Research for innovation and impact

Annual
Report
2016

CGIAR

RESEARCH PROGRAM ON
Roots, Tubers and Bananas

CONTENTS

Research for innovation and impact
RTB Annual Report 2016

Published by the CGIAR Research Program on Roots, Tubers and Bananas (RTB)
RTB thanks all donors who supported the program through their contributions to the CGIAR Fund:
http://www.cgiar.org/who-we-are/cgiar-fund/fund-donors-2/

RTB Program Management Unit
International Potato Center
Av. La Molina 1895, La Molina, Perú
rtb@cgiar.org • www.rtb.cgiar.org
Press run: 300
August 2017

Correct citation
RTB. 2016. Research for innovation and impact. Annual Report 2016. Lima (Peru).
CGIAR Research Program on Roots, Tubers and Bananas. • Available online at:
www.rtb.cgiar.org/2016-annual-report

ISSN: 2308-5932
DOI: 10.4160/23085932/2016
Hecho el Depósito Legal en la Biblioteca Nacional del Perú Nº 2013-10010

Coordination: Holly Holmes
Writing: David Dudenhoefer
Editing: Holly Holmes, Graham Thiele, Michael Friedmann, Claudio Proietti
Design: Communications Department, International Potato Center

Printed by Comercial Grafica Sucre S.R.L. • Av. Bausate y Meza 223, Interior 1, La Victoria, Lima-Perú

DASHBOARD

The CGIAR Research Program on Roots, Tubers and Bananas in 2016

69,773
Trainees in short-term programs facilitated by RTB
30,788 - Men
24,273 - Women

43
Technologies or Natural Resource Management practices released by public and private sector partners globally

1,780,000
Households that applied new technologies or management practices as a result of RTB research

121
Publications in ISI journals

124
Trainees in long-term programs facilitated by RTB
72 - Men
52 - Women

4
Policies / regulations / administrative procedures presented for legislation

64
Tools produced by RTB
27% with explicit target of women farmers

366
Program partners

447,000
Hectares of newly adopted improved technologies or management practices as a result of RTB research

FOREWORD

BARBARA H. WELLS
CIP Director General

GRAHAM THIELE
RTB Program Director

2016 marked a successful if somewhat challenging year for RTB. We submitted the proposal for Phase II of the program, which received a grade of 'excellent' by reviewers, and were officially approved by the CGIAR System Council to commence the phase in January 2017. Most notably, research in this next cycle includes enhanced systems research and an expanded emphasis on scaling. Achieving our ambitious targets for impact in Phase II means focusing on the most promising technologies and innovations, and combining these with the approaches that can take them to scale.

Three International Potato Center (CIP) scientists were awarded the World Food Prize for their work to develop and bring to scale biofortified, nutritious orange-fleshed sweetpotato. We are proud to say that much of this work is an integral part of our research program. Additionally, two of RTB's participating centers, CIP and the International Institute of Tropical Agriculture (IITA), were jointly awarded the Al-Sumait Prize for African Development for their efforts in reducing poverty and improving food security.

In 2016 we concluded Phase I of RTB, so it's timely to take stock of some of our headline achievements.

We engaged strategic new partners. The Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) came on board early in the phase as a full RTB program participant and leads the cluster on cassava processing with unique skills such as drying technology, and is making important contributions to genomic research. Wageningen University & Research took on leadership of a research cluster in 2016 and strengthened our focus on scaling. Other significant upstream partnerships were with Royal Holloway University of London with path-breaking work on metabolomics; Natural Resources Institute for postharvest evaluation and sensory analysis; and Cornell University for next generation breeding and gender. Novel downstream partnerships included National Agricultural Research Organisation of Uganda for postharvest innovation and National Root Crops Research Institute of Nigeria for cassava seed system development.

We built a strong cross-crop and cross-center knowledge base through internal competitive grants ("complementary funded projects"). This included proof-of-concept studies which identified genomic regions linked to important complex traits such as virus resistance, dry matter and carotenoid content in cassava, parthenocarpy and sterility in banana, and heat tolerance and micronutrient composition in potato. This will underpin work to accelerate genetic gains in Phase II. And four tools were developed to understand and intervene in seed systems which will be applied to enhance ongoing seed system interventions.

We made strong progress on gender research by developing and applying gender-responsive guidelines and tools for participatory varietal selection, assessment of end-user preferences, integrated pest management, and participatory value chain analysis. Fifteen RTB cases studies with GENNOVATE enhanced knowledge of changing norms and agency for gender equity, with one key finding around the role of women as gatekeepers of integrated agri-food systems.

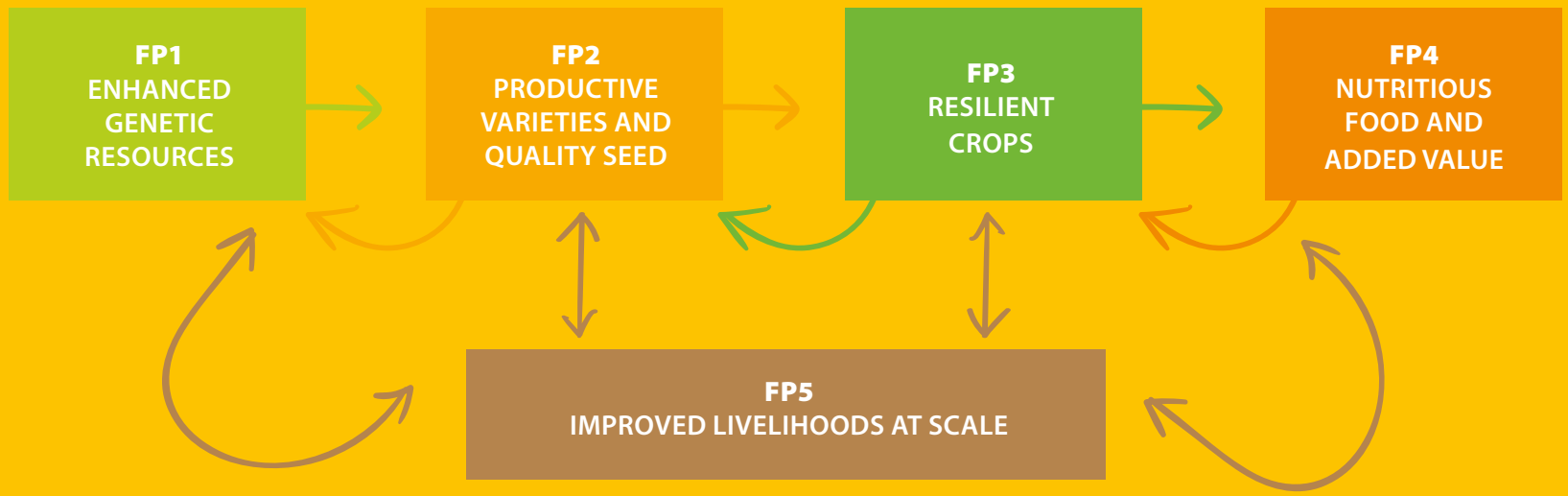
We take this opportunity to thank all our partners and donors for their incredible contributions to our work in Phase I, and look forward to an exciting journey together in Phase II.

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 value chains.

In 2016, RTB was both wrapping up its first phase and preparing for Phase II (2017–2022). A key part of the transition involved the restructuring of research for development activities in five interdisciplinary flagship projects (FPs), illustrated below and described throughout this report. Each flagship has a dynamic leader based in one of the centers and 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.

Flagship Projects



RTB consolidated its results-based management (RBM) with the reorganization into clusters. Monitoring and evaluation indicators linked to impact pathways were developed for each of the 25 clusters, to guide progress toward outcomes. RBM will be facilitated by an online planning, monitoring, evaluation, and learning platform that RTB co-developed with the CGIAR Research Program on Dryland Systems that was used for planning 2017 deliverables.

In 2016, RTB maintained collaboration with 366 partners, primarily national agricultural research organizations, academic and advanced research institutions, private companies and non-governmental organizations (NGOs). These valuable partnerships will play an increasingly important role in this second phase as the program works to scale out the technologies and approaches developed under its flagships. RTB will seek 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 will work to achieve the program's intermediate development outcomes – which are fully aligned with the Sustainable Development Goals – by 2022.

Sustainable Development Goals	Selected RTB Program Targets (2022)
	• 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 with increased capacity to deal with climate risks and extremes • 9,500 individuals (50% women) with improved capacities in partner organizations • At least 5 partnership and scaling models tested in a minimum of 5 target countries

FLAGSHIP PROJECT 1

ENHANCED UTILIZATION OF GENETIC RESOURCES

Flagship Project 1 (FP1) applies leading-edge science to ensure faster and more precise development of root, tuber and banana varieties that farmers and consumers demand, and enhances the long-term conservation of crop genetic diversity. During Phase I, thousands of RTB crop accessions underwent DNA sequencing, generating the critical mass of data needed to link genomic regions to traits. RTB centers made new partnerships: collaborating with Royal Holloway University of London (RHUL) to explore the potential of metabolomics (the study of metabolites involved in cellular processes), and with the Boyce Thompson Institute to develop common bioinformatics platforms for data management.

Important progress was made through genome-wide association studies (GWAS), which compare DNA sequencing and phenotype data to identify genetic markers associated with specific traits. GWAS in cassava resulted in the identification of quantitative trait loci (QTLs) associated with resistance to cassava green mite, cassava mosaic disease and cassava brown streak disease (CBSD), as well as high pro-vitamin A or dry matter content in storage roots —information that breeders can use to develop improved varieties. Researchers from Bioversity International and CIRAD used GWAS on a panel of banana accessions to identify QTLs linked to seedless fruit, an essential trait for consumers, which can guide breeding, whereas IITA is applying that sequencing data to an ongoing field study of drought tolerance in the same accessions. Meanwhile, researchers at CIP used GWAS on a panel of landrace potatoes to identify genetic markers associated with iron, zinc, or both, which can be used to accelerate breeding of biofortified varieties. The technique is also being used to identify genomic regions associated with heat tolerance in sweetpotato based on data from a field screening of 1,973 accessions.

Metabolite analysis at RHUL revealed the potential of yam foliage as a source of valuable compounds, and found metabolites that can be used to identify species from in-vitro banana and cassava material in genebanks.

RTB is creating a breeding community of practice that brings together breeders, molecular geneticists, pathologists, nutritionists and social scientists to prioritize breeding program objectives, develop strategies to incorporate end-users' needs into them, address gaps and share potential solutions.

Bioversity International's in vitro banana collection at the International Transit Centre, Leuven, Belgium.
N. Capozio/Bioversity International

Genomic research improves scientists' understanding of cassava diversity and domestication

RTB scientists are using next-generation DNA sequencing data to construct more accurate crop and species phylogenies, or evolutionary histories, shedding new light on the relationships among different populations and between cultivated crops and their wild relatives. This knowledge can help breeders locate new sources of desirable traits, or expand the use of interspecific breeding, and will facilitate marker-assisted selection and genomic-assisted breeding to accelerate genetic gains.

A collaboration between CIAT and IITA that included the DNA sequencing of more than 2,500 cassava accessions from Africa and South America – elite breeding clones, landraces and 21 cassava wild relatives – significantly enhanced scientists' understanding of the structures of African and South American cassava populations and the history of the crop's domestication. Analysis of genotyping by sequencing (GBS) data showed that accessions of most cultivated varieties (*Manihot esculenta*) are strongly divergent from the wild cassava relative *M. glaziovii*, except for improved varieties from IITA, especially Tropical Manioc Selection (TMS) clones. This confirms historical records that TMS clones trace back to an interspecific hybrid derived from backcrosses between *M. glaziovii* and *M. esculenta*, carried out in the early 20th century in Tanzania, in order to incorporate mosaic disease resistance into cultivated cassava.

Researchers also identified clones from research center collections with different names that are nearly identical. They determined that the recurrent use of a limited number of genotypes as parents has reduced the genetic diversity in breeding programs, especially in Africa. This knowledge will help breeders to restore genetic diversity in breeding populations.

Analysis of African cassava diversity initially concentrated on accessions from West African collections and farms, but is now being expanded to include 1,045 clones from Tanzanian breeding programs, which will be genotyped and analyzed in 2017. The Tanzanian germplasm is especially important because it contains critical sources of resistance to cassava brown streak virus, which causes major economic losses in East Africa.

