ANNUAL REPORT 2018

CGIAR

RESEARCH PROGRAM ON Roots, Tubers and Bananas

Making an Impact

Making an Impact
RTB Annual Report 2018
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 Trust Fund: http://www.cgiar.org/funders

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Press run: 300
September 2019

Correct citation
RTB. 2018. Making an Impact. Annual Report 2018. Lima (Peru). CGIAR Research Program on Roots, Tubers and Bananas.
Available online at: www.rtb.cgiar.org/2018-annual-report

ISSN: 2308-5932
DOI: 10.4160/23085932/2018
Hecho el Depósito Legal en la Biblioteca Nacional del Perú
No 2018-13810

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Printed by Tarea Asociación Gráfica Educativa.
Pasaje María Auxiliadora 156-164 Breña, Lima-Perú

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Innovations

90

Innovations reported in genetic (variety and breeds), biophysical, social science, production systems, management practices, and communication methods research areas.

Capacity development activities

86,499

Participants in short-term trainings and scaling activities.

222

Trainees involved in academic programs (BSc, MSc, PhD).

Outcome cases facts

2.93

Million households in 7 South and Southeast Asian countries are cultivating CIP-related potato varieties that represent 19% of the total area planted to improved varieties.

2.7

Million ha in 9 South and Southeast Asian countries are grown using CIAT-related cassava varieties.

10

Policies and regulations in the agriculture and nutrition sector developed and adapted based on scientific evidence provided by RTB Program participants.

Foreword

In 2018 we saw the fruits of restructuring the CGIAR Research Program on Roots, Tubers and Bananas (RTB) around well-defined and impactful flagship projects for Phase II. That was evident at our annual meeting in Cali which showed the passion for great science, a coming together around key crosscutting topics such as gender, scaling, seed systems and breeding, and the commitment of our scientists and partners to achieving impact.

This report, like last year's, is organized by our flagship projects; the highlights reported include: peering into the genomes of the tricky RTB crops, where breeders used innovative genomics tools to enhance future breeding; using network analysis to prevent seed-borne disease, where researchers have developed models to understand fast-changing seed systems; water management in potatoes, because conserving water is important for adapting to climate change; turning cassava peel waste into high quality animal feed and considering gender norms in controlling banana disease in the East African Highlands.

RTB is increasingly recognized as a well-run CGIAR Research Program that adds value to the work of its collaborating centers and partners, contributing to the many successful outcomes and impacts reported throughout this report. Our aim is to build on this tradition of excellence as we strive to ensure that the vitally important but still often neglected crops of RTB receive the recognition they deserve.

We thank all our partners and donors whose outstanding contributions have made these achievements possible.

Barbara H. Wells
CIP Director General

Graham Thiele
RTB Program Director

RTB at a glance

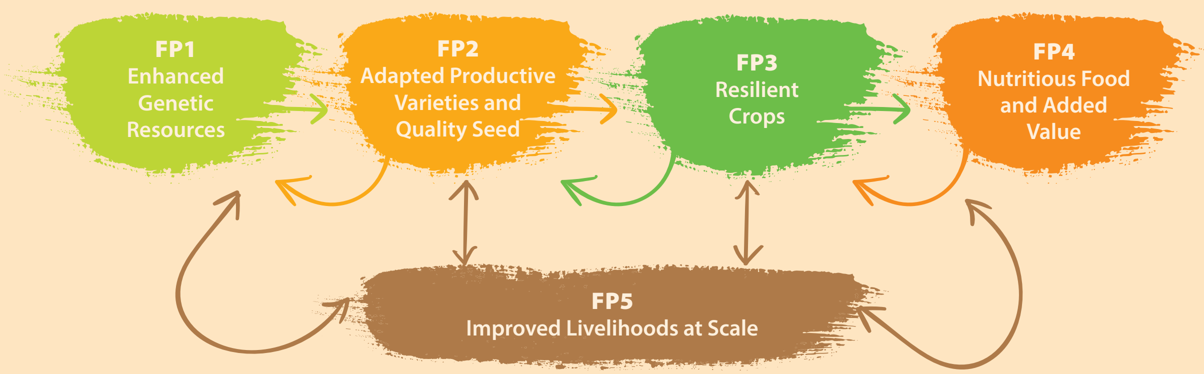
The CGIAR Research Program on Roots, Tubers and Bananas (RTB) was launched in 2012 to harness the untapped potential of banana (including plantain), cassava, potato, sweetpotato, yam, and other root and tuber crops to improve food security, nutrition and livelihoods. RTB brings together the expertise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

In 2018 RTB was consolidating research 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. Each flagship is composed of a set of interrelated research 'clusters' which have clear impact pathways through which RTB centers and their partners collaborate to achieve targeted outcomes. The areas of focus for each of the clusters were identified through an RTB assessment to determine the options with the greatest potential for impact.

The nested impact pathways at the cluster and flagship project levels are at the heart of the program's results-based management. A monitoring and evaluation system, aligned with the overall CGIAR performance management framework, has been developed and its implementation is facilitated through MEL, an online planning, monitoring, evaluation, and learning platform, collaboratively developed with several CRPs and centers.

In 2018 RTB maintained collaboration with 381 partners, primarily national agricultural research organizations, academic and advanced research institutions, private companies and nongovernmental organizations (NGOs). These valuable partnerships played an increasingly important role in this second phase as the program works to scale out the technologies and approaches developed under its flagships. RTB sought to accelerate the scaling of innovations linked with capacity development for partners, while ensuring that research benefits women and men alike and engages youth. Together, RTB and its broad network of partners worked to achieve the program's intermediate development outcomes – which are fully aligned with the Sustainable Development Goals – by 2022.

Flagship projects



Sustainable Development Goals	Selected RTB Program targets (2022)
1 No Poverty; 3 Good Health and Well-Being; 5 Gender Equality; 8 Decent Work and Economic Growth; 10 Reduced Inequalities; 17 Partnerships for the Goals	**20 million** people (50% women) increased their income **30,000** small and medium enterprises operating profitably in the seed and processing sectors **8 million** farm households increased yield through the adoption of improved varieties and sustainable management practices
1 No Poverty; 2 Zero Hunger; 3 Good Health and Well-Being; 5 Gender Equality; 6 Clean Water and Sanitation; 10 Reduced Inequalities; 12 Responsible Consumption and Production; 17 Partnerships for the Goals	**10 million** people (50% women) have improved their diet quality
2 Zero Hunger; 5 Gender Equality; 6 Clean Water and Sanitation; 12 Responsible Consumption and Production; 13 Climate Action; 15 Life on Land; 16 Peace, Justice and Strong Institutions	**1.9 million** ha of current RTB crops production area converted to sustainable cropping systems
5 Gender Equality; 10 Reduced Inequalities; 13 Climate Action; 16 Peace, Justice and Strong Institutions; 17 Partnerships for the Goals	**At least 2 million** households have increased capacity to deal with climate risks and extremes **9,500 individuals** (50% women) in partner organizations have improved capacities **At least 5 partnership** and scaling models tested in a minimum of 5 target countries

Flagship 1
Enhanced genetic resources

Flagship Project 1 (FP1) is developing leading-edge science for more efficient breeding of user-demanded root, tuber and banana varieties, while overcoming the limitations of conventional breeding for vegetatively propagated crops. Plant breeders are using new genomic tools across the RTB Program being developed in collaboration with top universities and research centers around the globe. This strategic investment will allow RTB breeders to quickly combine favorable traits, now spread across dozens of breeding lines, to develop new varieties that are more acceptable to consumers, with better nutritional value, higher yield and resistance to shifting pests and diseases in a changing climate. "The new tools developed by RTB allow the best use of the untapped genetic resources, genetic markers and other latest techniques, making it possible to get farmers the varieties they need much faster," says Luis Augusto Becerra, FP1 leader and principle research scientist at CIAT.

FP1 also contributes to enhancing the conservation and use of genetic diversity. So, these new tools are being used to characterize the genetic variability in genebank collections as well as the diversity maintained in farmers' fields.

Peering into the genomes of the tricky RTB crops

Cutting-edge tools are helping shorten expensive breeding programs. New kinds of marker-assisted selection allow breeders to see the genes of plants before growing them. Across the RTB Program, breeders are using new genomics tools to enhance the breeding of tomorrow's crops.

RTB crops are especially difficult to breed. For example, potatoes, sweetpotatoes, yams and bananas have polyploidy (more than two sets of chromosomes—often from slightly different ancestors), giving them complex genetic structures and making them hard to breed. As a further complication, there are multiple species of banana, yam and potato. As these crops are vegetatively propagated, they are slower to breed and to bulk up seed.

Genomics-assisted breeding can help to overcome these challenges. Luis Augusto Becerra, FP 1 leader, noted that "genetic tools make it possible for breeders to see into the genetic makeup of a plant before growing it in the field. This helps us to save time and money, and it accelerates breeding."

Therefore, across the RTB Program, scientists and breeders are developing tools so that genomics-assisted breeding can be implemented in the various breeding programs. Michael Friedmann, RTB science officer, explained, "RTB scientists are making great progress in developing genomic tools across the RTB Program. RTB is bringing together scientists and breeders to create synergies, develop new genetic methods, and enhance the efficiency of crop breeding." Friedmann recently coordinated the publication of a study in a special edition of the journal *Agriculture,* which tracked this progress in using the tools across the RTB Program.

Two of the most important new tools are genome-wide association studies (GWAS) and genomic selection (GS). GWAS is a form of marker-assisted selection in which thousands of genetic markers spread across the genome are used to identify molecular markers close to genes that are associated with desired traits, with a view towards accelerated breeding. Therefore, scientists across the RTB Program have been taking the steps necessary to develop the genomic resources to carry out GWAS and GS. They have participated in the sequencing of reference genomes for all the crops. Populations with individual plants differing in the levels of important traits have been developed, their DNA sequenced and the relevant traits measured. This information has been used to carry out GWAS to tag complex traits with molecular markers for cassava, banana, sweetpotato, potato and yam. Sets of markers are now being characterized for many important traits, ranging from higher yield, biotic and abiotic stress tolerances and quality traits. For example, GWAS was applied to evaluate the existence of cassava green mite (CGM) resistance alleles in 845 advanced breeding lines. The study detected 35 genetic markers in the cassava genome. Seventeen candidate genes were found to be associated with CGM resistance, potential sources to develop pest-resistant cassava.

