analyze what works and what does not work to attract African youth to agribusiness. This analysis becomes particularly relevant in a context where youth rarely decide on the objectives of the agribusiness interventions, how they will be implemented, or the quality of products and services they will produce. The youths' expectations also limit their participation in collective action. Most interventions pay little attention to identifying and addressing the constraints which could improve the youths' participation in the groups.

The most successful interventions, by governments and donors are "integrated." They bring together capacity development, financing, and mentoring. Agribusiness, which includes farming plus retailing and all the other industries and services through to retail, needs to be rebranded as a competitive career path for youth. Young people also need improved access to land, better skills, enhanced information, and communication technology (ICT), and more market access.

Agripreneur selling biofortified *gari* made from yellow cassava. Ibadan, Nigeria. G. Thiele (RTB)

TV and radio have been able to motivate youth to enter agribusiness, but promotional campaigns often portray youth agribusiness as easy and successful, when it is really arduous work. Nevertheless, most of the interventions. Most of the interventions by government and projects in Africa have successfully inspired youth to engage in agribusiness, especially when coupled with the clever use of ICT. But women have about 25% less internet access than men. Expanding access to ICT is an opportunity to attract youth to agribusiness, especially if young women can gain more access to the Internet.

> ***Interventions tend to act as though youth are only interested in money, when in fact they are also influenced by how soon an activity will pay off, by its social status, and the difficulty of acquiring the skills***, explains Mastewal Yami. She goes on to say that youth also need access to land, financing, training, technical support. ***The Songhaï Center in Benin has been able to integrate these capacities. Of 300 youth who graduate from Songhaï, 70% successfully engage with agribusiness after graduating.***

Vitamin A cassava sellers inside their shop. Ibadan, Nigeria. G. Thiele (RTB)

Youth can be motivated by media, grants, training and investment in infrastructure that make rural communities more comfortable and more productive. ENABLE Youth, a program with IITA, helps young people develop business plans and seek loans in seven African countries.

These findings are being used to foster youth engagement in agriculture by developing innovations that enhance a prompt return on investment, promoting access to knowledge through ICT and fostering youth-friendly business opportunities through ICT innovations such as Nuru, and Cassava Seed Tracker, mentioned elsewhere in this report, and Cassava Peel Tracker, discussed in the 2018 report.

This review suggests that the best approach is to integrate mentorship, financing training and contacts with the private sector and with funding agencies. Youth also need to be involved in the design of the interventions.

Why do women and men innovate in different ways?

Researchers need to understand why women and men innovate in different ways. New insights from Nigeria show how gendered constraints can condition women's and men's adoption of biofortified cassava, why adoption differs between regions, and how to address the unique challenges that women face.

Why do women and men innovate in different ways? And why does this pattern change from one region to another? The answers to these questions can help researchers to address the different constraints that women and men face in agricultural production.

Cassava breeders in Nigeria wondered why women were adopting biofortified cassava in Benue State, while across the country in Oyo State, it was not the women, but the men who were adopting biofortified cassava. A study team interviewed groups of farmers and walked transects through the farm landscape to understand the motivations behind growing biofortified cassava.

In 2011, biofortified cassava varieties were introduced to Nigerian farmers, who have had time to get to know the new cultivars, which have yellow roots and are rich in vitamin A. Severe vitamin A deficiency is common in Nigeria and contributes to blindness and other health problems.

Across Nigeria, women process cassava, much of which is turned into *gari*, a coarse-grained flour. Unlike fresh cassava roots, *gari* can be stored, is easy to transport and can be mixed with boiling water to create a paste to enjoy with sauce and meat, fish or cheese. *Gari* is a versatile foodstuff in high demand in Nigerian cities.

While *gari* is easy to eat, it is tedious and time-consuming to make, and almost all this difficult work is left to women, in cottage industries. Women have to peel the roots with a knife, take them to a neighbor who grinds them in a small machine, then ferment the mash, press it and fry it on a large steel pan on a red-hot fire.

> "***Women are willing to do this exerting work, in part because it allows them to earn money independently, but they would like it to be easier and safer,*** says gender researcher Olamide Olaosebikan."

Farmer showing high-yield cassava from his newly-purchased seed. (IITA)

Bridget, village seed entrepreneur selling her cassava stems. Benue, Nigeria. G. Thiele (RTB)

In Benue State, women grow biofortified cassava because they have benefitted from awareness campaigns that stressed the health advantages of the new varieties. Plus, the yellow roots make yellow *gari*, preferred by consumers in Benue. In the past, the women processors had to add costly palm oil to the white cassava mash to make the gari yellow. Now they use less palm oil, or none at all. Since the men in Benue don't fry *gari*, they are less interested in yellow cassava.

In Oyo State, the preferences of male and female farmers are the opposite of their counterparts in Benue. In Oyo, consumers prefer a white, sour gari, so women who make it prefer white roots. In Oyo, since men rarely make gari, they prefer to sell the roots fresh to gari processing centers within Oyo and Ogun States. From Oyo, yellow *gari* can be trucked to the mega-city of Lagos, where there is niche demand for it in various restaurants and homes.