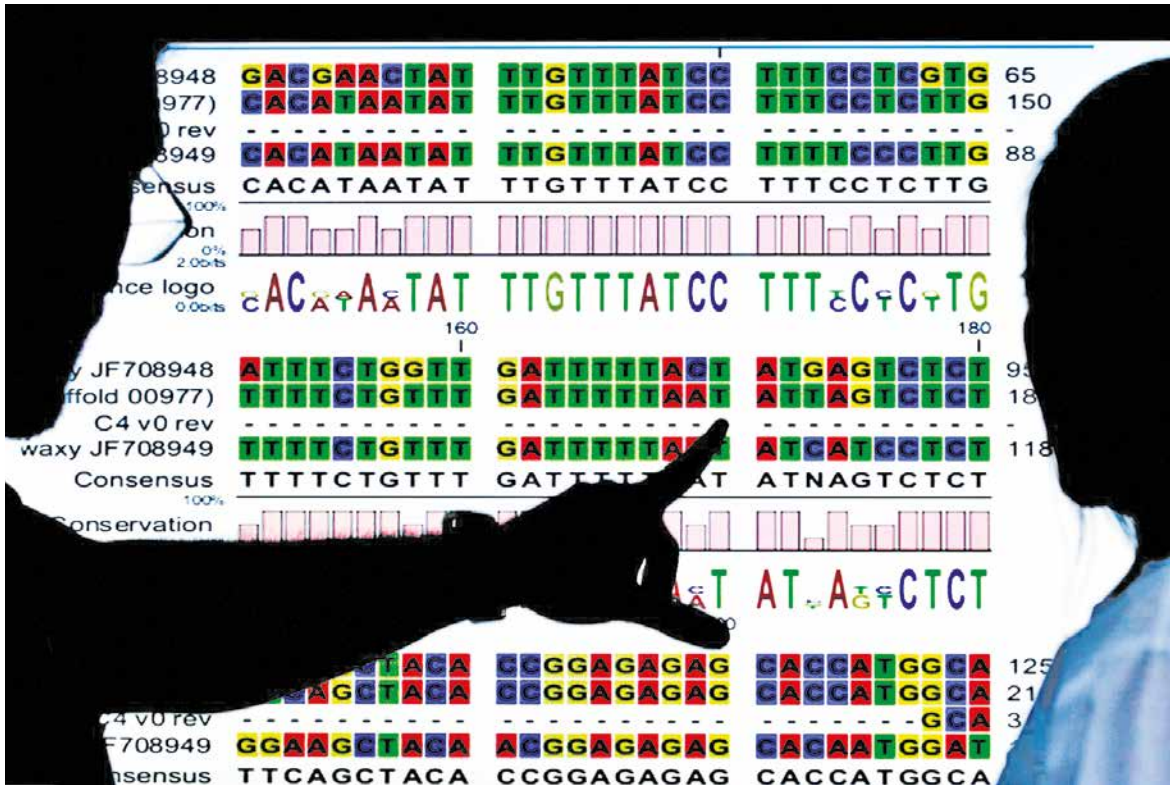
Scientists at CIAT used a genome wide sequencing approach on Latin American accessions that provided new insight into cassava's genetic differentiation in South America, and allowed researchers to revisit the hypotheses of the crop's center of origin and closest wild relative. An estimation of genome-wide allele range of expansion suggests that cassava was domesticated on the western edge of the Amazon Basin, along the Andes mountain range, rather than the southern border of the Amazon basin, as suggested by previous research. At the same time, a genome-wide excess of shared derived alleles between cultivated cassava and its closest wild relatives using Patterson's D statistic revealed that cassava's most likely ancestor was revealed to be *M. peruviana* Müll.-Arg. rather than *M. esculenta ssp* flabellifolia, as is widely believed.

According to CIAT molecular geneticist and FP1 leader, Luis Augusto Becerra, this discovery indicates that *M. peruviana* could be a source of genes for important traits that cultivated *M. esculenta* lost during domestication. For example, resistance

to whiteflies, which are vectors for various cassava diseases, has been reported in *M. peruviana.*

"We now need to prioritize exploring and preserving *M. peruviana* germplasm," Becerra said. He explained that because *M. peruviana* has largely been ignored by breeders, it is underrepresented in collections, and suggested that an international field collection effort is needed to preserve *M. peruviana* diversity, since its natural habitat may be threatened by environmental destruction.
As an example of *M. peruviana's* potential, Becerra cited the case of the cassava wild relative *M. walkerae*, which is resistant to postharvest physiological deterioration (PPD)— a process that renders the roots of most cassava varieties inedible within a matter of days. CIAT cassava breeders successfully transferred genes for PPD resistance from *M. wankeria* into cultivated cassava years ago, and are developing varieties that combine PPD resistance with consumer-preferred traits. CIAT researchers recently characterized some 200 *M. wankeria* genes linked to PPD resistance.

Such discoveries can help breeders to develop more resilient cassava varieties, with resistance to diseases, pests, or abiotic constraints that could become more intense under climate change.



Decoding the cassava genome. N.Palmer/CIAT

Breeding biofortified potatoes to relieve micronutrient malnutrition

CIP scientists are developing potatoes with high micronutrient content as part of a broader effort to address micronutrient deficiencies, which disproportionately affect the health of rural women and children. Those efforts have resulted in new potato breeding populations of nutrient-dense candidate varieties with up to 32–45 parts per million (ppm) dry weight iron and 22–37 ppm dry weight zinc, depending on the variety and location where the crop is grown. This represents an increase from baseline levels of 20 ppm iron and 16 ppm zinc in most potato varieties. Assuming bioavailability of 15%, eating 200 grams per day of a potato variety from the high range of these populations would provide 30% of the estimated average requirement of iron for a woman of child-bearing age, compared with just 12% from currently available potato varieties.

Andean-type, biofortified candidate varieties with outstanding culinary properties from these populations are in the advanced stages of evaluation in Rwanda, Ethiopia and Peru, whereas higher-yielding, commercial-type candidate varieties will be distributed for testing in September 2017.
Merideth Bonierbale, leader of CIP's Genetics, Genomics and Crop Improvement Division, explained that these candidate varieties are the products of an intricate process that began with the identification of Andean landraces with relatively high mineral concentrations. This breeding population then underwent recurrent selection to increase iron and zinc levels, followed by crossing with parental lines bred for other traits – but still

relatively high in iron or zinc content – in order to produce high-yielding, disease-resistant and resilient biofortified potatoes.

To facilitate selection for micronutrients, CIP researchers adapted X-ray fluorescence technology (XRF) to develop a rapid and accurate assay for estimating iron and zinc contents in tuber samples, in collaboration with A4NH and HarvestPlus. Calibrations and external validations showed that XRF could be used to estimate iron and zinc in solid or freeze-dried potato samples with high precision and reproducibility. CIP subsequently trained researchers from the Rwanda Agricultural Board (RAB) and the Ethiopian Institute of Agricultural Research in field sampling, sample preparation and XRF methods at CIP in Peru and RAB in Rwanda. By late 2016, approximately 20,000 potato samples had been analyzed.

At the same time, CIP is using genotyping by sequencing (GBS) to accelerate and improve the accuracy of biofortification as part of the transition to next-generation breeding. CIP researchers formed a panel of 170 landrace potatoes with genetic variation for zinc and iron content, which was genotyped using GBS and planted for field tests at two locations in the Peruvian Andes: one site with adequate soil zinc (Huancayo) and the other with zinc-deficient soil (Huancaní). The experiments were part of an effort to evaluate the suitability of genome-wide association studies (GWAS) for identifying genes or genomic regions associated with high iron, zinc and vitamin C content.

By late 2016, approximately 20,000 potato samples had been analyzed.

The GWAS analysis, using a mixed linear model, identified four markers significantly associated with iron concentration and seven with zinc concentration. At the site with adequate soil zinc, the iron and zinc content of varieties were positively correlated and a marker on chromosome 8 was significantly associated with both traits. However, at the zinc-deficient site, the correlation for these traits was non-significant. Moreover, GWAS did not detect the marker on chromosome 8, which highlights the importance of maintaining adequate amounts of available zinc and iron in the soil for such studies.

Genetic markers such as those associated with iron and zinc on chromosome 8, and zinc on chromosome 1, are located near annotated genes that encode metal transporters. Researchers will further study these loci and validate their utility as candidates for marker-assisted selection in 2017. Once these markers are validated, breeders can use them to accelerate the development of new biofortified potato varieties and increase the predictability of such breeding efforts. Ultimately, these high-throughput methods for accelerating genetic gain for iron and zinc content will contribute to the development of biofortified potato varieties with the traits that consumers want and the resilience that farmers need.

Farmers in Ethiopia cultivating biofortified potato. G. Wgiorgis/Ethiopian Institute of Agriculture Research

Unraveling the secrets of yam genomes to improve breeding

Despite yam's importance as a food security and cash crop, knowledge of its genome lags far behind that of other crops. RTB is helping to bridge this gap through genomic and metabolomic research to better understand yam diversity, and provide breeders with knowledge to accelerate and enhance the development of improved varieties.

When RTB began work, no reference genome existed for any of the six economically important yam species and little genetic research had been done on the crop. During RTB's first phase, IITA contributed to the completion of reference genome sequences for the two most cultivated yam species, *Dioscorea rotundata* and *D. alata*, in partnership with Iwate Biotechnology Research Center and Earlham Institute. IITA researchers planted 840 *D. rodundata* accessions for phenotyping and sent them to Cornell University for genotyping by sequencing (GBS) in order to identify genes linked to important traits. IITA also sent 100 *D. alata* accessions from Africa to CIRAD to be genotyped using GBS, along with approximately 900 *D. alata* accessions from Asia and the South Pacific. In addition, metabolite profiles were completed for 49 genotypes from the five different yam species routinely used in breeding.

"There are a lot of issues that we don't understand about yam," said Ranjana Bhattacharjee, a molecular breeder at IITA.

> "Yam was completely neglected, and it is still a neglected crop, but thanks to RTB we're making important progress."

Yam in vitro cultures at IITA's genebank in Ibadan, Nigeria. IITA

She explained that IITA has prioritized genomic research on *D. rotundata* because it is the most commonly grown species in West Africa and constitutes most of the yam produced worldwide. Of the 840 *D. rotundata* accessions that underwent GBS and phenotyping, 500 were from IITA's core collection, 300 were elite breeding lines, and 40 were collected at Nigerian markets. Researchers analyzed GBS data to assess genetic diversity and population structures, and completed a hierarchical cluster analysis that revealed three major clusters: elite breeding lines clustered separately from the landraces, whereas the third cluster likely represents triploid yams, though Bhattacharjee said a ploidy analysis is needed to confirm this.

Upon analyzing the GBS data, researchers realized that many accessions labeled as different varieties were actually genetically identical. They identified 240 unique clones among the many duplicates and planted them for further phenotyping and characterization. These accessions will be used as a training population for genome wide association studies, and for testing the use of genomic selection to accelerate yam improvement.

Researchers have also collected two years of phenotypic data on 21 traits from a large set of accessions. Traits of interest include flowering, tuber weight, oxidation, earliness, resistance to anthracnose disease, and quality characteristics such as dry matter and 'poundability', which is important for West African women, since they pound boiled tuber flesh for traditional dishes.

"Earliness, tuber oxidation and flowering are important traits that genomic data could make a big difference in breeding for," observed Bhattacharjee. She explained that a scarcity of female flowers makes it difficult to cross yams, and she hopes to use genetic and metabolite data to determine which parents will produce enough flowers to facilitate breeding.

'Poundability' is an important trait for West African women who pound boiled yam flesh for traditional dishes. IITA

Researchers at Royal Holloway University of London have completed metabolite profiles of 49 genotypes of *D. rotundata, D. alata, D. cayenensis, D. bulbifera* and *D. dumetorum*. Combined analysis of leaf and tuber material identified a subset of metabolites that allow accurate species classification and highlighted the potential of predicting tuber composition from leaf profiles. "Metabolite data can provide deeper insight into genes of interest," said Bhattacharjee, who hopes to use it to better understand the metabolic pathways that control important traits. She added that she would like to have metabolite profiles for the 240 accessions in the training population in order to use the data for high-throughput phenotyping. This could complement genomic data by accelerating the selection of offspring, which would help breeders to develop new varieties faster.

MusaTab tablet app facilitates recording banana data in the field

MusaTab is an Android application for recording characterization data in the field. Crop Diversity

In order to improve the conservation and utilization of global banana diversity, RTB helps Musa (banana and plantain) collection curators and researchers around the world collect, share, and access information about different cultivars. As part of this effort, Bioversity International and partners, within the framework of the Global Musa Genetic Resources Network MusaNet, created a novel tool called MusaTab —an android application for recording banana characterization data using tablets.