GS does not rely on individual molecular markers to select for traits, but rather uses the genome sequence information of an individual to predict the traits, by first developing predictive models on a training population that is both sequenced and characterized for the traits of interest. Then, new individuals are selected for a trait such as yield, based on their sequence information, that is fed into the models. RTB scientists have begun to develop and characterize these training populations and are exploring different models and strategies for the best predictive values. Consequently, models with high predictive values for banana fruit filling and fruit bunch traits were identified, showing the potential of genomic prediction to increase selection efficiency in banana breeding. Likewise, GS studies in cassava were used in Uganda to predict tolerance to cassava brown streak disease (CBSD) for 35 West African clones, based only on their sequence information. This was particularly important, since this severe disease has not reached West Africa yet, and so, breeding material in West Africa cannot be screened for tolerance to the virus.

Therefore, genomic tools can aid in the selection of superior genotypes, especially in relation to complex traits, which will result in increased genetic gains in the breeding programs. As RTB crops share complex genomes, advances in one crop can help inform strategies for the other crops. By bringing together breeders and molecular biologists, RTB is facilitating the implementation of genomics-assisted breeding across its target crops. By developing an overall framework for tracking progress in the use of these tools we can guide their uptake and use.

Crop	Trait Category	QTL	GWAS	GS	Molecular markers	Diagnostic
Banana/plantain	Yield			Validation		
	R to pests & diseases	Discovery/proof of concept		Validation	Validation	Available for uptake
	Fruit quality	Discovery/proof of concept	Validation	Validation		
Sweetpotato	Yield	Discovery/proof of concept				
	R to pests & diseases					
	Storage root quality	Discovery/proof of concept				Available for uptake
White Yam	Yield					
	R to pests & diseases	Validation	Discovery/proof of concept		Discovery/proof of concept	Validation
	Tuber quality		Discovery/proof of concept			
Potato	Yield		Validation			
	R to pests & diseases		Validation		Available for uptake	Available for uptake
	Tuber quality					Discovery/proof of concept
Cassava	Yield			Discovery/proof of concept		
	R to pests & diseases	Available for uptake	Available for uptake	Validation	Validation	Available for uptake
	Storage root quality	Validation	Available for uptake	Validation	Available for uptake	Available for uptake

Progress in the development of genomic tools in RTB breeding programs • R = Resistance

Discovery/proof of concept | Validation | Available for uptake

Molecular markers save time and money for evaluating virus resistance in potato breeding

Breeding potatoes for disease resistance can be costly. A recent study shows that compared with the conventional approach, the use of molecular marker analysis allows breeders to evaluate virus resistance twice as fast, while saving nearly 90% of the cost.

Hannele Lindqvist-Kreuze, a molecular breeder at CIP in Lima, Peru, is part of a team that has shown how molecular markers can be used to cut costs in plant breeding. By using molecular markers to identify virus resistance in potato plants, plant breeders can cut costs by 88%, compared with conventional methods. "We are constantly looking for ways to improve the efficiency of the potato breeding program at CIP, and marker-assisted selection (MAS) is certainly a great tool to take us faster towards the goal of increased genetic gains in the farmers' fields," says Lindqvist-Kreuze.

The conventional method of evaluating resistance to PLRV (potato leafroll virus) and potato virus Y involves several steps of tedious, painstaking work. To confirm the results, the potato plants also have to be screened for viruses using serological tests for the antibodies in a lab. Moreover, the virus resistance assays require several plants of the same type which have to be producing tubers or they have to be propagated by cuttings (i.e., bigger, older plants). The whole procedure can take 105 days.

With the new, alternative method, molecular markers are used to identify the genes that are known to confer resistance to disease. These genes can be assayed from a single leaf of a young plant, by isolating the DNA and assessing it for the presence or absence of the genes. The procedure can be accomplished in just 50 days and the resistance to both viruses can be tested at once, from the same sample. The costs of using the conventional phenotyping method was USD68.80 per plant, versus just USD8.00 for molecular markers. Costs could be lowered even further using a high-throughput genotyping system, if many samples are assayed at once.

Therefore, much time and money can be saved by using molecular marker analysis. Conventional phenotyping costs over eight times as much money and takes twice as long, and requires more screenhouse space and expensive serological and other tests to check for disease resistance. Although molecular markers are frequently asserted to be efficient, Lindqvist-Kreuze and her team provide actual numbers to confirm such claims. In the future, breeders will be able to select resistant genotypes and cross them earlier in the breeding cycle.

Unraveling the sweetpotato's genetic structure to speed up breeding

CIP scientists made key contributions to a pathbreaking study of two of the sweetpotato's nearest relatives which helps to unravel the complex genetic structure of the sweetpotato itself. Mapping the genome of these two sweetpotato relatives, led by the Boyce Thompson Institute at Cornell University, provides high-quality references for the sweetpotato. The study also resequenced 16 genotypes of sweetpotato widely used in CIP's African breeding programs, to identify genes that will help breed varieties with high vitamin A content

The sweetpotato has a large and complex genetic structure, with six sets of chromosomes and some 1.6 billion base pairs (half as many as humans). As an added twist, many genes are heterozygous. Because of this complexity, sweetpotato breeders have not had a good reference guide to the sweetpotato genome, making it difficult to apply genomic tools to enhance sweetpotato breeding. But a 2018 paper published in the journal *Nature Communications* sheds crucial light on the sweetpotato's genes.

The sweetpotato (*Ipomoea batatas*), a member of the morning glory family, is closely related to the wild species *Ipomoea trifida* and *Ipomoea triloba*. These two species are similar to the sweetpotato in flower, vine and leaf, but without the edible roots. Another crucial difference is that both of the wild relatives have just two sets of chromosomes, like humans, but unlike the sweetpotato with its six sets of chromosomes.

For years, researchers have wondered if either of the wild species could be the ancestor of the sweetpotato. The *Nature Communications* article reveals that both may be. Most of the sweetpotato's genes (84%) are also found in these two close relatives, but the sweetpotato shares 5.4% of its genes uniquely with *Ipomoea trifida*, and 3.4% only with *Ipomoea triloba*. This means that the sweetpotato probably has a mixed ancestry.

The *Nature Communications* paper reports on a complete analysis of the two wild *Ipomoea* species and of 16 sweetpotato varieties, a collection better known as MDP (Mwanga Diversity Panel), named after Robert Mwanga, the CIP sweetpotato breeder awarded the World Food Prize. Comparing the 16 varieties with the two wild *Ipomoea* genomes made it possible to find genetic markers which can help to locate genes associated with flesh color and other important traits.

To support this research, CIP's role was to provide crucial populations and data to enhance the development of fully functional reference genomes that are representative of CIP's target breeding programs. Among the populations provided by CIP are the *I. trifida* bi-parental mapping population that was used to anchor (assign chromosome positions using a genetic linkage map) to the reference genomes. Additionally, RNA from different experiments was provided to support annotation (identifying position and functions of genes) and access to the crucial 16 varieties.


Farmers planting OFSP.
H. Rutherford/CIP

Until now, most orange-fleshed sweetpotato (OFSP) varieties have been high in vitamin A but low in dry matter, which has contributed to limited adoption of new varieties. This research may help sweetpotato breeders to come up with sweetpotatoes that are high in vitamin A and starch that would provide a more nutritious and acceptable crop for African farmers and consumers. "However, CIP's main role in supporting the tool development process is the interest to apply the tools, being the main applied research partner in this important collaboration. We have already started to apply the reference genomes and other novel analytical tools to answer our research questions such as understanding the negative association between starch and beta-carotene content, which is an important contributor to poor adoption of most OFSP in Africa, for example," says Dorcus Gemenet, research scientist at CIP.

Good quality reference genomes and other data analytical tools can thus enhance practical applications of genomics in breeding programs. As remarked by Mwanga, "the high-quality reference genomes allow us to tease out the genetics of important traits that are difficult to target together and can provide us with molecular tools to facilitate breeding for several such desired traits."

Good-bye banana streak virus

The banana streak virus (BSV) is integrated in the B genome of the plantain. So, if the plantain parents are used for breeding, the BSV genes are contained within the new variety. Recently, scientists have found a way to disable the virus in the plantain's genome, allowing new opportunities to improve the hardy plantain and develop hybrids.

Plantains are resistant to major diseases and other stresses. They also have a good root structure. Plantains would be ideal to use in plant breeding, except for one problem; they can contain a pathogenic virus (BSV) inserted right into the B genome of the plantain.

Domesticated bananas come from two banana species: *Musa accuminata* (AA) and *M. balbisiana* (BB). Plantain varieties are AAB, that is, they have two sets of chromosomes from *M. accuminata* one set from *M. balbisiana*. The BSV virus is integrated as multiple copies at a single locus of the B genome of *M. balbisiana* and its derivatives, including plantains.

The virus is often latent, producing no symptoms, only to flare up under stresses such as drought or even while the banana plants are being reproduced by tissue culture (which is important for eliminating other types of virus). The BSV symptoms include yellow streaking of the plant leaves, stunting, dark blotches and splitting of the trunk (pseudostem). The bunches are smaller, and the plant can even die.

Because BSV is incorporated into the B genome, when the parents with B genome are used in crop breeding, they pass the virus along to the new varieties. This has been a major drawback for plantain breeding and for disseminating hybrids. A method was needed to disable the virus from the genome of parents used for plantain breeding.

In 2018, a team led by Leena Tripathi at IITA in Nairobi used gene editing technology (CRISPR/Cas9) to disable the BSV virus from the plantain's chromosome. "The breeding lines can be improved by inactivating the integrated BSV with genome editing and these breeding lines can then be used to develop plantain hybrids with no risk of activation of functional virus," says Tripathi, principal scientist in plant biotechnology at IITA.

The team grew eight edited plants in the glasshouse and subjected them to drought stress. Six of these plants showed no symptoms of BSV. Genetic analysis confirmed that all copies of the integrated BSV had been mutated into non-functional forms. The BSV virus on chromosome B was no longer pathogenic.