To benefit women and men fairly, new technologies must take their unique preferences into account. But even for a specific example like new cassava varieties, men and women may have different demands in different regions. Understanding why preferences vary by place and by gender helps researchers to create varieties and technologies that equitably benefit both men and women. The experience with yellow cassava provides valuable insights that can be used by other root, tuber and banana crop scientists to generate more gender-responsive innovations.

KNOWLEDGE PRODUCTS

PUBLICATIONS

150 Peer-reviewed journal articles published

140 Publications in ISI journals (93%)

119 Open access journal articles (80%)

CGSPACE

Publications downloaded
108,839

Publications views
171,913

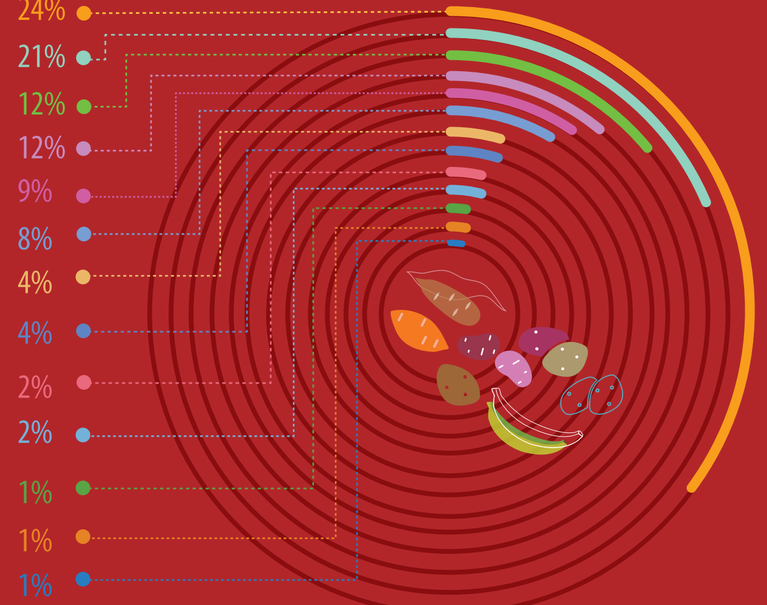
412 NEW KNOWLEDGE PRODUCTS made publicly available through the RTB Collection in CGSpace

Group Yanapai supports smallholder farmers in highland Peru.

PARTNERS

Three hundred and nineteen organizations have contributed to the results presented in this annual report. Our partners have contributed to at least a scientific article reported under RTB and/or have implemented a joint project or initiative funded by or mapped under RTB. The distribution of partners by organization type is presented in the graph below. Out of the 319 partners, 33% are academic institutions, 18% are from a National agricultural research system (NARS), 12% are advanced research institutions, 9% are from the private sector and 8% are government departments at the national or subnational level.

78	Academic institutions	24%
68	National Agricultural Research System (NARS)	21%
38	Private sector	12%
37	Government	12%
28	Advanced Research Institutions	9%
25	Non-governmental organizations (NGO)	8%
12	CGIAR Center/Program (Center)	4%
12	International development organizations	4%
6	Community based organizations (CBO)	2%
5	Regional and sub-regional organizations	2%
4	Financing institutions (including foundations)	1%
4	International agricultural research centers	1%
2	Farmers (individual or group)	1%



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Uganda-NARO • The National Agricultural Research Organisation

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India-University of Horticultural Sciences, Bagalkot (UHS-Bagalkot)

USA-USAID • United States Agency for International Development

WOTRO • Nederlandse Organisatie voor Wetenschappelijk Onderzoek/Dutch Research Council

FINANCIAL REPORT

The initial Windows 1&2 budget was USD 19.5 million. Nevertheless, foreign exchange changes and cost sharing percentage (CSP) had a negative impact that resulted in a reduction of USD 0.8 million, bringing the budget down to USD 18.7 million. Considering the USD 2.8 million of carry-over from 2018, the final allocation for 2019 W1&2 was USD 21.5 million. The total 2019 budget for RTB was USD 95.3 million, USD 21.5 million (23%) from Windows 1&2, and USD 73.7 million (77%) from Window 3, bilateral and RTB participant centers' own funds.

2019 Expenditure

RTB total expenditure for 2019 was USD 83.2 million, or 87% of the budget, of which USD 19.1 million (23%) was from W1&2, and USD 64.1 million (77%) from W3, bilateral and centers' own funds. W1&2 expenses reached 89% execution of the final budget and W3, bilateral and centers' other own expenditure, reached 87% execution. W1&2 implementation in 2018 and 2019 was similar in absolute (USD 19.1 million) and relative terms (23% of total expenses).

The RTB flagships have an average execution of 90%. No flagship has overspent. The flagship that has the highest implementation rate is flagship 2 with 99%, and the lowest are flagship 1 and 3 with 84%.