MusaTab allows users to record observations, consult or enter data, take photos of plants, and score Musa spp. descriptors in the field. It is one of various tools available through the Musa Germplasm Information System (MGIS), a global exchange system on Musa germplasm diversity managed by Bioversity International. MGIS provides open access to passport data, botanical classification, morpho-taxonomic descriptors, molecular studies, photos and geographic information system data on 4,608 Musa accessions in 21 collections around the world.

https://www.crop-diversity.org/mgis/

FLAGSHIP PROJECT 2

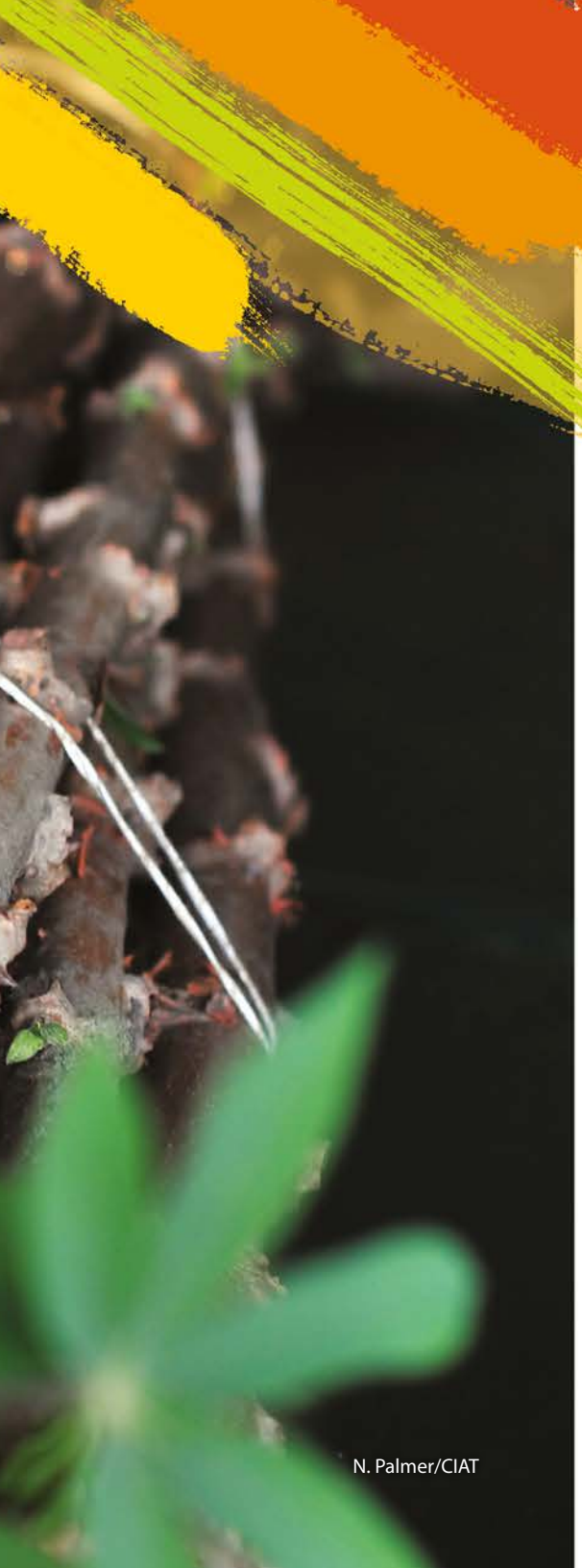
QUALITY PLANTING MATERIAL AND PRODUCTIVE VARIETIES

The objective of Flagship Project 2 (FP2) is to make available good-quality planting materials of a diverse set of high-yielding RTB varieties that are adapted to the needs and preferences of different stakeholders in the value chain. To do this, RTB supports efforts to improve breeding pipelines and accelerate the release of new varieties, while ensuring that those varieties have traits that both women and men want. The flagship, led by Elmar Schulte-Geldermann, leader of CIP's Seed Potato for Africa program, also works to reduce bottlenecks in the production and distribution of planting material for those varieties, and improve RTB seed systems and farm-level seed management in general. RTB exploits existing crop diversity while supporting the development of nutrient-rich, resilient varieties that allow farmers to produce food on marginal lands and under climate change.

Among Phase I highlights, RTB centers collected gender-differentiated trait preference data to improve crop breeding, developed resilient and consumer-accepted varieties, and undertook research to improve seed systems. CIP worked with the national potato program in Ethiopia to incorporate gender into participatory varietal selection (PVS) in order to improve the adoption of improved varieties. IITA worked with 23 yam breeders and technicians at breeding programs in Ghana and Nigeria to design and implement a PVS methodology for yam, which was used with 4,328 farmers to evaluate 24 yam varieties, and collect trait preference data to guide yam breeding.

A cross-center project in five sub-Saharan Africa (SSA) countries used questionnaires and interviews to assess consumer preferences and gender differences in the perception of cassava product quality, resulting in a baseline of data available for cassava breeding programs. Bioversity International scientists undertook a gender-differentiated baseline study of banana trait preferences, in collaboration with National Agricultural Research Systems (NARS) in Uganda and Tanzania, to improve banana breeding in those countries.

Meanwhile, RTB centers supported national partners in the development and dissemination of improved varieties. These include recently released varieties such as the nutritious sweetpotato variety 'Lawrence' in Mozambique; the high-yielding yam variety TDr 98/00933 in Nigeria; the disease-resistant cassava varieties 'Naro Cas1' and 'Naro Cas2' in Uganda; the pest- and disease-resistant hybrid banana 'Kiwangaazi' released in Uganda; and several salt- and heat-tolerant potato varieties released in Bangladesh, Tajikistan and Uzbekistan. These improved varieties will strengthen the food security and incomes of millions of smallholders.



N. Palmer/CIAT

Cross-crop research produces tools for improving smallholder access to quality planting material

Because RTB crops are propagated clonally—by planting tubers, suckers, stalks, or vine cuttings—they present common challenges for farmers that include low multiplication rates, perishable planting material and low yield as a result of seed degeneration. Government agencies and non-government organizations (NGOs) have developed seed systems to disseminate improved varieties and high-quality planting material (commonly referred to as 'seed'), but only a small fraction of smallholders have access to those formal seed systems. To increase farmer access to quality planting material and improve yields, RTB centers have collaborated on cross-crop research to develop tools for improving seed systems and seed degeneration management.

RTB researchers developed a multi-stakeholder, seed systems framework and used it to analyze 13 formal and informal seed systems for five RTB crops in Africa and Latin America, extracting lessons that can be applied across crops and contexts. CIP then used the framework for a scoping study of potato seed systems in Karnataka and Maharashtra, India, identifying bottlenecks that prevent more farmers from gaining access to quality seed potatoes. RTB researchers will make the framework more gender responsive and use it to assess more seed systems in 2017.

Seed degeneration – the transmission and accumulation of pests or pathogens from one seed cycle to the next via planting material – is a major cause of yield loss, and is consequently a priority for RTB. Researchers conducted literature reviews on seed degeneration, developed a theoretical seed degeneration model, and used it to assess the effectiveness of different approaches to managing seed degeneration. This resulted in the development of an integrated seed health strategy, which combines the use of disease-resistant varieties with on-farm management practices such as roguing (removing plants with disease symptoms), positive selection (choosing healthy planting material in-field for the next planting cycle), and strategic replacement of seed with disease-free material.

To better understand the dynamics of seed degeneration, researchers have conducted field trials in different agro-ecologies of eight African and South American countries. The trials used popular varieties of banana, cassava, potato, sweetpotato and yam infected with 11 pathogens and spanned multiple cropping cycles over several years. They included evaluations of common on-farm management practices, generation of data on pathogens and vectors, and the effects of weather, varietal resistance levels, seed management, and other agronomic practices on seed degeneration.

The resulting data are being used to develop crop-specific seed degeneration models that scientists can use to predict how varieties will perform in specific agro-ecologies under determined disease pressures, weather conditions and management strategies. They will be used to develop management performance maps and decision support tools that research and extension agencies, and seed producers

Potato farmers in Ecuador, where research found the incidence of pathogens within a seed lot was naturally reduced at higher altitudes. CIP

can use to identify the best options for managing degeneration.

The field research has shed new light on pathogen dynamics and management strategies. For example, potato research in Ecuador demonstrated that reversion (naturally occurring reduction of pathogen incidence within a seed lot) takes place at higher altitudes. Researchers used impact network analysis to study planting material movement in informal sweetpotato seed systems in northern Uganda, completing in silico simulations of the introduction of a novel virus to identify nodes within those distribution networks of importance for disease sampling and mitigation.

"There is a bias against informal seed systems, and most interventions try to create seed systems from scratch," said CIP seed specialist Jorge Andrade, who coordinates the RTB seed systems research.

> "It is important to understand the dynamics of informal seed systems and farmer demand for planting material before designing any intervention."

Andrade explained that RTB is developing a toolbox of analytical and diagnostic methodologies that government agencies, NARS, NGOs, and donors can use to improve the design and execution of seed-system interventions and the management of seed degeneration.

Sweetpotato net tunnels help African farmers boost yields

Whiteflies and aphids spread viruses that accumulate in sweetpotato plants from one cropping cycle to the next, causing major yield loss in certain varieties and regions of SSA. CIP is consequently promoting the use of net tunnels—mini net houses made from locally available materials—in areas of high virus pressure.

CIP and partners are teaching farmers and vine multipliers to use net tunnels to preserve disease-free mother stock. Researchers have found that by using planting material from net tunnels, farmers can increase their yields by 50–100%, significantly boosting their food security and incomes. While materials to build a net house cost about USD120 in Kenya or Tanzania, researchers in Kenya found the average benefit of using planting material from net tunnels was USD839 over the course of 33 months. By late 2016, more than 600 net tunnels were in use in Kenya, Tanzania, Rwanda and Uganda, and CIP is scaling out the technology in 2017.

Cutting-edge technologies speed up yam seed production in West Africa

Bioreactor for yam. M.Friedmann/RTB

Yam's low multiplication rate slows efforts to get improved varieties to farmers. To overcome this, IITA has developed systems for rapid production of pathogen-free seed yams using SETIS™ type temporary immersion bioreactor systems (TIBS) and aeroponics (in which roots grow in a fertilized mist in an enclosed, light-free environment). Pathogen-free yam plantlets are introduced into TIBS for multiplication, and the resulting plantlets are hardened and potted in soil for harvest after six months as pre-basic seed, or planted in an aeroponic system for basic seed production.

The first public sector aeroponic system in Ghana, inaugurated in 2016 at the Council for Scientific and Industrial Research's Crops Research Institute, in Kumasi, was planted with TIBS plantlets. Because a power outage can cause total production loss, the Kumasi system uses solar power as a backup. By the end of 2016, it was producing pathogen-free minitubers and vine cuttings of two improved and two local yam varieties.

Adapting remote-sensing data for an array of applications in agriculture

CIP scientists made progress in 2016 on forecasting tuber yields in potato over large areas by linking modeling and remote-sensing data. Using satellite images of a potato-farming area in the US state of Idaho, researchers parameterized physiological and crop growth models that were then used to forecast yield. According to Roberto Quiroz, leader of CIP's Crops and Systems Sciences Division, the parameterized model prediction was compared with crop statistics from the area in the satellite image. The comparison showed that combining modeling and remote-sensing data can produce excellent results.