The edited plants still need to be tested in the field for a number of generations, to ensure that they do not become re-infected. Before these new plantains can be used, they will need to pass through the national biosafety committees which manage genetically modified and gene-edited crops.

This is the first report of the successful knockout of endogenous virus DNA from a host plant genome. This pioneering study paves the way for breeding programs to improve the plantain, and to allow the genes from this robust plant to be crossed with other types of bananas and the resulting hybrids shared and disseminated.

Leena Tripathi and team looking at the genome-edited banana plants in the laboratory. M. Adero/IITA - Kenya

Flagship 2

Adapted productive varieties and quality seed

Flagship Project 2 (FP2) focuses on breeding better varieties and making sure that they match the needs and preferences of farmers and consumers, women and men. FP2 also strengthens the seed systems that get these varieties into farmers' hands. Farmers' and consumers' demands for new traits must be communicated back to breeders, so that the varieties now in the pipeline will be well-received when they are released. "It is essential to bring the farmers' criteria and preferences on board as early as possible in a breeding program. This makes sure that the new crop varieties developed by our plant breeders are the ones that farmers need. Now the emphasis is not on the number of varieties released, but on how well the variety meets all requirements of end users and making sure they get into use. This is crucial for improving nutrition in developing countries," says Maria Andrade, FP2 leader, plant breeder at CIP, and World Food Prize winner.

Tracking adoption of improved varieties of RTB crops in Asia

CIP social scientists met with agricultural experts from the top nine Asian potato- and sweetpotato-growing countries to estimate the adoption of improved potato and sweetpotato varieties. In these countries, 97% of the potato area is planted with improved varieties, and 19% of this land is in CIP-related varieties. For sweetpotatoes, 88% of the area is planted with improved varieties. Farmers in nine Asian countries have also accepted improved cassava varieties; 83% of the crop is of improved varieties. CIAT has contributed to the development of most of the cassava varieties released in Asia.

Plant breeding can help to improve the livelihoods of smallholder farmers in Asia, but tracking the adoption of improved crop varieties is challenging. To cover this vast continent, CIP researchers needed a less expensive alternative to large surveys, says agricultural economist Marcel Gatto. Between 2014 and 2016, they met with several hundred breeders, extension agents, crop and seed experts (347 for potato and 228 for sweetpotato) in 41 workshops using a method known as expert elicitation to estimate adoption rates. Seven potato-producing countries were selected: Bangladesh, China, India, Indonesia, Nepal, Pakistan and Vietnam. The sweetpotato-producing countries were Bangladesh, China, India, Indonesia, Nepal, Papua New Guinea, Philippines and Vietnam.

They found that 168 CIP-related potato varieties had been released, of which 63 (30%) were adopted. In the selected countries, potatoes are grown on 7.6 million ha of which almost all (97%) is planted with improved varieties. Of this, 19% is cultivated with CIP-related varieties, benefitting about three million households in China, India and Nepal. Varieties developed by CIP with NARS (national agricultural research systems) account for 25% of the total potato area in China, and 34% in Nepal, but little in India, Indonesia, Vietnam, or Bangladesh, and none in Pakistan. The low adoption of CIP-NARS varieties in Bangladesh is puzzling, because 16 of these varieties were released during 1990-2014.

The top-ranked variety from China, Kexin No. 1, a NARS variety, covers almost 10% (700,000 ha) of the total area planted in potatoes in the selected countries. The Indian early-maturing variety, Kufri Pukhraj, also a NARS variety, is grown on 510,000 ha. "One of CIP's biggest successes is Cooperation 88," explains Gatto. Cooperation 88 is a CIP-NARS variety that is resistant to late blight; it is planted on just 164,000 ha. However, when taken together, the 10 main CIP-NARS varieties cover over a million ha, much of it in China. "The CIP-related varieties are increasingly popular," says Gatto. But he also adds that "little is known about the enabling environment which has brought about these successes." Clearly, more research is needed to better understand how varieties become a runaway success.

NARS have released 434 improved sweetpotato varieties in the study countries. China has contributed most of these, with few releases in the other countries, except for Papua New Guinea, which reintroduced promising landraces. By 2015, Asian farmers had adopted 195 improved sweetpotato varieties, including 27 related to CIP. Some 88% of the area (3.6 million ha) in the study countries is planted with improved varieties, including 5% with CIP-related ones.

Access to credit and fertilizer can improve adoption of improved varieties. G. Smith/CIAT

Using the same expert elicitation method, the International Center for Tropical Agriculture (CIAT) collaborated with partners in nine countries in Asia to document the adoption of cassava varieties. Cassava experts from Vietnam, Thailand, Cambodia, Laos, Myanmar, The Philippines, Indonesia, China and India met in country workshops to estimate adoption.

In the nine countries, improved varieties cover 82.7% of the land planted to cassava (4.1 million ha). CIAT has participated in the development of most of the cassava varieties released in Asia; 2.7 million ha (65% of the area with improved material) is planted with CIAT-related varieties. In Vietnam over 90% of cassava land is planted with one of 85 improved varieties. A follow-up study looking at cassava varietal adoption in Vietnam using DNA-fingerprinting confirmed that improved varieties dominate cassava production.

Vietnamese farmers are especially likely to use improved varieties if they have credit and if they use more fertilizer. In countries where cassava is mainly grown for industrial products like starch, almost all of the cassava is improved. The plant breeding efforts by CIAT and its partners are paying off. The new cassava varieties and their industrial markets have generated great opportunities for improving the income of smallholder families in the region.

Revolutionizing sweetpotato breeding by exploiting hybrid vigor

Genetic studies allow breeders to identify sweetpotatoes that are more genetically distant, in order to separate them into different groups. Crossing genetically distant parents from the separate groups leads to offspring that have much higher "hybrid vigor" or heterosis. In other words, the offspring are dramatically superior to the parents in key traits such as yield, yield stability, stress resistance and earliness.

In sub-Saharan Africa, plant breeders are developing more nutritious sweetpotato varieties, especially those that are rich in vitamin A and ones that have more iron but also give higher yields. The large and heterogeneous genome of the sweetpotato makes this a challenge. Traditional sweetpotato breeding has involved hand crossing two lines to obtain true seed, which is then planted. Each individual plant that is grown from the true seed is potentially a new sweetpotato variety. Many parents are crossed at once and their offspring are grown and evaluated over generations, to painstakingly select the best lines. These lines which may then be crossed with each other and their progeny for more generations, until a new, improved variety is finally chosen for release to farmers.

In spite of all this work, the results can be disappointing if the parental plants are too similar genetically to begin with. Ideally, breeders want to start by crossing sweetpotato varieties which are genetically different from each other so that their offspring will have more hybrid vigor (heterosis) and a lot more yield. Finding genetically distant parental groups can be difficult with traditional search methods. Even sweetpotato varieties from distant geographic areas can be genetically similar. Outward appearance is also a poor indicator of genetic differences. Researchers needed a better way to evaluate the genetic differences in sweetpotatoes.

In Uganda, researchers from CIP recently used 31 genetic markers to study the relatedness of 141 sweetpotato parents, mostly from East Africa. Together with colleagues from IITA and the Universidad Nacional Agraria La Molina (in Peru), they characterized the varieties in a dendrogram, with genetic relatedness displayed like the branches of a tree. Most of the East African sweetpotatoes fell into two, genetically distinct groups (Clusters A and B). Consequently, in planning crosses for new hybrids, the parents from Cluster A will be crossed with parents from Cluster B. This new method to cross parent lines in sweetpotato as well as other RTB crops is called the heterosis exploiting breeding scheme (HEBS).

Research teams led by Wolfgang Grüneberg at CIP have demonstrated that HEBS works well and, within one breeding cycle of five years, leads to nutritious, improved breeding lines with great increases in yield, disease resistance and early maturity. "The resulting new hybrid populations were higher yielding, had more roots and more iron, thus exhibiting very high rates of genetic gains," Grüneberg explains. Indeed, the hybrid vigor obtained by crossing different parent groups is so high, that to reach such increases it would probably take 36 years of conventional crossing and selections, instead of just five years needed if HEBS is applied.

Using network analysis to prevent seed-borne disease

Researchers have developed models to understand changing seed systems using network analysis. In Uganda and Southeast Asia, these models shed light on how pests and diseases spread through social networks, and provided insights on how to improve crop health (in Uganda and Southeast Asia).

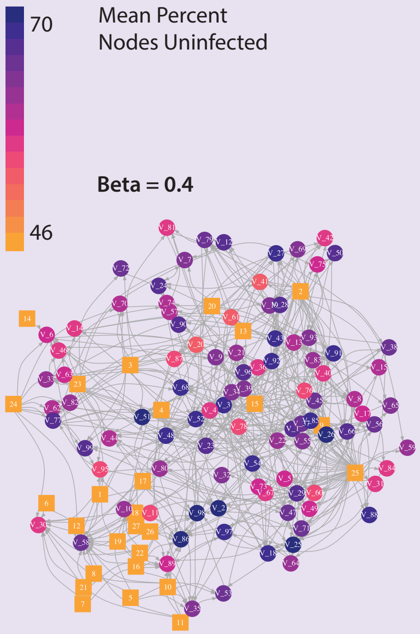
To ensure that healthy seed of improved varieties reaches farmers, Karen Garrett of the University of Florida and other RTB partners are developing tools to analyze seed flows and to learn how to best intervene in RTB seed systems. Impact network analysis, designed to evaluate management strategies in linked social and plant disease networks, helps to improve researchers' understanding of seed exchange networks as they become more commercial.

Network analysis can address complex questions such as the effect of climate change on seed degeneration, by explaining how information, pathogens and technologies move across seed networks and affect seed access, availability and seed quality.

In Uganda, RTB researcher Kelsey Andersen, from the University of Florida, used seed transaction data to build a network of seed and pathogen movement. Andersen and colleagues modeled scenarios for the introduction of a pathogen and evaluated the influence of its starting point and potential quarantine treatments on disease spread. The model showed how quarantine measures could most efficiently reduce the spread of the disease.