The chart shows the W1&2 budget and expenditure by flagship and the Project Management Unit expenditure of USD 1.5 million.

CGIAR Funding Windows

- **Windows 1&2 funds** are provided by the CGIAR to RTB for allocation across the agreed product portfolio. Window 1 funds are allocated by the CGIAR System Organization to different CRPs including RTB, while Window 2 funds are designated by donors specifically to RTB.
- **Window 3 funds** are allocated directly to CGIAR Centers by donors and are mapped into RTB when they are consistent with the RTB product portfolio. Window 3 includes a deduction of 2% of the total budget as contribution to the CGIAR System Organization.
- **Bilateral funds** are contracts directly signed between a center and a donor and mapped into RTB.

Flagship 2019 W1&2 Budget vs Expenses (USD Millions)

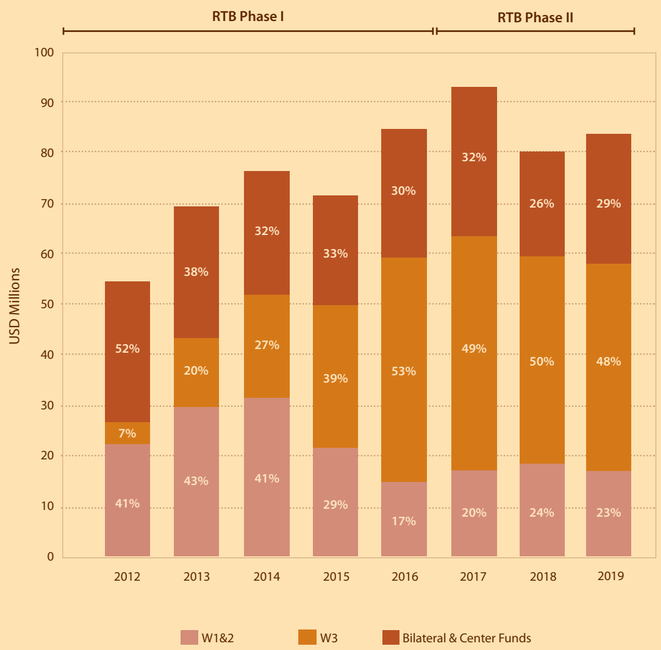
Flagship W1-2	Budget								
	Bioversity International	CIAT	CIP	IITA	CIRAD	WUR	Partners	PMU	Total
FP1 : Enhanced Genetic Resources	0.85	0.87	1.77	0.74	0.23	-	0.14	-	4.60
FP2 : Productive Varieties & Quality Seed	0.58	0.47	2.46	0.96	0.03	0.05	-	-	4.55
FP3 : Resilient Crops	1.29	0.45	0.83	1.59	0.05	-	-	-	4.21
FP4 : Nutritious Food & Added Value	0.18	0.54	0.69	0.73	0.25	-	0.11	-	2.49
FP5 : Improved Livelihoods at Scale	0.60	0.49	0.94	1.09	0.01	0.36	-	-	3.49
CRP Management & Support Cost	0.04	0.06	0.08	0.08	-	-	-	1.93	2.19
Total	3.54	2.88	6.77	5.18	0.57	0.41	0.25	1.93	21.54

Flagship W1-2	Expenses								
	Bioversity International	CIAT	CIP	IITA	CIRAD	WUR	Partners	PMU	Total
FP1 : Enhanced Genetic Resources	0.70	0.94	1.51	0.58	0.19	-	0.14	-	4.06
FP2 : Productive Varieties & Quality Seed	0.59	0.48	2.22	1.15	0.03	0.05	-	-	4.52
FP3 : Resilient Crops	1.20	0.36	0.82	1.12	0.03	-	-	-	3.53
FP4 : Nutritious Food & Added Value	0.18	0.27	0.58	0.72	0.23	-	0.11	-	2.10
FP5 : Improved Livelihoods at Scale	0.59	0.38	0.91	0.95	0.01	0.32	-	-	3.16
CRP Management & Support Cost	0.04	0.05	0.05	0.08	-	-	-	1.49	1.70
Total	3.30	2.48	6.09	4.60	0.49	0.37	0.24	1.49	19.07

RTB 2012 -2019

The distribution of budget by funding sources (W1&2) has been stable over the last two years. Funds from W1&2 have been maintained at 23%. The implementation rate in 2019 was 87% which is similar to 2018 and 2017. The cumulative expenditure reached USD 612.5 million over the eight years of the program (USD 173.7 million from W1&2, and USD 438.7 million from W3, bilateral and center funds).

RTB Expenditure: 2012 – 2019



ABOUT

The CGIAR Research Program on Roots, Tubers and Bananas (RTB) is a partnership collaboration of research-for-development stakeholders and partners. Our shared purpose is to exploit the underutilized potential of root, tuber and banana crops for improving nutrition and food security, increasing incomes and fostering greater gender equity – especially amongst the world's poorest and most vulnerable populations.

Alliance

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