Testing a drone in sub-Saharan Africa. CIP

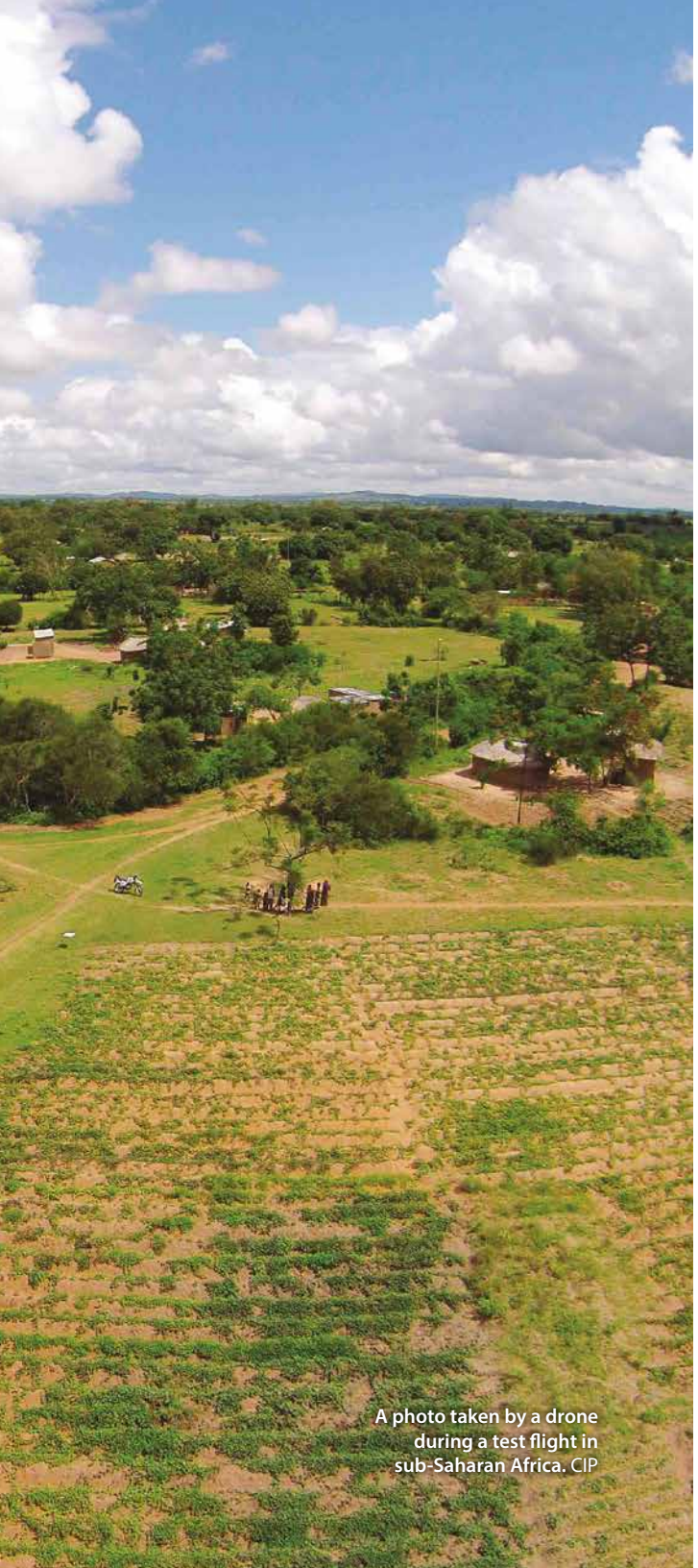
The experiment was the latest on a growing list of CIP's applications of remote-sensing data to agricultural research. CIP began using satellite images to estimate sweetpotato crop areas almost two decades ago, but those images were less useful for studying potato since potato-farming areas are often obscured by clouds. CIP scientists consequently began to explore other remote-sensing options, such as attaching cameras to balloons or miniature planes. In 2012, they tried an unmanned aerial vehicle (UAV)—commonly known as a drone—which soon proved to be the best tool for gathering high-resolution images.

Quiroz subsequently led the creation of a UAV-based, agricultural remote-sensing integrated platform that has validated the use of drones for analyzing crop area in the field in Peru and Tanzania. For more accurate assessments, algorithms were developed for geometric and radiometric correction of data from sensors in order to enhance their applicability to agricultural research.

Technological advances, coupled with the decreasing cost of hardware, have opened the door for a rapid expansion of applying this technology to agriculture. Yet CIP researchers have also assembled drones from parts in African countries, purchased sensors instead of cameras, and developed open-access software to make the technology as affordable as possible.

One such open-access program allows researchers to stitch together many different images to study large areas. Researchers in Tanzania used that program to stitch together more than 600 images taken during one UAV flight over Kilosa District. They produced an image that depicts about 100 ha, in which they identified more than 20 crops with less than 20% error. Quiroz noted that taking more photos would have reduced the error. He explained that his team is trying to develop a tool to correlate UAV remote-sensing data with satellite data in order to improve the accuracy of such large area analyses.

CIP and partners formed a 'UAV for Agriculture' community of practice (CoP) in Africa to share knowledge and software, but it has quickly expanded to include members outside Africa. The



A photo taken by a drone during a test flight in sub-Saharan Africa. CIP

CoP, which is hosted by the Technical Centre for Agricultural and Rural Cooperation at Wageningen University & Research, the Netherlands, had almost 1,000 members by the end of 2016.

While remote sensing has primarily been used to assess crop area, CIP researchers are exploring other applications such as yield prediction and detecting the onset of diseases or pest infestations, or the effects of climate change. Remote sensing has the potential to improve the accuracy of government agricultural statistics.

> The ability to detect crop pests or diseases early, or forecast low yields, can help governments predict and prepare for food shortages.

CIP researchers have used remote-sensing images to detect potato yellow vein virus before pathologists could detect it in individual plants, and the technology has implications for an array of other crops too.

In another innovative development, CIP programmers produced software in the R language that can extract information on individual plants in a field from a stitched, 120-megapixel image with a resolution of less than 5 cm. This non-intrusive technology has the potential to replace visual inspection for a more accurate, high-throughput phenotyping, since it would reduce human error. "This is a way of generating a public good that breeders around the world could use to improve the efficiency of their phenotyping," said Quiroz.

> "Technological advances, coupled with the decreasing cost of hardware, have opened the door for a rapid expansion of applying this technology to agriculture."

Rooted potato cuttings could transform African seed systems

Limited availability of disease-free seed potato is a major obstacle to increasing potato productivity in Africa. CIP has responded by promoting aeroponics and, more recently, apical potato cuttings to produce minitubers as starting material for seed production. Cuttings from tissue culture plantlets are rooted in a screenhouse, then planted in the field to produce seed tubers. Production of several rounds of 'mother' plants from an initial tissue culture plantlet prior to producing rooted cuttings for field planting results in very high productivity.

Integrating apical cuttings into seed systems can reduce the time in which high- quality seed potatoes are available to farmers by one cropping season, while increasing the efficiency of seed production compared to current practices. In Kenya, two businesses have already invested in rooted-cutting production and the national potato program and 40 seed multipliers are using the technology to produce seed tubers in their fields.

FLAGSHIP PROJECT 3

RESILIENT ROOTS, TUBERS AND BANANAS

Flagship Project 3 (FP3) works to close yield gaps of RTB crops arising from biotic and abiotic threats, and to develop more resilient production systems, strengthen food security and improve natural resource quality.

During Phase I, RTB centers supported work to assess, contain, and study options for managing major and emerging RTB pest and disease threats. RTB scientists helped coordinate a rapid international response to the first African outbreak of the banana disease Foc TR4, working with National Agricultural Research Systems (NARS), regional organizations and the Food and Agricultural Organization of the United Nations (FAO) on a pan-African strategy to contain the disease. CIAT and CIRAD partnered with national and regional organizations in Latin America and the Caribbean to develop strategies and technologies for controlling banana Moko disease, whereas Bioversity International and IITA have raised awareness of and contributed to efforts to monitor and contain banana bunchy top disease (BBTD) in sub-Saharan Africa (SSA).

CIP coordinated sweetpotato breeding platforms in SSA that have facilitated the development of sweetpotato varieties resistant to viruses and weevils. CIAT, IITA, and FAO partnered with Southeast Asian NARS for the release of parasitoid wasps as a biological control for cassava mealybugs in Indonesia, Laos, Thailand, and South Vietnam, which has significantly lowered populations of that crop pest, and crop losses, in the region. Meanwhile, a multi-center collaboration to improve the management of RTB-critical pests and diseases in SSA under climate change has compiled farm, disease, pest, and weather data from surveys and weather stations at study sites in Burundi and Rwanda. Concurrent laboratory research produced phenology models for insect pests and vectors that will be combined with field data to develop models for predicting future pest and disease risks under climate change scenarios. RTB scientists also contributed to the production of pest risk analysis documents and regional risk maps for some of the most important pest and disease threats to banana, cassava, and potato in East Africa, which will help government agencies in the region to respond to those threats.

Breeders at the International Potato Center. S.Quinn/CIP

New discoveries help tackle cassava witches' broom disease in Southeast Asia

Cassava witches' broom (CWB) disease, which reduces cassava yields by an average of 30–35%, is an emerging threat to the livelihoods of millions of farmers in Southeast Asia. CIAT is working with national partners to better understand the disease, improve surveillance, and help farmers manage it.

Cassava is an important cash crop for the region's smallholders, supporting the livelihoods of about 40 million people. Cassava has historically been spared major pests and diseases in Southeast Asia, but the recent spread of CWB disease, as well as invasive cassava mealybugs, poses a major threat to the region's farmers and economies.

The symptoms of CWB disease – such as a broom-like proliferation of leaves at the top of plants – were first described in Thailand the 1990s, yet scientists have only determined that it is caused by phytoplasmas in the past decade. The first regional surveillance of the disease was not conducted until the dry season of 2014, when CIAT and partners monitored 429 fields in five Southeast Asian countries and found CWB in 64% of the plots.

"We have only recently realized what a large-scale problem CWB is," said Kris Wyckhuys, an entomologist who works for CIAT in Asia. "It has reached near-pandemic levels in Cambodia, Central Vietnam, Western Thailand, and the Philippines."

Wyckhuys is collaborating with Southeast Asian partners to better understand the CWB pathogen and its insect vectors, and to design effective responses to the disease. Scientists knew the pathogen is spread by infected planting material and insect vectors, but nobody knew which insects acted as vectors. CIAT consequently collaborated with Thai, Philippine, and Vietnamese partners on a step-wise process to identify candidate insect vectors and elucidate their roles in pathogen transmission. Using a combination of field observations, laboratory feeding trials, and molecular diagnostics, researchers identified eight species of leafhopper and planthopper as probable vectors. Some of the insects are more common in rice fields, which led Wyckhuys to hypothesize that rice may serve as an asymptomatic host for the pathogen.

CIAT scientists also performed restriction fragment length polymorphism analyses on infected cassava material from Cambodia in 2016, and identified phytoplasmas belonging to ribosomal subgroups 16SrI-C. Wyckhuys worked with scientists at the Agricultural Genetics Institute in Vietnam to develop a loop mediated

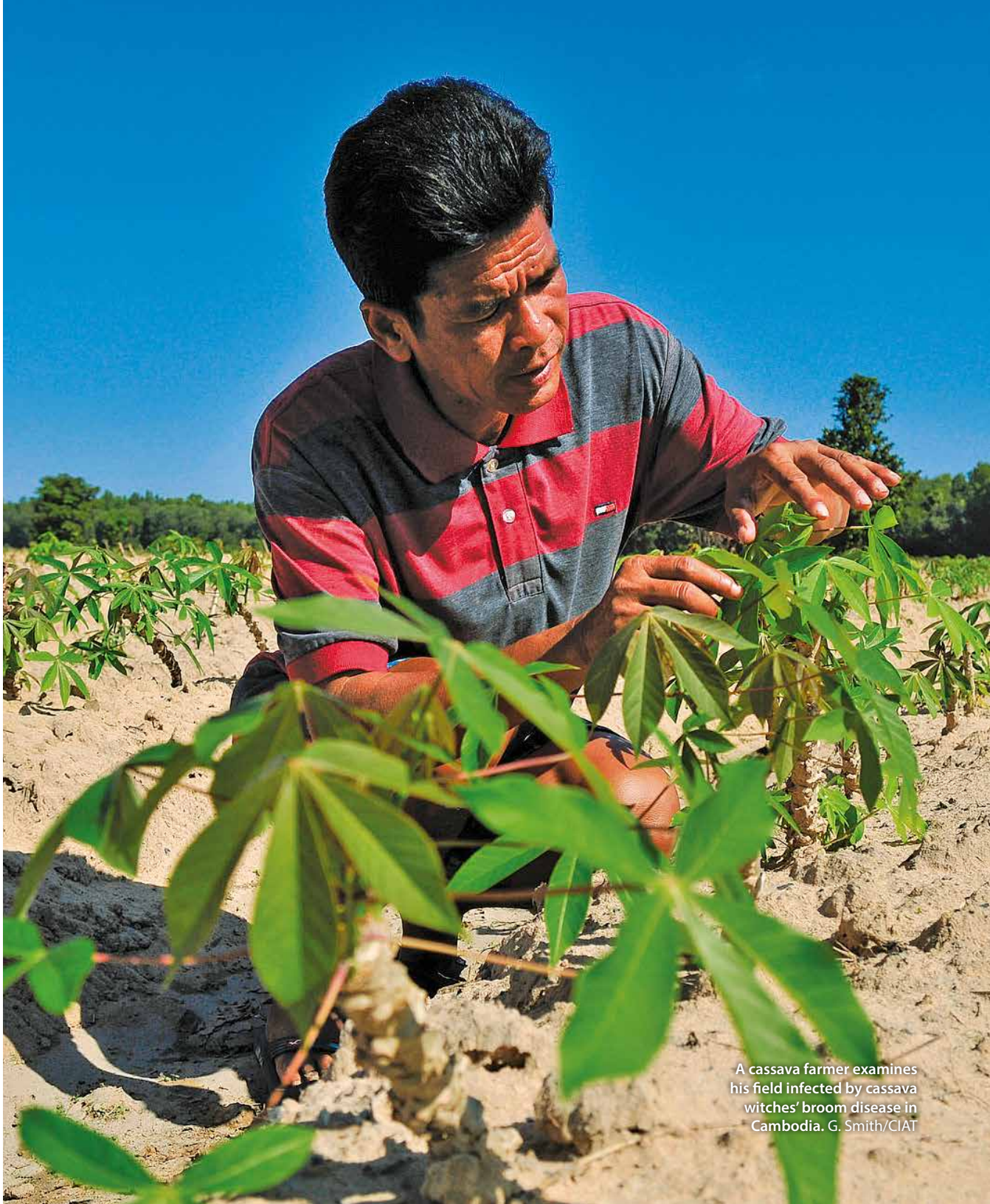
Symptoms of cassava witches' broom include a proliferation of leaves at the top of the stem in the shape of a witches' broom. G. Smith/CIAT

isothermal amplification-based, isothermal DNA amplification device (Smart Dart ™)to detect phytoplasmas in plant material. The device is small enough to be taken into the field to detect the disease in real time, which is especially important because infected plants are often asymptomatic. CIAT also developed a phone-based diagnostic key to facilitate rapid, field-level identification.