Farmers in Vietnam and Cambodia also have complex seed systems, according to Erik Delaquis of CIAT. Cassava farmers in Southeast Asia tend to use their own seed or exchange it nearby. However, traders also sell some cassava seed through inter-provincial and international networks, with 20% of Cambodia's recorded seed supply coming from Vietnam and Thailand; however each local seed network is different. This new perspective on regional cassava seed systems shows that as cassava becomes a more important commercial crop, sold to distant factories, seed is also starting to move along the same far-flung routes. Seed systems must also adapt to emerging pests and diseases, which hitch-hike on the long-distance seed trade to travel across the region. University of Florida and CIAT are now adding weather and other risks into their models, to help manage cassava mosaic disease in Southeast Asia.

The work in Uganda and Southeast Asia shows that network analysis can identify the best surveillance locations and model the effects of different management tactics. This can help to spot when and where disease will start, before it has a chance to spread further. Such targeted decision-making approaches are particularly valuable when resources for surveillance are limited – as in many developing countries. "We model where the disease is likely to move next, and the management strategies that are likely to be most helpful," said Garrett.



Networks of sweetpotato seed (vine) movement in northern Uganda were evaluated to identify strategies for sampling and mitigation. K.A. Garrett/University of Florida

Seller in the Gulu region of northern Uganda selling sweetpotato vines. P. Rachkara

Barcodes to keep banana breeding on track

Banana breeding is complex and getting seed from crosses is challenging. A new digital system, the Banana Breeding Tracking Tool (BTracT) now helps breeders keep tabs on each plant and manage data and activities at different sites. Each banana plant gets its own barcode, which is scanned on the BTracT handheld device. The barcodes are used to electronically record data on pollination, harvest and tissue culture. BTracT uses a web-based dashboard to follow each plant as it moves from tissue culture lab to screenhouse to the field. This reduces mistakes in identity, locates critical bottlenecks and makes banana breeding more efficient.

"The BTracT app and dashboard are providing real-time data to the breeding team and shifts the efforts from data collection and curation to making informed breeding decisions quicker and with accurate data," says Trushar Shah, bioinformatician at IITA.

Flagship 3

Resilient roots, tubers and bananas

Flagship Project 3 (FP3) helps to develop the strategies needed to protect roots, tubers and bananas from pests, diseases and abiotic stresses. "It's not enough to breed the best new varieties. We also have to see that the crops are grown in ways that allow them to express their full genetic potential," says James Legg, FP3 leader and plant virologist at IITA.

These efforts include spotting new diseases as they emerge in countries for the first time, finding the best way to manage pests and diseases and working with farmers to develop sustainable agronomic practices which will boost their yields and protect them from the impacts of climate change.

Coming to grips with the spread of cassava mosaic disease in Southeast Asia

As a new cassava disease spreads across Southeast Asia, researchers respond with a regional strategy to manage it. The viruses that cause cassava mosaic disease (CMD) are spread locally by an insect vector, but move over long distances through stem cuttings, which are used as seed. Understanding the seed networks that spread the disease helps to develop solutions to control it.

Cassava is the third most widely grown crop in Southeast Asia, after only sugarcane and rice. In Cambodia and Vietnam, most cassava is grown by smallholders, as a cash crop to sell to processors who make starch and other products for domestic and export markets. Disaster struck in 2015, when CMD was first reported in eastern Cambodia. By 2017 the disease was lowering crop yields across Cambodia and southern Vietnam, threatening the 55 million tons of cassava produced in the region.

The disease is caused by the Sri Lankan cassava mosaic virus, which is spread by the whitefly (an insect vector), and through the informal, commercial seed network that farmers use to access stems as planting material.

The newly arrived disease was a call for regional action. In 2018, CIAT, IITA and other partners of the GCP21 (Global Cassava Partnership for the 21st Century) met to propose a regional strategy for CMD: integrating surveillance data across the region, mapping disease distribution and spread, sharing information about the disease with farmers and extension agents, propagating and trading virus-free stakes, testing varieties already grown in the region to see which ones were most CMD-resistant, limiting exchange to healthy planting material and breeding new CMD-resistant cassava varieties.

In 2018 a survey of cassava seed systems in Cambodia and Vietnam, was conducted by CIAT. According to the survey, the exchange of University of Florida, Wageningen University and Research, (WUR), Fujian Agriculture and Forestry University, University of Queensland, China Academy of Agricultural Sciences, University of Battambang – Cambodia, General Directorate of Agriculture – Cambodia, Tay Nguyen University – Vietnam, Hung Loc Agricultural Research Center – Vietnam, the exchange of planting stems is likely the main source of risk for long-distance disease spread (see also the story on network analysis in FP2). The study found that, as in many parts of the world, farmers collect most of their cassava seed on their own farm, or they exchange seed with other farmers within their own community. But Cambodia and Vietnam also host an efficient, large-scale, commercial cassava seed network, trading large volumes of seed both within and between countries. In Asia, millions of tons of cassava roots are trucked from farmers' fields to processing factories each season; these transportation channels also provide a practical and inexpensive network for exchanging cassava stems. Warm, humid southern Vietnam can produce stems all year long, allowing traders to sell large amounts of planting material to farmers in northwest Cambodia, a rapidly growing cassava area with a three-month dry season that limits seed availability.

Potato cyst nematode found in Kenya

The potato cyst nematode (PCN) is a serious pest from South America which has been found recently in sub-Saharan Africa (Kenya and Rwanda). Surveys with IITA, CIP, the international center for insect physiology and ecology (icipe), the Kenyan government, and other partners (Kenya Plant Health Inspectorate Services, Kenya Agricultural and Livestock Research Organization Kenyatta University, and Food and Agriculture Organization (FAO) - Kenya) revealed that PCN is widespread in Kenya. Because it did not have a nematologist on staff, CIP teamed up via RTB with the IITA nematologist and the nematology laboratory at icipe and Kenyatta University. Knowing one's enemy can be half the battle: Once PCN was found in Kenya, RTB and survey partners collaborated to make posters and other educational material to warn farmers of the dangers of the pest, and to teach some basic management techniques. After the surveys, Kenya issued phytosanitary guidelines to ensure that certified seed potato is produced only on soil that is free of PCN, a crucial measure for managing this important pest.

"Viruses do not recognize international borders. Like the stem exchange networks themselves, solutions to the CMD epidemic must be regional," says Erik Delaquis, a CIAT researcher who was involved in the seed network study.

Seed exchange networks efficiently provide new varieties to large numbers of farmers, while allowing farmers to recover from seed loss. But these seed networks can inadvertently move seed-borne diseases like CMD hundreds of kilometers in a single season. Understanding how the seed trade spreads disease is critical for designing policies that allow farmers to access the seed they need, while making sure that the stems are healthy. The RTB seed systems team has developed tools for evaluating disease surveillance and management strategies in seed systems, in collaboration with Kelsey Andersen and Karen Garrett of the University of Florida. The RTB team is currently developing recommendations for optimizing sampling and interventions in the cassava seed systems in South East Asia.

James Legg, who leads RTB's FP3, notes that, "one of the key strengths of RTB is that it allows cassava experts from Africa (IITA), Latin America and Asia (CIAT) to share experiences in battling complex regional pandemics such as the one currently spreading through Southeast Asia." The RTB seed systems team is therefore working closely with plant virologists as well as breeders from CIAT and IITA to ensure that partners in Asia get access to CMD-resistant varieties as well as the best tools available for monitoring disease spread and rapidly producing virus-free planting material. Virologist Wilmer Cuéllar is leading CIAT's efforts to slow the spread of the CMD pandemic. He points out that success depends on strengthening the capacity of national research and plant protection teams. CMD will almost certainly spread even more widely before the benefits of the control efforts begin to take effect. However, mitigating the CMD pandemic in Southeast Asia will remain a top priority for the immediate future. With the international collaboration and partnerships that RTB can draw on, the team is confident that cassava will continue to play a key role in the economic development of Southeast Asia.

Cassava planting material in Cambodia. E. Delaquis/CIAT

Inspecting cassava for disease. Communities have been taught more sustainable planting methods to improve cassava production. Kampong Cham province, Cambodia. G. Smith/CIAT

Every drop counts! Water management in potato

Conserving water is important for adapting to climate change, and is crucial for smallholders growing potatoes in semi-arid regions. Collaboration between CIP and institutions in Kenya and China highlights appropriate techniques for saving water: intercropping with legumes and partial root-zone drying irrigation.

Across the world, potato growing helps smallholders to generate income and feed their families. Yet many smallholders cannot afford the irrigation, fertilizer and plastic mulch which are often suggested for growing potatoes. Recent research offers hope for profitable, environmentally friendly technologies to save water without sacrificing tuber yield.

Intercropping can help potatoes to retain soil moisture, but until now there has been little research on legume-potato intercroping. A recent collaboration between researchers from CIP and the University of Nairobi compared monocropped potatoes with legume intercropping. Harun Gitari, Elmar Schulte-Geldermann and colleagues looked at an intercrop of potatoes with dolichos (lablab), garden peas and common beans. The fields intercropped with legumes had more ground cover and the soil retained more moisture than potato monocrops. Potatoes intercropped with dolichos kept more soil moisture than any other treatment. Potatoes grown with dolichos only suffered a slight yield loss. In a semi-humid area of Kenya, the same researchers also found that potatoes intercropped with legumes grew roots that were up to 35% deeper, allowing the plants to absorb moisture from deep within the soil, even when the top 30 cm were too dry for the potato roots to capture water. The intercropped legumes provided more shade that kept the soil moister and cooler– just right for potatoes. The legumes themselves can also be eaten, contributing to the families' food security.

China is the largest potato producer in the world, growing over one quarter of the global total—yet much of the crop is planted in semi-arid regions where water is valuable. One disarmingly simple way to use water more efficiently is to irrigate only half of the field at a time.

A recent study by Junhong Qin and colleagues at CIP and the Chinese Academy of Sciences compared full furrow irrigation with two water-saving techniques in Zhangbei County, China. One of the water-conserving techniques was drip irrigation, where perforated PVC pipe or special soft-plastic drip hoses irrigate the base of each plant drop-by-drop. The second water-saving method, "partial root-zone drying furrow irrigation," or PRD, only waters every other furrow. Half of the furrows are watered one time, and the other furrows are watered the next time the field is irrigated.

When the young potato plants are deprived of water, they synthesize a hormone (abscisic acid) in their roots. The hormone closes the stomata in the plant's leaves, reducing water loss. A thirsty plant learns to lose less water.

When the experiment was started at the moment tubers were beginning to form, drip irrigation and PRD used only half as much water as full furrow irrigation. But by starting irrigation two weeks later, water use could be decreased to 36% of the full furrow requirement.

The potato yield was the same with all three treatments: PRD, drip irrigation and full furrow irrigation. But PRD saves the costs of installing the drip

Potatoes grown alone (left) leave a lot of soil bare, but potatoes intercropped with lima beans (center) or dolichos (right) cover the ground and retain more soil moisture. D. Ramirez/CIP

irrigation system, reduces carbon emissions and avoids the plastic pollution caused by disposing of the drip irrigation tubes at the end of their life. PRD saves half the irrigation water of full irrigation, but without sacrificing potato yield.

Intercropping potatoes with legumes and PRD irrigation are two examples of appropriate technology that can offer practical ways of saving water in a thirsty world while maintaining productivity.

A faster, more accurate way to detect disease-resistant yams

Yam anthracnose disease attacks the water yam, an important food crop in West Africa. In the field, the disease is influenced by the weather, and measuring its severity is subject to human error. Lava Kumar, Kolade Olufisayo and colleagues at IITA have developed a more accurate method to evaluate this disease.

A healthy leaf is placed in a Petri dish and inoculated with spores. At different time points, up to 14 days, images are captured with a digital camera. The percentage of the leaf that is covered with lesions is later measured using a program called Leaf Doctor, and percentage ranges converted to a rating scale. "By evaluating the leaves in the lab instead of in the field, we can test 100 samples for USD15 each in a week. This gives us a fast, cheap and accurate way to see which genotypes of water yam are disease resistant. Developing convenient lab assays is essential for improving the efficiency of phenotyping and breeding for resistant varieties," explains Kumar.

Flagship 4

Nutritious food and value added

RTB crops are being bred to make them more nutritious, for example by boosting their level of vitamin A. New strategies are being developed to take these new crop varieties to the farmers who grow them and to consumers as well. "We must make sure that the public appreciates the nutritional value of these important new varieties and that they are widely available to the people who need them, for improved health," says Tawanda Muzhingi, FP4 leader and food scientist at CIP.
The advocates of new crops in the policy arena are being trained to encourage their use. Researchers are also working on ways to turn roots, tubers and bananas into new food products, which will make them more widely available. Recipes are being created to preserve the nutrients of the new varieties. One exciting technique is also turning wasted cassava peelings into commercial animal feed.

A champion never gives up: turning cassava peel waste into livestock feed

Cassava peelings generate millions of tons of waste, and much of it is a source of pollution. In Nigeria, an RTB scaling champion, Iheanacho "Acho" Okike, and his team are sharing an appropriate technology with small-scale processors who turn the peels into an ingredient used to make high-quality animal feed, generating income, providing jobs and cleaning up the messy peels. New apps make it easier to put buyers and sellers in touch with each other, and to blend the processed peels into finished products.

Sometimes even a great idea can take a few years to mature. Iheanacho "Acho" Okike has spent the last 14 years figuring out a way to make livestock feed from cassava peelings, and now his dream is becoming a reality. The world's largest cassava producer, Nigeria, generates 12-15 million tons of cassava peels waste. The waste can pollute water, or be burned which contaminates the air. Meanwhile, demand for maize and soybean as animal feed is skyrocketing.

The first big problem was figuring out a way to get the peels dry enough, fast enough so that they would not deteriorate. Then one evening in 2015, Okike had a eureka moment. He was telling some friends about the cassava peel dryers he was experimenting with. "I was asking myself, why are we going around and around with this peel processing? Why don't we treat peels the same way that we make gari?" After all, millions of people in West Africa already know how to make gari, a kind of cassava meal, using simple equipment like graters and dryers.

Okike was then a researcher at International Livestock Research Institute (ILRI), but there was limited funding to work on the idea. Peter Kulakow, cassava breeder at IITA, knew how hard Okike was working. So, Kulakow gave ILRI a subcontract through IITA with RTB so that Okike could finish the experiment. "This funding helped us to get the equipment from China and from Nigeria. By the time the two years were over we had a full grasp of the experimentation and the proof of concept," Okike explains.

The next problem was scaling. In 2018 Okike won a competitive call from the RTB Scaling Fund. By then he had transitioned to IITA, where he was given the coveted title of "RTB scaling champion." After attending a scaling workshop in April, 2018 in Nairobi, and working with a consultant from WUR, Okike explained that "It was clear that we needed to identify partners and the elements of our technologies, the soft elements like institutionalization, awareness creation, communication and marketing, as well as the hard elements like machinery, factory layout. Once we were able to split these two, we knew which partners to use for which parts."

In 2018 the project trained 120 people in Nigeria in a three-day course. It was given 12 times, each time to a group of 10 trainees who earned hands-on experience with processing, machinery maintenance and factory

A trained cohort on graduation day. I. Okike /IITA

Hands-on training in processing. I. Okike /IITA

hygiene. Course participants also learned to use an app, Cassava Peel Tracker©, that was based on another app developed by IITA (Cassava Seed Tracker). The Cassava Peel Tracker uses GPS locations of people who process gari, so the trainees could set up their factories near the gari makers. Cassava Peel Tracker allows users to find peels, and producers to find markets.

On the last day of the training, people learned about obtaining credit: a course given by the Bank of Industry with whom the project had an Memorandum of Understanding. But most of the ones who have set up factories have done so with their own funding, or with loans from relatives or friends. This experience has shown that the best people to train are those who are in the gari business already. They already have the equipment as well as the peels which are a nuisance, and as such within days of taking the training they are up and running. Many people who have taken the training are now making the mash and selling it to livestock and fish feed millers, for example. Some are feeding their own animals.

In 2018 the cassava peel project signed an MoU with Single Spark, a company from the Netherlands. They have an app called FeedCalculator© which shows you different formulations of various ingredients to make different livestock and fish feeds. Now the people who take the course are trained to use FeedCalculator.

Graduates of the course join a community of practice on WhatsApp called Cassava Peel First Movers, where 190 practitioners exchange information on markets, difficulties and good experiences.

The years of effort are now paying off, as simple techniques for turning cassava peels into animal feed are becoming business opportunities for many Nigerian entrepreneurs and cassava processors, who are now earning money from what was once waste and a source of pollution.

Communication to improve feeding practices for infants and young children

Feeding children orange-fleshed sweetpotatoes (OFSP) can help to alleviate vitamin A deficiency. Growing these improved sweetpotatoes is a necessary step, but is not enough. Mothers and caregivers also need training and support to learn how to prepare food safely while retaining vitamins to improve their young children's nutrition. Integrated communication strategies using different channels are more effective than a one-off message.

Malnutrition is a major public health problem in many developing countries. In Kenya, vitamin A deficiency is particularly serious, afflicting 34% of children under five years of age – more than 2.4 million. Many low-income households rely on roots, tubers and bananas, so it is important to make these crops more nutritious. Plant breeders are enriching these crops to make them higher in specific micronutrients that vulnerable populations need. OFSP, for example, is an excellent source of vitamin A. Growing the crops is a first step, but agriculture alone will not solve malnutrition. Multidisciplinary expertise is needed, and many partners must work together. Local people need training to learn the best ways to feed the new varieties to their children.

CIP and partners in western Kenya have been working for 10 years to bring the benefits of OFSP to vulnerable children by combining agriculture, health and nutrition. A recent study under the SUSTAIN (Scaling Up Sweetpotato Through Agriculture and Nutrition) research project compared the effectiveness of different social and behavior change communication strategies for promoting good practices using OFSP for improved infant and young child feeding. Janet Mwende Mutiso of the University of Nairobi, and Julius Juma Okello of CIP interviewed a sample of 665 mothers and caregivers of Homa Bay County to understand the impact of the training. About 17% of the women had participated in mothers-to-mothers clubs, 33% received one-on-one nutrition counseling, 78% attended health talks and 39% had attended a cooking demonstration.

The different communication strategies were carefully designed and implemented based on lessons from previous interventions. At the mothers-to-mothers clubs, nutrition education was given by community health volunteers using counseling cards developed by SUSTAIN to explain feeding practices. The nutrition counseling involved one-on-one nutrition talks with mothers of babies with acute nutrition cases, who deserved more attention. Mothers who attended health talks at the health clinics also received coupons that gave them access to subsidized OFSP planting material from local vine multipliers. The cooking demonstrations were especially designed to show how to prepare OFSP for toddlers.

All of these communication strategies promoted feeding practices to improve the nutrition of young children: age-appropriate meal frequency (little kids need to be fed more often), a diverse diet (with four groups of food per day), the right texture and amount of food for small children and feeding children OFSP roots and OFSP leaves.

To assess the effectiveness of the communication, the women's responses were analyzed in four categories of similar ages: 1) pregnant mothers with children under two; 2) mothers of babies five months old and younger; 3) moms with kids from six to 23 months and 4) other women aged 19 to 49 years who cared for under-twos. The women in the last two groups were more likely to adopt the practices, probably because more of them had attended health talks where benefits of OFSP were discussed.

Interactive strategies that included face-to-face communication with mothers were the most effective. Combining several strategies and communicating more frequently enhanced learning more than using just one strategy. "This kind of study provides important evidence for designing effective nutrition support programs. These also need to be cost-effective if we want to reach millions of children. It is therefore essential that we can recommend to government services and other agencies what communication interventions provide the best value for money," says Simon Heck of CIP, the leader of the SUSTAIN project.

The study also revealed that OFSP can be an effective entry point for starting to change diets and children's feeding practices. 11% of the participating women gave their children fully diverse diets, and 35% offered meals in the right frequency. 21% fed their children OFSP roots and 11% gave them OFSP leaves. "Most children below six years old prefer the OFSP to their other staple foods, making it easy to reach them with OFSP," says Robert Mwanga, plant breeder at CIP.

Mothers and caregivers learning how to prepare food safely while retaining vitamins to improve their young children's nutrition. H. Rutherford/CIP

Cooking away the vitamins or baking in the goodness? How nutrients can survive food preparation

Plant breeders have strived for years to put nutrients, especially pro-vitamin A, into cassava and sweetpotato. Now the challenge is to follow the new varieties into the kitchen, to make sure that cooking and other processing methods retain the valuable nutrients, and that the prepared food is safe and nutritious.