To strengthen surveillance across the region, CIAT produced a training video and organized training events in Cambodia, Vietnam, Laos, Thailand, and the Philippines, where ministry and research institute representatives learned how to recognize CWB symptoms and use the Smart Dart™. Government officers, researchers, and companies across the region are currently using Smart Dart as well.

Because CWB pathogens are spread through planting material, CIAT is testing thermotherapy as a way of killing the phytoplasmas in infected planting material. CIAT has successfully used thermotherapy in Latin America to clean cassava planting material of phytoplasmas responsible for frogskin disease. Wyckhuys explained that the technology needs further validation in the field before it can be promoted for CWB.

Meanwhile, CIAT and partners are advocating greater surveillance and controls to slow the spread of CWB. They are also promoting a farm-level, integrated disease management approach that entails fertilizing and removing diseased plants from a portion of a farm—dubbed the 'corner of prosperity'—from which farmers select quality planting material for the next crop cycle. In addition to helping farmers manage the disease, this approach can improve farm productivity in general, which makes it a good way to help smallholders while enlisting them in the battle to control CWB disease.

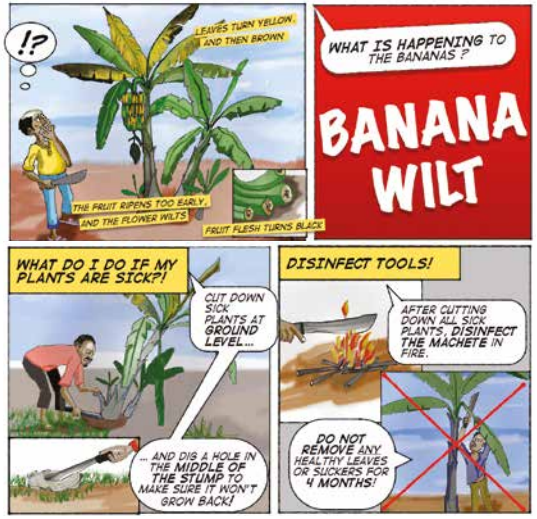


A cassava farmer examines his field infected by cassava witches' broom disease in Cambodia. G. Smith/CIAT

Collaboration on research and training to control banana Xanthomonas wilt in East and Central Africa

Banana Xanthomonas wilt (BXW)—a bacterial disease spread by insects, birds, bats, larger animals, and farm tools—is the biggest constraint for banana production in East and Central Africa. Since its appearance in Uganda in the early 2000s, BXW has spread rapidly in the region, causing food insecurity and income loss. Bioversity International and IITA have collaborated with Uganda's National Agricultural Research Organization, the Democratic Republic of Congo's National Institute for Agronomic Study and Research, and other partners on basic research, field testing options for controlling BXW, and scaling-out effective control approaches.

African NARS initially recommended destroying all banana 'mats' (2–20 plants growing together) with BXW symptoms and replanting with clean material, but many smallholders resisted this approach because of the labor and hardship caused by production loss. Bioversity International scientist Guy Blomme conducted field studies that showed farmers could reduce incidence of the disease to less than 2% within months by removing only infected banana plants, which requires less labor and income loss than complete mat removal. That approach, called single diseased stem removal (SDSR), is part of a BXW control package that Bioversity International, IITA, and partners are promoting in several SSA countries. The approach also includes the early removal of male buds to prevent insects from infecting plants with the bacteria, and sterilizing farm tools after contact with diseased plants.



An excerpt from a poster developed by Bioversity International and FAO promoting the SDSR technique.

RTB is supporting greater regional cooperation around BXW and results-based management of efforts to scale out control measures, monitor their effectiveness, and use gender research to enhance their impact. This has included baseline studies of 900 households in eastern DR Congo and 1,217 households in Uganda, where sex-disaggregated data were collected to shed light on differences between men's and women's application of BXW control measures. Banana pest and disease surveys were also completed in Burundi and Rwanda during the dry and rainy season, in collaboration with the UK research agency Fera to draft a pest risk analysis document for BXW.

Bioversity International and IITA work with NARS, agricultural ministries, farmer organizations, and non-governmental organizations (NGOs) to tailor control measures to local conditions and farmers' needs. Whereas commercial farmers prefer removing entire mats, subsistence farmers have adopted SDSR. Bioversity International researchers estimated that the latter approach results in individual household income recovery of USD115/acre a year.

While BXW control initiatives often include establishing seed systems to multiply and disseminate disease-free planting material for replanting, researchers have recently determined that symptomless banana suckers sourced from infected plots can be used as planting material within BXW-affected zones. This is an option for farmers in areas where clean planting material is unavailable.

IITA and Bioversity International collaborated with FAO on a project in Burundi, Rwanda, and DR Congo that educated farmers about BXW control options and facilitated the propagation and dissemination of clean planting material for improved varieties. Bioversity International produced a video on BXW in several languages, and distributed 5,000 copies together with printed materials to national programs and NGOs for use in training activities. According to IITA agronomist Emmanuel Njukwe, in 2016 more than 15 NGOs promoted BXW control methods such as SDSR and early male-bud removal in these three countries.

According to Njukwe, many local banana varieties are so tall that bud removal is difficult for farmers, which hinders efforts to control the disease. IITA is consequently promoting the cultivation of shorter hybrid varieties (FHIA 17, FHIA 21, and FHIA 25) that were developed in Honduras decades ago and are distributed by the International Transit Center and Bioversity International. Though they are not BXW resistant, the hybrids are easier to keep from becoming infected with the disease. And because they produce large bunches of bananas that are good for local uses, they are quite popular in the region. Consequently, IITA is working with the private sector and farmer cooperatives in Burundi, DR Congo, and Rwanda to scale up the supply of clean planting material for those hybrid varieties.

Tanzania study finds that communities can reduce cassava disease's impact

Cassava brown streak disease (CBSD) is a major constraint for smallholders in East and Central Africa, where new outbreaks have been reported in the past two decades. Caused by viruses that are spread by infected planting material and sap-sucking whiteflies, CBSD can destroy a significant portion of a farmer's cassava production. Government institutions in sub-Saharan Africa (SSA) have focused on breeding high-yielding cassava varieties—some of them CBSD tolerant—and supervising the production and dissemination of disease-free planting material for them. However, plants are rapidly infected with the virus in areas where CBSD is prevalent, due to the abundance of whiteflies. In response, researchers at Tanzania's Ministry of Agriculture, Livestock and Fisheries and IITA tested community phytosanitation – coordinated monitoring and on-farm practices – for controlling CBSD in areas where clean planting material is introduced.

The three-year (2013–2016) community phytosanitation pilot study engaged smallholders in two Tanzanian districts - Mkuranga, near the eastern coast, and Chato, in the northwest where CBSD incidence was higher than 90%. It began with a year of sensitization of men and women farmers and monitoring by locally recruited taskforces, followed by removal of all infected plants and replanting with CBSD-free planting material of improved varieties ('Mkombozi' in Chato and 'Kiroba' in Mkuranga) on a portion of the community's farms. Community members monitored the fields and controlled CBSD by roguing plants that showed symptoms.

Disease-free planting material was also distributed to farmers in another community in the same area where farmers did not employ such phytosanitation measures, as a control. To ensure that families had enough to eat and sell while the new cassava crop matured, participating farmers were given seed for more quickly maturing crops such as maize, sweetpotato, beans and cowpeas.

In the second year, the area in each community planted with the new variety was expanded, with disease-free planting material distributed to the original participants and a second group of farmers. In the third year, clean planting material distribution was expanded to include a third group. Whereas CBSD incidence was greater than 90% in the communities when the project began, maximum incidence was less than 40% in the third season in Chato.

Meanwhile, in the control community where farmers planted disease-free cassava but did not practice phytosanitation, incidence was greater than 60%. Kriging and geostatistics showed that community phytosanitation had an area-wide impact in reducing the levels of CBSD inoculum pressure.

> "This research demonstrated that community actions to control CBSD produced strong reductions in disease inoculum levels, said IITA plant health specialist and FP3 leader, James Legg."

For Khalifa Omari Nkrumah, a cassava farmer in Mkuranga and father of six, the project has opened up new income opportunities, allowing him to sell clean seed from his farm to neighboring farmers and communities.

"It has helped me—as you can see I have bought solar panels, I have dug a borehole, I have made my own cupboard for storing my clothes

Cassava farmer, Khalifa Omari Nkrumah, inspects the health of his cassava plants. H. Holmes/RTB

and food … and my child is at boarding school and I send to her bus fare," he said, speaking of the profits made from selling cassava seed.

Khalifa now cultivates two plots, one to produce roots for household consumption and the other dedicated solely to the production of seed. "I can wake up in the morning and uproot a cassava plant and boil it for breakfast. Or even for ugali, my wife cooks with my kids and we eat," he added.

In the first year of growing the improved varieties, farmers also achieved yield increases of 94% relative to the local variety baseline in Chato and 124% in Mkuranga. However, the most important indicator for the pilot project was that the improved variety 'Mkombozi' yielded 86% more in the areas of Chato where farmers practiced community phytosanitation than in the control area.

In Mkuranga, while there was an 81% reduction in CBSD incidence compared to the control area, this did not result in higher yields because the improved variety planted there, 'Kiroba', is CBSD tolerant. These results indicate that while farmers who plant CBSD-susceptible varieties can significantly improve yields by practicing community phytosanitation, those who have access to varieties that are CBSD tolerant or resistant may be less motivated to adopt the practice.

Legg explained that resistant varieties are currently unavailable in most areas affected by CBSD, so the research team recommends that community phytosanitation be considered as a component of integrated cassava virus management programs, particularly in areas that are severely affected by CBSD and where new cassava plantations are being established with varieties that lack tolerance or resistance to the disease.

Guidelines for facilitating community-based recovery of banana production in BBTD-affected areas

Farmer showing banana plant infected by banana bunchy top disease, Nigeria. IITA

RTB has supported cross-center research to strengthen containment and efforts to help communities recover from banana bunchy top disease (BBTD) a viral disease spread by aphids that is devastating banana and plantain production as it spreads across SSA. Scientists from Bioversity International, CIRAD, IITA, and partner institutions in eight countries conducted three years of field research that resulted in participatory guidelines for banana recovery in BBTD-affected areas.

Those guidelines are based on the experiences of pilot teams in 20 villages in eight countries. They outline the four stages of BBTD recovery: community mobilization, establishment of a banana-free period, development of a BBTD-free seed supply, and replanting fields with reduced risk of BBTD reinfection - highlighting the role of women in each stage. The research team also produced a cross-site synthesis report on gender roles in banana cropping systems and BBTD control to orient more effective engagement of households and communities.

FLAGSHIP PROJECT 4

NUTRITIOUS FOOD AND ADDED VALUE THROUGH POSTHARVEST INNOVATION

Flagship Project 4 (FP4) harnesses the nutritional potential of RTB crops, expands their utilization, and adds value through postharvest innovation. The flagship, led by Simon Heck, leader of CIP's Resilient, Nutritious Sweetpotato program, supports the fuller, equitable, and sustainable utilization of RTB crops for healthier diets and improved income opportunities. RTB is working to overcome constraints that have hindered roots, tubers and bananas from entering urban markets, while ensuring that innovations benefit both women and men and promote youth employment along the value chain.

RTB centers have improved postharvest process modeling to enhance sustainability and profitability. For example, a project led by researchers from CIAT, CIRAD, and IITA developed guidelines for the design of energy-efficient cassava flash dryers, potentially contributing to the sustainability of a rapidly growing industry of small- and medium-scale cassava processing enterprises. The guidelines have been widely disseminated in Southeast Asia, Latin America, and sub-Saharan Africa (SSA).

A cross-center project to find uses for waste from cassava processing that partnered RTB with the CGIAR Research Programs on Humidtropics, and Livestock and Fish resulted in a technology for turning cassava peels—approximately 20% of root mass—into a dried, high-quality cassava-peel mash for use as livestock feed. Feed millers evaluated the mash in feeding trials with chicken and sheep, and found it to be a suitable substitute for 15% of maize in livestock feed mixtures.