New varieties of RTB crops, especially cassava and sweetpotato, have been bred to be richer in pro-vitamin A. The RTB Program is now working to improve the foods made from these varieties, to make sure that they retain the nutrients that have been painstakingly bred into them. CIRAD, Natural Resource Institute (NRI), IITA and CIP have teamed up to address the challenge in collaboration with the CGIAR Research Program on Agriculture for Nutrition and Health (which includes the HarvestPlus project).

New varieties of yellow, pro-vitamin A- rich cassava are now being bred and disseminated in sub-Saharan Africa. However, several studies published in 2018 conclude that yellow cassava often loses most of its carotenoids during processing.

Victor Taleon with other colleagues at HarvestPlus and Tawanda Muzhingi, FP4 leader, found that when yellow cassava is boiled, it retains almost all its pro-vitamin A: 93–97%. On the other hand, food processing removes most of the vitamin A. Fufu (a thick, fermented paste eaten as a staple) loses all but 1–3%. Chikwangue, a steamed cassava bread, keeps just 4–18% of the vitamin.

Toluwalope Eyinla and colleagues from IITA and the University of Ibadan studied the retention of beta-carotene (pro-vitamin A) in yellow cassava after sun drying, oven drying and flash drying. When making cassava chips and milled flour, over 80% of the beta-carotene is lost in sun drying, over 90% in oven drying and 95% and more in flash drying. Likewise when the cassava is made into flour and then into cooked dough, it retains only 1–2% of the beta-carotene.

Different cassava varieties react to cooking in unique ways. At CIAT, food scientist Ingrid Aragón and colleagues measured the pro-vitamin A in unfermented flour, fermented flour and gari (a dried cassava grit). The fermented flour and gari retained the most provitamin A (4–15%); however, cooking and fermenting change the pro-vitamin A content of each cassava variety in different degrees. Keeping vitamins depends on the processing method and the variety.

On the bright side, cassava has other properties that make it suitable for food manufacturing. A literature review by Oluwatoyin Ayetigbo of the University of Hohenheim, and colleagues at IITA found that yellow varieties tend to be lower in starch content and dry matter. However, the starch from white and yellow cassava varieties is similar in morphology, thermal, crystallinity and flow properties, so yellow and white cassava are equally suitable for making starch, flour and the products derived from them (like bread).

In another encouraging development at CIAT in Colombia, Luis Londoño found that up to 81% of the pro-vitamin A was retained when cassava was made into casabe, a flat bread that has been made from cassava since pre-Colombian times in the

Making sweetpotato puree at Organi Ltd in Kenya. J. Low/CIP

Amazon and Caribbean basins. Recall that boiled cassava, another traditional recipe from the Americas, also retains the vitamins.

As biofortified crop varieties are taken up by food processors, food safety is becoming an important issue. This is the case with sweetpotato, as RTB researchers are examining it critically, to create awareness and to support our partners as they adopt best practices.

Informal and formal food processors are now processing OFSP into puree used to make breads and fried products in Kenya, Malawi and Uganda. CIP scientists and colleagues at the University of Nairobi found that OFSP food processors in Kenya were not complying with good manufacturing practices. Microbial counts on food equipment as well as on the hands of personnel and in packaged OFSP puree were above legal limits. Steaming kills germs in cooked roots, but then the puree is recontaminated in the bakeries. Food handlers need training to produce safe, healthy OFSP puree. A regional workshop on managing food safety by small-scale root, tuber, and banana processors in Africa was conducted by CIP in collaboration with NRI, University of Illinois, UNICEF, FAO and Biosciences eastern and central Africa (BecA) ILRI. "As Africa is urbanizing rapidly, every year more people buy their food at the store. It is up to food researchers and manufacturers to make sure that the food stays healthy and wholesome at every step from the field to the plate," says Muzhingi.

In the future, it will not be enough to simply breed new cassava varieties that are rich in pro-vitamin A, but to empower small and medium–scale processors to produce food products that are safe to eat and retain their nutrients, while pleasing local palates.

Advocates for biofortified crops in Nigeria and Tanzania

The Building Nutritious Food Baskets (BNFB) project has promoted biofortified varieties with the help of local advocates, who have been trained with a toolkit of educational materials. In Nigeria and Tanzania, the advocates have become champions of biofortified crops such as vitamin A-rich varieties of cassava, sweetpotato, and maize and beans with high zinc and iron content. The advocates have trained over 11,000 community volunteers and other change agents. A million farmers are now growing biofortified crops in Tanzania and Nigeria.

Adopting balanced diets that include foods rich in vitamins and minerals can improve human nutrition, but healthy eating habits and new nutritious crops are not always well-known and widely adopted. That is where advocacy and training come in. From 2015 to 2018, the BNFB project has promoted biofortified varieties through a common approach to advocacy across multiple crops. The project is led by CIP and implemented with four CGIAR centers and HarvestPlus as well as community, national, regional and international stakeholders. The BNFB project has trained 101 men, women and youth as advocates for healthy varieties such as OFSP, yellow cassava and other staples. The advocates have learned technical and advocacy skills which they use to promote policy change and to raise new investment, as well as to train community volunteers and other change agents. The project developed a toolkit on biofortification with flyers, fact sheets, banners, success stories and an investment guide to support nutrition education and to create awareness. The advocates trained by BNFB have helped to promote a better understanding of the benefits of biofortified crops.

Four learning toolkits have been written to give the advocates more information on sweetpotatoes rich in vitamin A, beans that are high in iron and zinc, and pro-vitamin A maize. These toolkits were used to train 11,433 change agents (including 5,976 women), who are now promoting varieties that are rich in vitamins and minerals.

As a result of advocacy, biofortification (building vitamins and minerals into crop varieties) has been written into 11 government policies, plans and strategies in Nigeria and Tanzania. As proof of commitment, donors, NGOs, the private sector and governments have invested over USD6.5 million in biofortification programs. Another USD13 million is in the pipeline.

The Tanzania Food and Nutrition Center (TFNC) is the government agency that is responsible for technical and policy issues on nutrition. The CEO of the TFNC, Vincent Assey, says, "BNFB has developed our capacity to make people understand the difference between biofortified crops and genetically modified crops." Assey adds that "We have now seen that biofortification is a sure way of tackling the malnutrition problems in the country."

Vitamin A deficiency affects at least 30% of the population of Nigeria, and is especially severe for small children and women of reproductive age. Most people who suffer from the lack of vitamin A, iron or zinc show no physical symptoms of malnourishment, which is why micronutrient deficiency is called the "hidden hunger." In Nigeria, Gift Buduzhi Oguzor is a community nutritionist who leads an effort to

Parliamentarian Advocacy May 2018. J. Maru/CIP

Nigeria National Advocates for Biofortification. F. Kassim/Partnership for Nutrition in Tanzania

promote OFSP in Rivers State. After taking a 10-day training-of-trainers course supported by BNFB, Gift became a champion for OFSP. By March 2018 he had trained over 275 change agents with little support from BNFB.

International research centers can develop new crop varieties, but only governments can release them. The BNFB project has fast-tracked the release of seven biofortified varieties, including Solo Gold, a new OFSP in Nigeria.

Farmers are also picking up on the new varieties. Nearly a million farm households are growing biofortified crops in Tanzania and Nigeria. Nine processors in Tanzania and Nigeria continue to sell products such as pro-vitamin A maize flour, OFSP flour, bean flour, bakery products and baby food.

Hilda Munyua, the BNFP project manager says, "The project has played a catalytic role in strengthening the capacity of advocates and champions through a take-lead, empower and take-off approach, and they continue to engage policy makers and train new agents of change."

Flagship 5

Improved livelihoods at scale

Flagship Project 5 (FP5) helps other RTB innovations go to scale. Gender specialists consider the way in which changing roles of men and women need to be considered to scale RTB innovations while paying special attention to gender equity. RTB also examines its own partnerships to ensure that the most efficient methods of stakeholder participation are used. "We are generating evidence of the opportunities and bottlenecks for the development and uptake of RTB innovations. This informs the RTB teams about which research and development activities and partnerships have the highest likelihood of achieving impact at scale," explains Marc Schut, FP5 leader and senior innovation and scaling scientist with IITA and WUR. FP5 teams also review impact, for example, implementing surveys with genetic fingerprinting to pinpoint which crop varieties have actually been adopted.

DNA fingerprinting and varietal adoption: getting the full picture

DNA fingerprinting allows researchers to identify a crop variety genetically. While survey teams can ask farmers what crop varieties they are growing, an evaluation method that combines survey data with DNA fingerprinting can identify crop varieties more accurately, which is important in adoption and impact studies.

To assess the impact of adopting improved crop varieties, researchers usually ask farmers what is in their fields. But when farmers are not aware of the exact names or origin of the varieties that they grow, the adoption rate can be underestimated or exaggerated. To get a more accurate picture, researchers working with RTB crops have combined DNA fingerprinting identification with questionnaires.

DNA fingerprinting to estimate varietal adoption was pioneered by Mywish Maredia at Michigan State University, Byron Reyes at CIAT and others for wheat in Ethiopia, rice in Bolivia, cassava in Ghana and beans in Zambia. All researchers found a mismatch between what farmers said they were growing and the varieties identified with DNA fingerprinting.

Ricardo Labarta, agricultural economist, explains that in 2015 CIAT researchers collected cassava stakes and applied a questionnaire to 307 households in Cauca, Colombia, as described in 2018 in the *Journal of Agricultural Economics*. In over half the cases, the variety name given by farmers was not the one found by DNA fingerprinting. The farmers reported growing improved varieties on 25% of their acreage, while the DNA analysis raised this estimate to 29%.

The falling costs of DNA fingerprinting have made it easier to combine with questionnaires, for example on the IITA Cassava Monitoring Survey in Nigeria. As Tahirou Abdoulaye explains, the survey starts with a questionnaire, asking farmers what crop varieties they grow, and if these are improved or local. The survey-takers then visit the farmers' fields and collect some cassava leaf tissue in a vial with a

Cassava samples regrown at CIAT's greenhouse and ready for DNA extraction. R.Labarta/CIAT barcode label to avoid confusion. Abdoulaye and colleagues found that the adoption of improved cassava varieties would have been under-reported if the questionnaire data had been accepted at face value. According to the farmers, 54% of them were growing improved cassava varieties, while DNA fingerprinting gave a much higher figure, 68%.

Frédéric Kosmowski of the CGIAR Standing Panel on Impact Assessment, and colleagues at CIP, the University of Canberra, the World Bank and the Central Statistical Agency of Ethiopia compared what Ethiopian sweetpotato farmers said they were growing with varieties identified with DNA fingerprinting; 20% of farmers identified a variety as improved when it was really local, and 19% said a variety was local when it was improved.

In Vietnam, different methods used to assess cassava adoption also gave different results. Labarta and Dung Phuong Le of CIAT and Maredia of Michigan State University asked panels of experts to estimate the land area in Vietnam devoted to improved cassava varieties. While the expert panels estimated single varieties with high adoption rates, a follow-up DNA fingerprinting study with Vietnamese farmers found 85 different improved varieties being extensively used in over 90% of production areas.

Combining DNA fingerprinting with questionnaires allows collaborative learning between impact assessment teams working with different crops and in different regions, to better refine and standardize the method. The results from the studies help to reduce identification bias, identify material that is uncommon or is less familiar to farmers, and shed light on the distribution and potential flow of crop varieties.

Recording cassava samples descriptors in Cauca. R.Labarta/CIAT

Citizen science and an app for managing banana Xanthomonas wilt

Researchers from IITA in Rwanda are working on a new app to help farmers manage banana Xanthomonas wilt (BXW). The idea is to use "citizen science" to upload data from farmers' cell phones. However, an initial study has found that while most farmers do have access to cell phones, they need more training to be able to get the most from their keyboard, camera and other features. Farmers also want the app to come ready-made with information, images and videos on how to manage bananas in general, as well as BXW.

EVOCA (Environmental Virtual Observatories for Connective Action) is a project with WUR, RTB and other partners. EVOCA encourages users to share information (for example, on water issues or crop pests and diseases) via cell phones to contribute to collective knowledge and action in five case studies in rural Africa. One case study with CIP in Ethiopia helps farmers to manage late blight and bacterial wilt, two important potato diseases.

Another case study in Rwanda is designing an app to help farmers deal with banana disease, explains Mariette McCampbell, a former visiting scientist at IITA, now at WUR. "There are two groups of scientists, one that thinks that African farmers have no cell phones, or if they do, they have no air time, or the phones are not charged up. And there is the second group that thinks that the whole world is ready to start using their smartphones for everything. The reality is probably somewhere in the middle," McCampbell says.

McCampbell is conducting fieldwork in Rwanda with IITA, Bioversity International, the Rwandan Agricultural Board and others to find ways to use "citizen science" to manage BXW. Citizen science has been around in northern countries for some time, as local people gather data on birds, insects or other topics to share with scientists. But citizen science is new in the developing world. The wide availability of cell phones offers a new opportunity to link farmers with researchers by making more explicit use of cell phones and their new communication opportunities.

In rural Rwanda, most people now have access to cell phones, but not necessarily all the time. The problem is not just air time or electricity. Farmers may not have a network signal all the time, and most have analog phones, not smart ones. Even so, having a cell phone is a huge step for rural people, who with their first phone also get their first camera, their first video player, their first text messenger, their first GPS … all in their pocket. This is a lot of technology to learn about all at once. "We have spent years learning to use keyboards and cameras, so we cannot expect the farmers to learn to use all of this technology in a two-day training," McCampbell says. Researchers who want to interact with farmers on the phone, for example, to get geospatial data on disease, will have to invest more in training.

Field pre-testing of BXW-App with farmer-promoters at one of the focal villages for intervention. J. Adewopo/IITA

Beta version of the BXW-App (pronounced "Box-Up"), reading for field pre-testing. J. Adewopo/IITA

With the right training, cell phones may be just the tool to teach farmers how to manage BXW. In Rwanda, McCampbell found that there had been a huge effort to teach BXW management. The Belgian government funded farmer field schools and the trained farmers were expected to share information with their neighbors. The Rwandan government's extension service goes right down to the village level with farmer-promoters. But still, farmers were not adopting the new disease management techniques, such as removing the male flowers (to keep bees from carrying bacteria from diseased plants to healthy ones) and disinfecting hand tools between working on two plants.

McCampbell found that even seemingly straightforward techniques were ignored if farmers did not know why they worked. For example, single diseased stem removal means culling a diseased sucker from the banana mat–yet even this can be misunderstood. Some extension agents thought that if they removed a diseased sucker, the whole mat would be cured. They were dismayed when diseased suckers kept appearing. So, recommendations for farmers need to explain why a control technique will work or not.

As part of the participatory development of the app, farmer-promoters and sector agronomists said that they did not want to simply upload data. They wanted answers right away for BXW and even for banana management in general. So designers enhanced the app with information on BXW, fertilizer use and even when to plant bananas, all in the Kinyarwanda language. The team also added photos, drawings and videos. The extension agents liked those visual aids most of all, because illustrations help to share ideas more effectively and give credibility to the person sharing the ideas.

"Phones don't replace face-to-face ways of sharing information, but they are in addition to face-to-face, which will never reach everyone," McCampbell adds. Hopefully, the BXW app will be a positive example of a way to use cell phones as an entry point to engage young people in agriculture.

Controlling banana disease in the East African Highlands: considering gender norms in guiding interventions

Farm families in the East African Highlands grow bananas for food and to sell. In some areas the banana has become a key commodity and a major contributor to household income. However, production is constrained by the bacterial wilt disease (BXW). The roles of men and women in banana management and their control over revenues blend traditional gender norms with existing legal frameworks which prescribe shared ownership of land for married couples. Understanding gender norms and asset ownership in banana production helps researchers design and implement more efficient communication pathways to control BXW in banana production.

Anne Rietveld of Bioversity International led case studies as part of the GENNOVATE project to understand the way in which gender norms shape agricultural production in East Africa. Rietveld explained that "because the banana is a semi-perennial crop, women often cannot plant it because they may be perceived as making a claim to the land." Therefore, it is usually men who own the banana plantation, yet women also work on it. Enoch Kikulwe (Bioversity International) and colleagues who were working on controlling BXW in Uganda also found that women usually work on the land of their male relatives. Kikulwe and his colleagues calculated gender gaps in ownership, control and decision making around banana production. They found that men are 32% more likely than women to claim ownership of bananas and 25% more likely to sell them. Nevertheless, most of the work to control BXW was done by women, probably because they are more involved in the day-to-day management of banana plantations. Additionally, women were found to be less likely to adopt BXW control practices than were men. In this scenario focusing interventions on men (as was often the case in the past) would fail to deliver on disease control.

Lydia Kyomuhendo detaches leaves of a BXW-infected banana plant from the pseudo-stem before chopping the plant into smaller pieces to speed up the decaying process. S. Tumukuratire/National Agricultural Research Laboratories Kawanda

These findings suggest that addressing gender-based constraints and improving farmer perceptions are essential for scaling BXW control and management. Technologies should be more affordable and accessible to women, and gender-related differences in access and use of household resources should be considered in technology design. Conversely, changing farmer perceptions is essential for scaling, thus BXW communication should pursue pathways that are efficient such as radio and extension services while at the same time being appropriately crafted to reach women effectively.

Even though women often contribute to the management of bananas and their diseases, men often reap the benefits. Rietveld explains that income from bananas is used for different things, such as paying for children's school fees or sometimes for food or health expenses. Yet, in other households, men spend part of the money on their own leisure. This lack of control over benefits strongly discourages women from investing time and resources on pest control. However, gender norms are slowly changing although men's control over resources remains strong. There are multiple factors including government regulations, more access to information and interventions to foster women's empowerment that can contribute to increase the adoption of BXW control practices and more equitable distribution of benefit.

Juliet Nakazi disinfects a tool with fire after using it to chop down a BXW-infected plant. D. Kimeze/National Agricultural Research Laboratories Kawanda

Knowledge products

Publications

111
Peer-reviewed journal articles published

91
Publications in ISI journals (82%)

90
Open access journal articles (81%)

CGSpace

308,874
Publication views from CGSpace

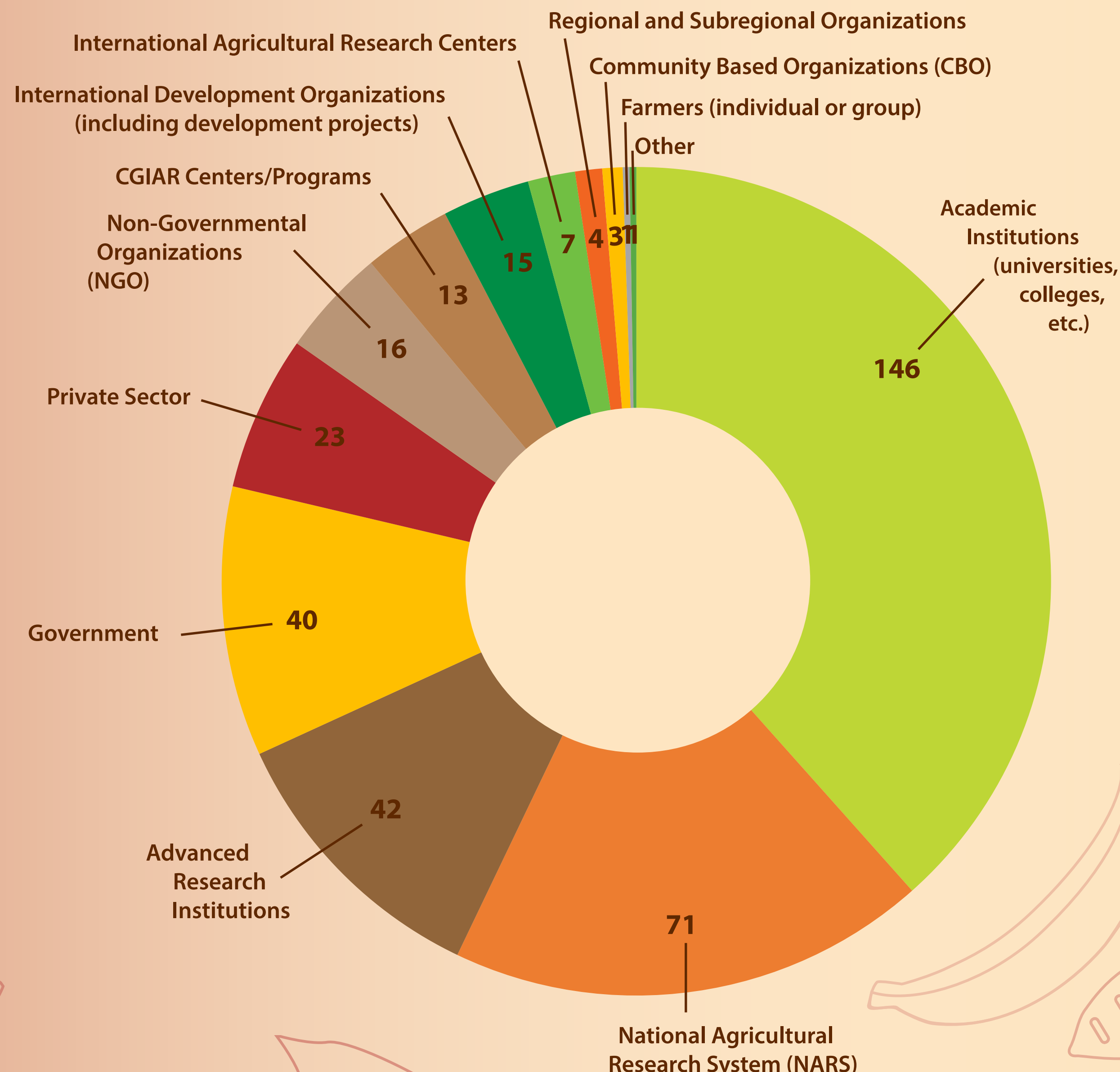
50,482
Publications downloaded from CGSpace