CIP's promotion of orange-fleshed sweetpotato (OFSP) purée as a substitute for wheat flour in baked goods has been successfully piloted and could improve diets and incomes in several SSA countries. An assessment of a CIP-coordinated, public–private venture that launched the Golden Power Biscuit and other baked products made with OFSP in Rwanda found that the venture improved earnings of 516 smallholders who supply sweetpotatoes to the factory, and that women suppliers earned significantly more than men.

OFSP purée is just one component of CIP's highly successful initiative to breed, disseminate, and promote the consumption of biofortified OFSP varieties in SSA (see World Food Prize story). In a comparable biofortification initiative, collaboration between CIAT and IITA facilitated the development of pro-vitamin A, yellow-fleshed cassava varieties in Nigeria that have been distributed to more than 350,000 households by HarvestPlus and the Nigerian government.

CIP sweetpotato breeder and one of four World Food Prize laureates, Maria Andrade, with a tub of pureed orange-fleshed sweetpotato. CIP

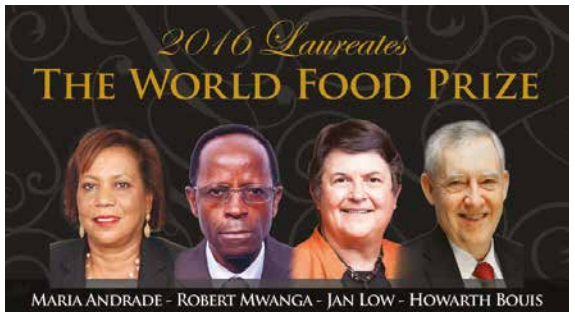
World Food Prize recognizes evidence of efficacy of OFSP to reduce malnutrition

The 2016 World Food Prize was awarded to three CIP scientists—Maria Andrade, Jan Low, and Robert Mwanga—and Howarth Bouis of IFPRI/HarvestPlus. It is an acknowledgement both of their achievements and the effectiveness of CIP's strategy to reduce micronutrient malnutrition by getting millions of families in SSA to grow and consume pro-vitamin A orange-fleshed sweetpotato (OFSP). This approach builds on a strong evidence base that OFSP can contribute to reducing vitamin A deficiency (VAD), and serves as a model for other biofortified crops.

VAD increases the risk of blindness and premature death in children as well as maternal mortality and night blindness among pregnant women. Governments and international organizations have largely relied on capsule supplementation to reduce VAD. Now, however, CIP has shown that an integrated approach that combines agriculture and nutrition education to enable smallholders to grow and eat biofortified OFSP (125 grams of which meets the daily vitamin A requirement of a child under five) and other vitamin A-rich foods can reduce child and maternal VAD.

Proof-of-concept research on the potential of OFSP to reduce VAD was led by Jan Low in Mozambique. Researchers there tested the agriculture–nutrition–education approach and documented that vitamin A intakes among children under five were eight times higher in intervention areas and that a 15% decline in prevalence of VAD among those children could be attributed to this integrated approach. A subsequent HarvestPlus-led study demonstrated that the approach could go to scale cost-effectively. More recently (2009–2015), the Mama SASHA project (Sweetpotato Action for Security and Health in Africa) in Western Kenya linked OFSP access to pre-natal care counseling at rural health facilities. A longitudinal cohort study found that dietary vitamin A intake among both mothers and infants in the project's intervention areas was nearly twice that of control areas, and that VAD decreased among mothers in the intervention areas.

On the basis of such findings, CIP and partners have scaled up efforts that link agronomic support for farmers with nutrition education, while testing and disseminating value chain innovations and OFSP branding strategies that include radio spots, printed materials, and market-based promotions. Most of this work has been organized under the CIP-led Sweetpotato for Profit and Health Initiative, a multi-partner, multi-donor effort that delivered improved sweetpotato varieties to an estimated 2.89 million households in 12 SSA countries between 2009 and late 2016, and has a goal of reaching 10 million African households by



125 grams of OFSP meets the daily vitamin A requirement of a child under five. S.Quinn/CIP

2020. RTB adds value to this initiative through its emphasis on gender research, cross-crop learning, results-based planning, and monitoring and evaluation strategies.

Developing and delivering resilient OFSP varieties adapted to African environments and preferences have been major challenges. The first OFSP varieties CIP promoted in SSA were from other regions. Yet it soon became clear that breeding in Africa was essential to develop varieties that were adapted to local conditions, with a flavor and consistency that local people like, and were disease- and drought-tolerant in order to realize high yields. CIP developed an accelerated breeding scheme that has reduced the time from crossing to release from 8 years to 4–5 years. In close coordination with the Alliance for a Green Revolution in Africa, CIP has strengthened the capacities of sweetpotato breeders in 14 national agricultural research systems. CIP now coordinates three regional breeding platforms in SSA and a community of practice that meets annually and shares knowledge, protocols, and technology. National programs breeding sweetpotato in SSA have increased from just two in 2005 to 12 in 2016, resulting in 56 new sweetpotato varieties—40 of them OFSP—being released in nine SSA countries since 2009.

CIP has partnered with the public and private sectors to get biofortified OFSP varieties to farmers and training trainers in vine multiplication and appropriate agronomic practices. At the same time, CIP's branding campaigns and value chain work have opened new markets and established OFSP's reputation as a healthy food. SSA government officials increasingly see OFSP as a crop that can improve nutrition and strengthen food security while helping communities adapt to climate change.

Understanding women's and men's perceptions of the benefits of OFSP

To improve adoption of OFSP, CIP and partners used a social relations approach to examine men and women farmers' perceptions of the benefits of growing OFSP linked to an agriculture–nutrition intervention in the Phalombe and Chikwawa districts in Malawi. Researchers gathered sex-disaggregated data from focus groups with 10 participants each for a total of 178 farmers. Both men and women farmers cited economic and health benefits as key motivations for cultivating OFSP; however, data revealed significant differences between men and women in use of the crop and earnings from its sale. For example, women often trade OFSP roots for other crops to diversify the family diet. The sale of vines as planting material is considered especially financially rewarding, but women's inclusion in vine markets is limited by access to resources (e.g., irrigation equipment), control over household income, and cultural norms that favor the selection of men to participate in projects.

Multi-crop project in Uganda catalyzes postharvest innovations

Harriet Muyinza, a researcher at Uganda's National Agricultural Research Organization (NARO), has confirmed that by pruning certain varieties of cassava a week before harvest, farmers can increase the shelf life of their roots. It is one of a combination of methods for extending cassava shelf life that she learned about during a knowledge-exchange trip to Colombia that CIAT organized for researchers from NARO, IITA, and the International Institute of Rural Reconstruction. Muyinza subsequently tested those technologies in Uganda, in collaboration with IITA, and supported their promotion with local farmers and traders, in order to reduce postharvest losses and improve incomes from the sale of fresh cassava roots.

A researcher from Makarere University in Uganda holds a waxed (back) **and a non-waxed** (front) **cassava root.** S.Quinn/CIP

Cassava has a very short shelf life due to rapid postharvest physiological deterioration, a process that leaves some varieties streaked black and unpalatable within 72 hours. This results in significant income loss for farmers, traders, and retailers—most of whom are women. RTB supported the transfer of technologies for extending cassava shelf life from Colombia to Uganda as part of the Expanding Utilization of Roots, Tubers and Bananas and Reducing Their Postharvest Losses (RTB-ENDURE) project, which tested, validated, and promoted postharvest innovations for banana, cassava, potato, and sweetpotato in Uganda from 2014 to 2016.

Muyinza and other participants in the south-south knowledge exchange also learned about a technology for dipping cassava roots in wax upon harvesting, which can extend their shelf life to up to 30 days. To be most effective, waxing should be applied to undamaged roots, meaning the technology must be combined with appropriate agronomic practices. The technology is commonly used in Latin America but had never been tried in Uganda prior to this initiative. With RTB support, NARO researchers tested the effectiveness of waxing on eight selected cassava varieties grown in Uganda, and confirmed the quality of waxed roots and the willingness of consumers to pay more for them. The project supported the establishment of two pilot centers where roots are waxed for sale in Ugandan supermarkets, and the publication of manuals describing how to set up such packing houses and otherwise improve the postharvest handling of cassava roots.

RTB-ENDURE was funded by the European Union and received technical support from the International Fund for Agricultural Development. The cassava initiative was one of the project's four sub-projects, which established multi-stakeholder partnerships to analyze market opportunities for banana, cassava, potato, and sweetpotato; catalyze public–private partnerships; introduce technologies; and build value chain actors' capacities. CIP postharvest and value chain specialist Diego Naziri, who coordinated RTB-ENDURE, explained that this was accomplished through a step-wise approach that began with scoping studies by multi-agency teams. The teams produced a selection of businesses cases for research on postharvest innovations from which the four best-bets were chosen for two years of funding. He observed that the scoping stage was competitive, but once the four sub-projects were selected for funding, the initiative shifted to a cooperative model. The model promoted cross-crop learning and dialogue, and harmonized methodologies for ensuring gender integration and supporting multi-stakeholder platforms.

> "The strong involvement of the private sector from the onset and attention to evolving consumer preferences helped farmers to access new value chains and ensured that the sub-projects respond to market needs, Naziri said."

In addition to the technologies for extending cassava shelf life, the project produced two other successful innovations that are now being scaled out: a technology to produce pig feed from sweetpotato vines and roots, and an initiative to reduce postharvest losses along the cooking banana value chain and link farmers to better markets.

The short shelf life of cassava results in significant income loss for farmers, traders and retailers. S.Quinn/CIP

Turning sweetpotato vines into animal feed takes off in Uganda

Approximately 17% of Ugandans (primarily women and youth) raise pigs, and feed represents 62–70% of their variable production costs. RTB-ENDURE scaled out the use of a sweetpotato-vine-based silage as pig feed in Uganda, based on prior research in Kenya and Rwanda that showed it could reduce feed costs by up to 40%. CIP collaborated with ILRI, NARO, Makerere University, and other partners to produce manuals, train farmer associations and non-governmental organizations, and help them start business centers that sell silage and offer fee-based training. Those centers trained youth and farmer groups that purchased their own shredders, and linked farmers to markets through Pig Production and Marketing Ltd., which is also promoting silage use. A total of 77 tons of silage was produced during the second half of 2016; interest in the technology continued to grow in early 2017. CIP expects 10% of sweetpotato and pig farmers in Uganda's Masaka, Mpigi, Kamuli, and Mukono districts to adopt the technology.

Sweetpotato foliage can be turned in to silage for pig feed.
N.Palmer/CIAT

Improved banana cultivars and value chain innovations create income opportunities

Cooking-banana is the main staple crop in Uganda, where post-harvest losses claim almost 15% of production, highly seasonal harvests result in low market prices, and middlemen earn a disproportionate share of profits. RTB-ENDURE coordinated cooperative farm and value chain research by Bioversity International, CIRAD, IITA, NARO, government extension officers, and the industry association Uganda Fruits and Vegetables Exporters and Producers Association on innovations to reduce postharvest losses and improve market access while prioritizing gender equity. Results included expanding cultivation of improved varieties with longer shelf life, developing a staggered planting system that allows farmers to harvest fruit outside the peak season, and market testing of differentiated products such as peeled bananas. Varieties with hardy, market-preferred fruit were disseminated via 10 mother gardens and 11 macro-propagation chambers. Several of these are managed by women's groups, whereas two groups began marketing their bananas collectively and sub-county platforms were formed to link more farmers to markets.

A banana exporter in Uganda packs her produce.
S.Quinn/CIP

FLAGSHIP PROJECT 5

IMPROVED LIVELIHOODS AT SCALE

The scaling of innovations lies at the core of achieving RTB's ambitious targets of reaching millions of beneficiaries by 2022. This is precisely the objective of Flagship Project 5 (FP5): to improve livelihoods by scaling RTB solutions in agri-food systems. It builds upon and strengthens the impact of the technologies and approaches developed within the other four flagship projects, tailoring and targeting those innovations within existing agri-food systems while ensuring that they are gender equitable and generate opportunities for youth. The flagship conducts forward-looking analysis of trends and provides decision support tools used to tailor, integrate and scale technologies, based on farmer typologies and practical investment steps.

"Roots, tubers and bananas are important crops that enhance farmer livelihoods in different ways," notes Marc Schut, leader of FP5 and social scientist at IITA. "How depends on the exact geographical location and the related challenges and opportunities for farmers, as well as their production objectives in terms of ensuring household food, income and nutrition security."

A key part of FP5's work on gender in 2016 included analysis and reporting of a global set of case studies conducted by RTB and the CGIAR Research Program on Integrated Systems for the Humid Tropics (Humidtropics) on the way that gender norms affect the pace, quality and effectiveness of agri-food systems innovation, and how innovation processes influence gender. This was part of the GENNOVATE program (Enabling Gender Equality in Agricultural and Environmental Innovation), an unprecedented global research collaboration involving 11 CGIAR Research Programs (CRPs) and nine centers conducting 137 case studies in 26 countries.

RTB has played a leading role coordinating what is the largest cross-CRP collaboration in the CGIAR system. RTB and Humidtropics undertook 24 case studies between 2014 and early 2016 in 10 countries in sub-Saharan Africa (SSA), Asia and Latin America. The study aims to inform the design of RTB research strategies and interventions for more gender-equitable and higher impact adoption and adaptation of technologies and practices.

N. Palmer/CIAT

Assessment reveals that most cassava grown in Vietnam has a CIAT pedigree

Cassava is the third most important export crop in Vietnam, and CIAT has had a major impact on the country's cassava production through nearly three decades of collaboration with Vietnam's national agricultural research systems. An innovative study of cassava diversity in farmer fields in 2016 that combined standard crop adoption survey methods with DNA fingerprinting revealed that the vast majority of Vietnam's farmers grow improved varieties developed using CIAT germplasm, and showed that the country's farmers adopt new varieties more quickly than experts assumed.

While the Vietnamese lowlands are dominated by rice, the local staple, higher land is increasingly dedicated to cassava, 70% of which is converted to starch for export markets at a value of approximately USD1.3-1.5 billion per year. Between 2000 and 2015, the area planted with cassava in Vietnam more than doubled, with approximately 560,000 ha dedicated to the crop in 2015. As the area expanded, yields increased—from approximately 8 t/ha prior to 2000 to 19 t/ha in 2015—thanks to farm mechanization, better agronomic practices and improved varieties.

For a precise assessment of the cassava varieties that Vietnamese farmers are growing, CIAT researchers used a combination of farmer surveys and DNA fingerprinting. CIAT tested this approach with a pilot study in Colombia's Cauca Department, where researchers collected 436 cassava samples from 305 farms in 19 municipalities. DNA analysis of those samples resulted in the identification of 60 main varietal types and 60 unique genotypes that were not represented in CIAT's genebank. Researchers determined that only nine of those 120 genotypes were improved varieties, and that only 20 of the 320 farms surveyed (9.22%) were growing them.

Researchers encountered a completely different situation in Vietnam, where more than 3,700 samples of cassava planting material were collected in 82 farming communities scattered across the country's main cassava production regions. DNA analysis of those samples revealed that 90.62% of the cassava grown in Vietnam is of improved varieties related to CIAT germplasm, and just two varieties, 'KM94' and 'KM419', cover almost 70% of the country's cassava farming area.

According to CIAT's analysis, 31.67% of the cassava area in Vietnam is planted with the variety 'KM94', which was developed at Kasestart University, Thailand, from a cross of CIAT germplasm with a local variety. Originally released in Thailand in 1992 as 'KU50', the variety was subsequently evaluated in Vietnam, where it was released in 1995 as 'KM94'. DNA analysis also revealed that 38% of the country's cassava area is planted with the 'KM419', which was developed using CIAT germplasm by a breeding program that partnered CIAT with several Vietnamese institutions. 'KM419' was chosen through participatory varietal selection and officially released in 2013.

According to Dung Phuong Le, a research associate with CIAT in Vietnam, she and other researchers were surprised to find that 'KM419' was so widely cultivated within just three years of its release, especially since 'KM94' was generally assumed to be the most popular variety in Vietnam. She noted that an expert consultation undertaken prior to the DNA analysis estimated that 'KM94'

Harvesting improved cassava varieties in Dong Nai province, Vietnam. G.Smith/CIAT

occupied approximately 60% of Vietnam's cassava area.

CIAT scientists attribute the rapid adoption of 'KM419' to its high yield (35–45.8 t/ha), high starch content, adaptability, and short duration from planting to harvest. Dung noted that 'KM419' is more popular in southern Vietnam, where farms are larger, most farmers sell exclusively to the starch export market, and farmer incomes are higher.

While providing a more accurate assessment of varietal adoption, the DNA analysis revealed widespread confusion among farmers about which varieties they were growing, and alerted scientists at CIAT's genebank of gaps in their collection. This technology has great potential for improving adoption assessments and the conservation of crop diversity, among other applications.

Predicting the risk of banana pathogen TR4 and returns on investments in controlling it

The highly destructive strain of the Fusarium wilt fungus known as TR4 poses a major threat to banana production. TR4 has been spreading in Asia since 1967, and was detected in Africa in 2013. Scientists from Bioversity International and IITA are working with regional banana networks on responses to the threat. As part of a cross-crop RTB priority assessment exercise, Bioversity International scientists produced an ex-ante estimate of the return to different research options for addressing production losses from TR4.

A comparison of internal rates of return (IRR) on research investments showed high rates of return[1]: (1) improved surveillance and quarantine measures—IRR 13%, for a net present value (NPV) of USD193 million; (2) integrated crop and disease management—IRR 30%; for an NPV of USD505 million; (3) new TR4-resistant banana cultivars—IRR 20%; an NPV of USD187 million; and (4) transgenic TR4-resistant cultivars—IRR 28%; an NPV of USD 137 million.

[1] Based upon a period of 25 years for the return on the investment.

Gender-responsive research training strengthens RTB's work in Africa

To develop and scale out effective new technologies and approaches, RTB researchers need to address the needs and preferences of end users—men and women, young and old. RTB has striven to integrate gender into targeted research areas, particularly breeding, seed systems, and pest and disease management. This effort received recognition in 2016, when three RTB gender researchers served as mentors for participants in the inaugural course of an applied training program called Gender Responsive Researchers Equipped for Agricultural Transformation (GREAT). The course, which focused on RTB crops, began with eight days of training in September 2016, in Kampala, Uganda, where biophysical and social scientists from Bioversity International, CIP, CIRAD, IITA, and an array of national programs learned how to integrate gender into their research.

Participants in the GREAT course.

GREAT is a collaboration of Cornell University and Makerere University, in Uganda, supported by the Bill & Melinda Gates Foundation. Cornell scientist Hale Tufan, who co-leads the initiative with Margaret Mangheni, explained that, "GREAT fellows learn that by identifying, understanding, and acting on gender issues in their research, they can make more informed decisions, build on the real needs and conditions of beneficiaries, and deliver appropriate innovations."

During the September training, GREAT fellows designed gender-responsive research projects in areas ranging from sweetpotato breeding to banana disease management. They then spent four to six months completing field research, with support from mentors assigned by GREAT. Afterwards, they returned to Kampala to analyze and interpret their data during a second session in early 2017.

Anne Rietveld, the RTB gender focal point at Bioversity International, contributed to the course's curriculum and served as a mentor. She observed that the training strengthened participants' ability to use both quantitative and qualitative data, while promoting the integration of biophysical and

social science research. "It was quite holistic, from a research point of view," she said.

Tufan noted that among the skills covered were ways to facilitate group interviews in a gender-responsive manner through group composition, time of day, framing of questions, and moderating discussion. Such details can facilitate the participation of women, and help researchers gain insight into their needs, preferences, and barriers in RTB crop production.

> We feel proud to create opportunities for silent voices to be heard, especially those of women and girls, Tufan said.

Rietveld, who mentored a team of banana researchers in Burundi, was one of three RTB gender researchers who served as GREAT mentors in 2016. CIP gender research coordinator Netsayi Mudege helped a team in Ghana integrate gender into their sweetpotato improvement research, whereas IITA gender researcher Renee Bullock mentored Francois Iradukunda, a Bioversity International systems scientist who manages a project in Burundi that promotes on-farm measures for controlling banana Xanthomonas wilt (BXW).

Iradukunda reported that he took advantage of the GREAT training and mentoring to design research to better understand the gender dynamics of banana cropping systems and how they influence adoption and scaling out of the BXW control measures his team promotes. He explained that he applied methods he had learned in Uganda for convening focus group discussions with 'farmer learning groups' that had already been established to monitor progress at pilot sites in Burundi.

His research confirmed that women have less control over banana production and profits than men, and less access to sources of information such as radio, which hinders their adoption and implementation of BXW control measures. Yet banana forms part of intercropping systems in which women play many roles, so they can have an important impact on efforts to control the disease.

On the basis of the results of his research, Iradukunda will make recommendations for gender-responsive messaging for scaling out BXW control measures. He will also use his findings to develop strategies for minimizing the potentially harmful effects of gender differences in asset control, labor allocation, and income on efforts to manage BXW, and to create more equitable banana farming systems. He added that GREAT changed the way he will conduct research in the future.

> I will ensure that gender aspects are integrated into all my research activities, from planning to implementation, Iradukunda said.

Improved cassava varieties contribute to poverty reduction in rural sub-Saharan Africa

A woman harvests cassava on her farm, Tanzania. H.Holmes/RTB

By partnering with national programs, IITA has contributed to the development and release of more than 40 improved cassava varieties that combine pest and disease resistance with superior postharvest qualities and yield potential. To estimate the impact those varieties have had on smallholder livelihoods, researchers applied a regression model to data from a survey of 1,919 households in Tanzania, Democratic Republic of Congo, Sierra Leone, and Zambia. The model showed an approximately 10% reduction in poverty among adopters. Given an adoption rate of 34%, this implies that an estimated 24,309 households (equivalent to 194,469 individuals) in the districts studied rose out of poverty, with a greater reduction in poverty among female-headed households. This implies that, controlling for the differences in household characteristics, female-headed households may relatively benefit more than male-headed households from improved cassava varieties.

Gender matters in cassava technological innovation: lessons from GENNOVATE Vietnam

Cassava has experienced major growth as a boom commodity in Vietnam, being produced on an industrial scale to meet a growing national and global demand for starch, animal feed and biofuel. Responding to this demand, research has typically focused on technologies such as high-yielding varieties, better fertilization, integrated pest management, new intercropping options and more efficient processing equipment. However, the different practical interests of men and women users of these technologies, and the social and gender constraints and incentives they face, are rarely considered in agricultural research for innovation.

A cassava farmer in Quang Binh province, Vietnam, where the GENNOVATE study took place. J.Newby/CIAT

As part of GENNOVATE, a global effort by CGIAR Research Programs and centers to understand how agricultural innovation shapes and is shaped by gender roles and norms, an RTB case study was conducted in a cassava farming village to explore gender dimensions of cassava production and processing.

The case study revealed that women work as much as men on cassava and likewise have just as deep knowledge of the crop as well. Women were found to be creative farmers, conducting their own experiments to find the best planting intervals and the best angle to cut cassava stems for planting material, which affects the ease of rooting. They also use local social networks to increase labor use efficiency via exchange work with other women. This creative innovation by women relies on internally available resources, while wealthy men invest in new cassava technologies introduced by external agencies. These men have the freedom to take financial risks and furthermore they have strong social connections with government and the private sector.

Women's dependence on internal resources for innovation is nevertheless further constrained by the possibility of the husband's disapproval. This was the top factor they identified during focus group discussions that prevented the implementation of their preferred innovation. Both men and women perceive that men are 'the pillar of the house' who should make major decisions. As a result, women's interests in cassava, such as labor-saving technologies and utilization for feeding domestic animals, are often not included in the priorities of cassava research and interventions undertaken by the government and research institutions.

Exploring gendered interests and social constraints is the first step to facilitate more inclusive and effective agricultural and institutional innovation.