212
New knowledge products made publicly available through the RTB Collection in CGSpace

Partners

Partnership is central to international agricultural research for development. Collaboration mobilizes research results by 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. Moreover, the scale and scope of partnerships change along the continuum from research to development.

In 2018 RTB worked with 381 formally established partners, including private sector, national agricultural research organizations, advanced research institutions, academic institutions, governmental and NGOs. Innumerable CBOs, and farm households not individually listed here were also central to the program's success.



Donors

- African Agricultural Technology Foundation
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- International Development Research Centre, Canada
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- Iowa State University
- Irish Aid
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- Queensland University of Technology
- Swiss Agency for Development and Cooperation
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- United States Department of Agriculture
- Université of Lausanne

Financial report

The 2018 financial year started with the positive outlook communicated by the System Office. RTB received a Windows 1&2 (W1&2) allocation of USD21.7M. This allocation comprised USD19.5M, that represented the "most likely" scenario, and an additional USD2.2M (+10%). Nevertheless, for internal management purposes, RTB started working with the likely scenario of USD19.5M, which was maintained until the end of the year because the additional funds were not confirmed.

Also, RTB assigned to participant centers a total carry-over from 2017 of USD2.3M. Hence, the total forecast for W1&2 was USD21.8M and represented 23% of the total budget.

A total of USD72.5M of W3, bilateral projects and RTB participant centers' own funds were mapped under RTB in 2018 and represented 77% of the total budget. The total 2018 budget for the program was USD94.4M.

2018 Expenditure

RTB total expenditure for 2018 was USD80.3M, or 85% of the budget, of which USD19.0M (24%) were from W1&2, and USD61.3M (76%) from W3, bilateral and centers' own funds. Execution rate of W1&2 budget reached 87% and 85% for W3, bilateral and centers' own funds.

The RTB FPs have an average execution of 86%. No FP exceeded its budget. FP3 had the highest execution rate (94%) and FP4 had the lowest (78%).

The chart to the right shows the W1&2 budget and expenditure by FP and the PMU (Program Management Unit) expenditure of USD1.6M.

CGIAR Funding Windows

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

Flagship 2018 W1&2 Budget vs Expenses (USD Millions)

Flagship W1-2	Budget								
	Bioversity	CIAT	CIP	IITA	CIRAD	WUR	Partners	PMU	Total
FP1 : Enhanced Genetic Resources	0.71	0.80	1.42	0.64	0.10	-	0.09	-	3.77
FP2 : Productive Varieties & Quality Seed	0.62	0.59	2.89	1.23	0.04	0.06	-	-	5.44
FP3 : Resilient Crops	1.28	0.38	0.77	1.20	0.08	-	0.31	-	4.01
FP4 : Nutritious Food & Added Value	0.21	0.58	0.70	0.78	0.24	-	0.10	-	2.60
FP5 : Improved Livelihoods at Scale	0.65	0.51	1.02	1.19	0.01	0.34	-	-	3.71
CRP Management & Support Cost	0.04	0.06	0.08	0.08	-	-	0.00	2.07	2.33
Total	3.52	2.91	6.88	5.11	0.48	0.40	0.49	2.07	21.86

Flagship W1-2	Expenses								
	Bioversity	CIAT	CIP	IITA	CIRAD	WUR	Partners	PMU	Total
FP1 : Enhanced Genetic Resources	0.71	0.79	1.34	0.63	0.10	-	0.09	-	3.66
FP2 : Productive Varieties & Quality Seed	0.59	0.58	2.36	1.21	0.04	0.06	-	-	4.84
FP3 : Resilient Crops	1.23	0.36	0.75	1.15	0.08	-	-	-	3.58
FP4 : Nutritious Food & Added Value	0.16	0.34	0.19	0.59	0.21	-	0.10	-	1.60
FP5 : Improved Livelihoods at Scale	0.63	0.51	0.86	1.17	0.01	0.28	-	-	3.45
CRP Management & Support Cost	0.04	0.06	0.08	0.08	-	-	-	1.67	1.93
Total	3.36	2.64	5.57	4.83	0.45	0.34	0.19	1.67	19.06

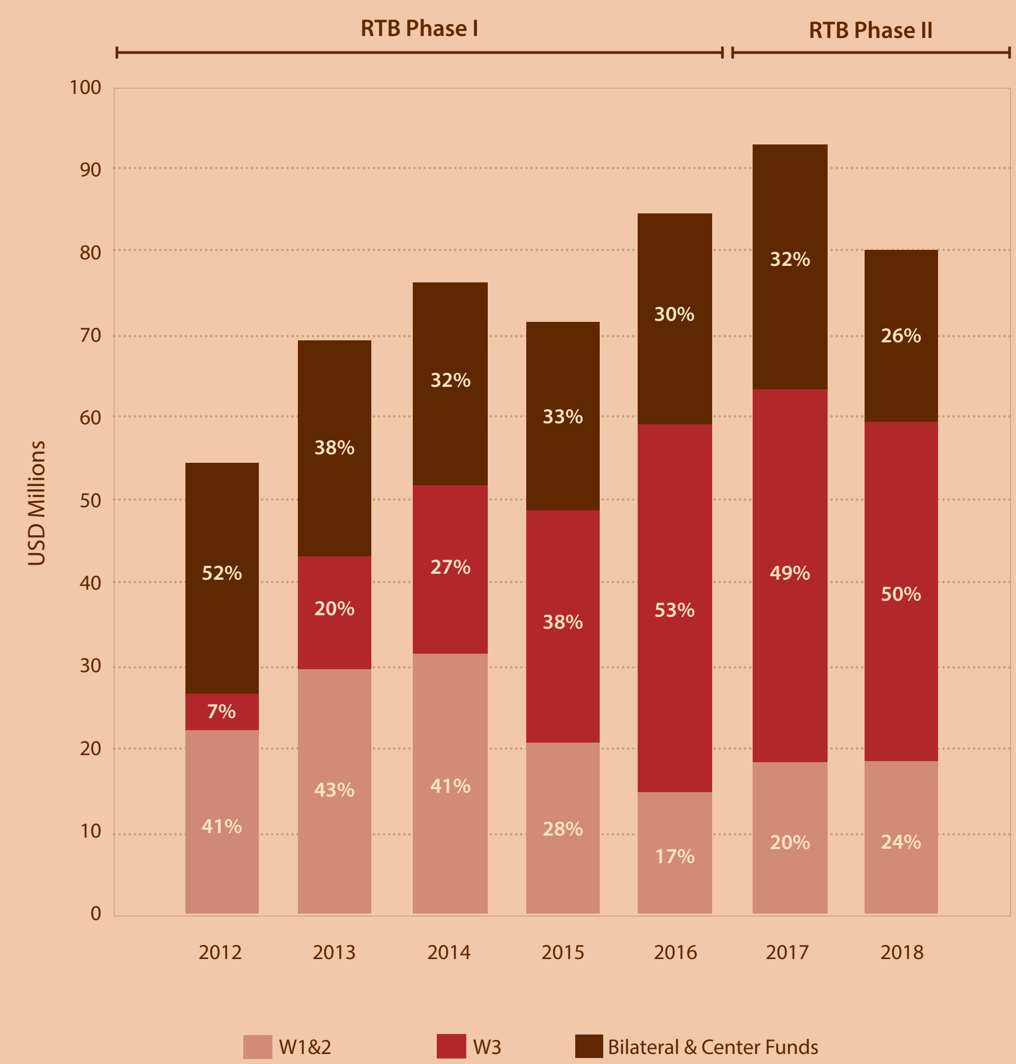
RTB 2012 – 2018

In absolute terms, the contribution of W1&2 to RTB's budget was stable in the last two years (USD20.5M in 2017 and USD21.8M in 2018).

Based on the actual expenditures reported for all the funding windows, the relative contribution of W1&2 has increased from 20% in 2017 to 24% in 2018. This change is explained by an overall reduction of USD13.9M in the amount of W3, bilateral and center funds for the same period.

The total expenditure in 2017 was USD93.5M against USD80.3M in 2018. The implementation rate in 2018 was 85%, similar to the rate recorded in 2017 (87%). RTB's cumulative expenditure has reached USD529.2M over the seven years of the program (USD154.6M from W1&2, and USD374.5M from W3, bilateral and center funds).

RTB Expenditure: 2012 – 2018



See the interactive website www.rtb.cgiar.org/2018-annual-report

ABOUT

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

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