KNOWLEDGE PRODUCTS

28
Open Access databases maintained

148,790
Total number of users of these open access databases

121
Publications in ISI journals
20 Banana, 43 Cassava, 23 Potato, 11 Sweetpotato, 15 Yam, 9 Multiple crops

43
Technologies or Natural Resource Management practices released by public and private sector partners globally

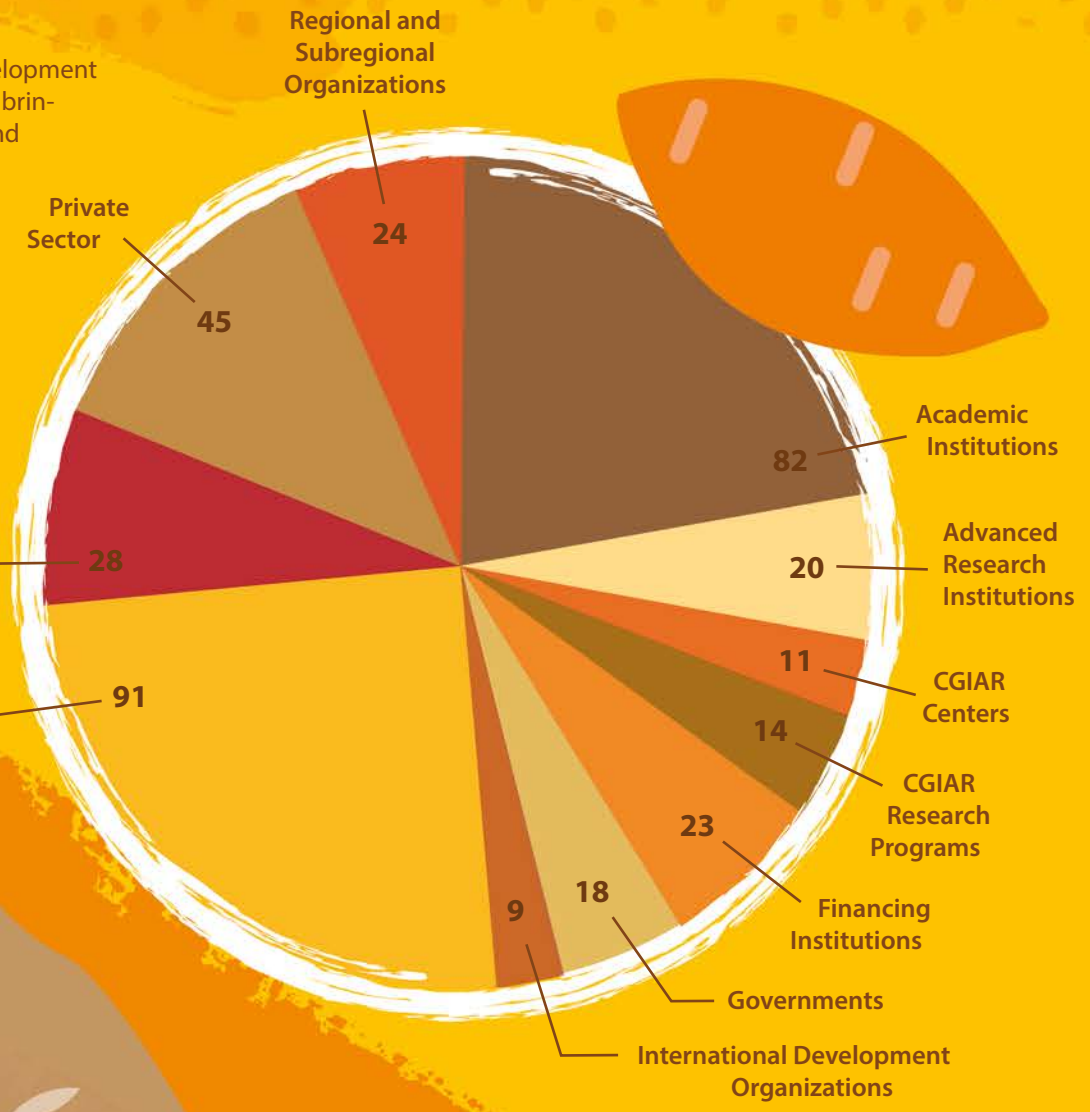
64
Tools produced by the program

9
Strategic value chains analyzed

RTB PARTNERS

Partnership is central to international agricultural research for development precisely because collaboration mobilizes research results through bringing together diverse actors at international, regional, national and local levels. Partnerships are crucial for RTB's success and form an intrinsic part of the theories of change which make outcomes possible, with the scale and scope of partnerships changing along the research to the development continuum.

In 2016, RTB worked with 366 formally established partners, including private sector, national agricultural research organizations, advanced research institutions, academic institutions, governmental and non-governmental organizations. Innumerable community based organizations and farm households not individually listed here were also central to the program's success.



RTB DONORS

African Development Bank

Australian Centre for International Agriculture Research

Bill & Melinda Gates Foundation

Cornell University

Department for International Development

Deutsche Gesellschaft für Internationale Zusammenarbeit

Donald Danforth Plant Science Center

Food and Agriculture Organization of the United Nations

Friedrich-Alexander-Universität Erlangen-Nürnberg

Government of Belgium

Government of Liberia (Ministry of Agriculture)

Government of Netherlands

Government of Odisha

Government of Switzerland

Government of Tanzania (Ministry of Agriculture, Food Security and Cooperatives)

Government of Uganda

Government of Zambia

International Bank for Reconstruction and Development

International Development Research Center - Canada

International Fund for Agricultural Development

Irish Aid

North Carolina State University

Programa Nacional de Innovacion Agraria – Government of Peru

Syngenta Crop Protection Ag

United States Agency for International Development

Universidad Nacional De Colombia

University of Greenwich

FINANCIAL REPORT

RTB started 2016 with an allocated Window 1&2 (W1&2) budget of USD17.0M, which was adjusted during the year to USD14.2M after funding cuts in November.

The total 2016 budget for the program was USD92.4M: USD14.2M (15%) from W1&2, and USD78.2M (85%) from W3, bilateral funds and RTB participant centers' own funds.

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.

2016 EXPENDITURE

Total expenditures in 2016 were USD84.9M, or 92% of the budget, of which USD14.1M (17%) is from W1&2, and USD70.8M (83%) from W3, bilateral and centers' other funds. W1&2 expenses reached 99% execution of the revised budget and W3, bilateral and centers' other funds expenditure, reached 91% execution. Expenditure for gender research was USD6.5M, representing 8% of RTB total expenditure in 2016.

The chart below shows the W1&2 budget and expenditure by flagship and the management expenditure of USD1.5M. RTB had an average execution of 99% of each flagship budget.

FLAGSHIP 2016 W1&2 BUDGET VS EXPENDITURE (USD MILLIONS)

Flagship W1 & 2	BUDGET						
	Bioversity	CIAT	CIP	IITA	CIRAD	PMU	TOTAL
FP1 : Enhanced genetic resources	0.61	0.28	0.68	0.39	0.10	0.41	2.49
FP2 : Productive varieties and quality seed	0.47	0.65	1.50	0.95	-	-	3.57
FP3 : Resilent crops	0.85	0.24	0.70	0.87	0.28	-	2.94
FP4 : Nutritious food and added value	0.04	0.42	0.03	0.35	0.44	-	1.28
FP5 : Improved livelihoods at scale	0.45	0.04	0.65	0.04	-	-	1.17
CRP management/coordination	0.03	0.03	0.04	0.03	-	1.39	1.53
Gender research	0.20	0.16	0.62	0.23	-	-	1.22
Total	**2.66**	**1.84**	**4.22**	**2.86**	**0.82**	**1.80**	**14.20**

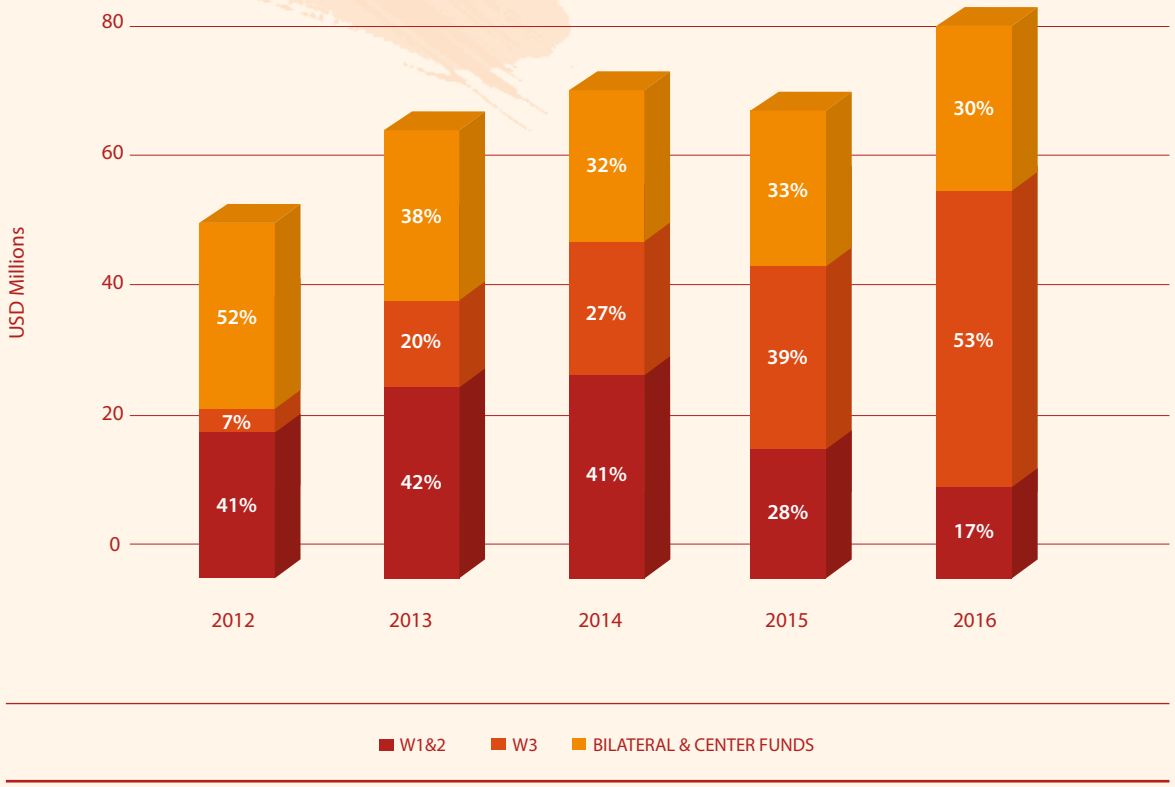
Flagship W1 & 2	EXPENDITURE						
	Bioversity	CIAT	CIP	IITA	CIRAD	PMU	TOTAL
FP1 : Enhanced genetic resources	0.61	0.36	0.73	0.38	0.10	0.26	2.44
FP2 : Productive varieties and quality seed	0.47	0.56	1.50	0.98	-	-	3.51
FP3 : Resilent crops	0.85	0.27	0.70	0.86	0.28	-	2.96
FP4 : Nutritious food and added value	0.04	0.39	0.03	0.35	0.44	-	1.25
FP5 : Improved livelihoods at scale	0.45	0.05	0.65	0.03	-	-	1.18
CRP management/coordination	0.03	0.04	-	0.03	-	1.44	1.54
Gender research	0.20	0.16	0.62	0.22	-	-	1.20
Total	**2.66**	**1.84**	**4.22**	**2.85**	**0.82**	**1.70**	**14.08**

RTB 2012 -2016

The distribution of budget by funding sources shows a declining contribution of W1&2 over time, falling from 44% in 2012 to 15% in 2016 – with a respective increase in W3 and bilateral funds, from 56% to 85%, in the same period.

The spending trend of RTB presented an overall increase of 55% in expenditure (USD84.9M in 2016 vs. USD54.6M in 2012) The cumulative expenditure reached USD355.0M over the five years of the program (USD116.0M from W1&2, and USD239.0M from W3, bilateral and center funds).

RTB EXPENDITURE 2012-2016



ACRONYMS

A4NH	CGIAR Research Program on Agriculture for Nutrition and Health
BBTD	Banana bunchy top disease
BXW	Banana Xanthomonas wilt
CBSD	Cassava brown streak disease
CIAT	International Center for Tropical Agriculture
CIP	International Potato Center
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CWB	Cassava Witches' Broom
DNA	Deoxyribonucleic acid
FAO	Food and Agricultural Organization of the United Nations
FP	Flagship project
GBS	Genotyping by sequencing
GREAT	Gender Responsive Researchers Equipped for Agricultural Transformation
GWAS	Genome-wide association study
IRR	Internal rates of return
IITA	International Institute of Tropical Agriculture
MAS	Marker-assisted selection
MGIS	Musa Germplasm Information System
NARO	National Agricultural Research Organization of Uganda
NARS	National Agricultural Research Systems
NGOs	Non-governmental organizations
NPV	Net present value
OFSP	Orange-fleshed sweetpotato
PPD	Postharvest physiological deterioration
PPM	Parts per million
PVS	Participatory varietal selection
QTLs	Quantitative trait loci
RAB	Rwanda Agricultural Board
RBM	Results-based management
RHUL	Royal Holloway University of London
RTB-ENDURE	Expanding Utilization of Roots, Tubers and Bananas and Reducing Their Postharvest Losses (project)
SASHA	Sweetpotato Action for Security and Health in Africa
SDSR	Single diseased stem removal
SSA	Sub-Saharan Africa
TIBS	Temporary immersion bioreactor systems
TMS	Tropical Manioc Selection
UAV	Unmanned aerial vehicle
UFVEPA	Uganda Fruits and Vegetables Exporters and Producers Association
VAD	Vitamin A deficiency
XRF	X-ray fluorescence technology

See the interactive website
www.rtb.cgiar.org/2016-annual-report

ABOUT

The CGIAR Research Program on Roots, Tubers and Bananas (RTB) is a broad alliance 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.

@rtb_cgiar www.facebook.com/rtbcgiar

LED BY CIP INTERNATIONAL POTATO CENTER A CGIAR RESEARCH CENTER

Bioversity International

CIAT Centro Internacional de Agricultura Tropical International Center for Tropical Agriculture

cirad AGRICULTURAL RESEARCH FOR DEVELOPMENT

IITA Research to Nourish Africa