INNOVATION AND IMPACT

CGIAR
RESEARCH PROGRAM ON
Roots, Tubers and Bananas

ANNUAL REPORT 2020

Innovation and Impact
RTB Annual Report 2020
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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July 2021

Correct citation
RTB. 2020. Innovation and Impact. Annual Report 2020. Lima (Peru). CGIAR Research Program on Roots, Tubers and Bananas.
Available online at: www.rtb.cgiar.org/2020-annual-report

ISSN: 2308-5932
DOI: 10.4160/23085932/2019
Hecho el Depósito Legal en la Biblioteca Nacional del Perú No 2018-13810

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Contents

Dashboard

CAPACITY development activities

407,907 Participants in short-term trainings and scaling activities

433 All degrees

159 Only PhD

163 INNOVATIONS developed and disseminated from all years

77 Reported in 2020 as new innovations, updated stage or same stage with new evidence

OUTCOMES case facts

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

12,700,000
Households benefited from RTB improved varieties and practices in SSA and Asia

SWEETPOTATO
6,200,000
Households using vines of improved varieties in 17 countries of sub-Saharan Africa countries

BANANA
600,000
Farmers adopted practices to control Xanthomonas wilt of banana in East Africa

CASSAVA
3,100,000
Households adopted improved varieties in Nigeria

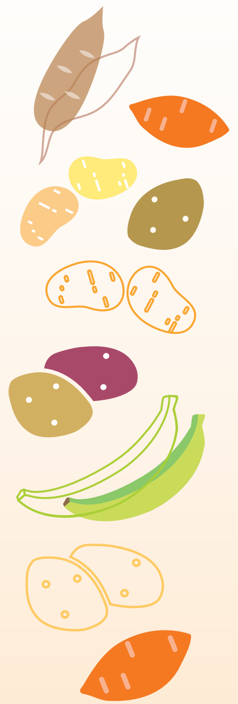
POTATO
2,800,000
Households using improved varieties in China, India and Nepal

Foreword

In 2020, the CGIAR Research Program on Roots, Tubers and Bananas (RTB) and its partners continued with a comprehensive portfolio of cutting-edge science while simultaneously giving more attention to scaling. As in previous years, this year's report is outlined around five clearly defined, high-impact flagship projects comprising research and innovation, including vital cross-cutting topics like gender, youth, and climate change.

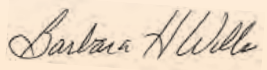
In this period of unprecedented change, we are actively promoting a smooth transition to One CGIAR. While 2021 is the final year of RTB, many of our innovations and partnerships will continue to contribute to science for crops that provide food security, especially as poor households in the developing world adapt to the crisis of climate change. We have built on our RTB partnership collaboration to create a set of collective knowledge assets that we call golden eggs, available as an online resource for wider use in One CGIAR. Golden eggs include frameworks, approaches, and tools, developed by a community of users. The golden eggs show the value-added of the RTB partnership collaboration in addition to crop-specific innovations. In the years ahead, these golden eggs will contribute to an array of research for gender-responsive development activities with wide applicability to roots, tubers and bananas as well as to other crops and cropping systems. We will nurture these golden eggs in the transition to the One CGIAR framework beginning in 2022, contributing to the UN's Sustainable Development Goals for 2030.

In 2020 we have met the challenges of COVID-19, a health crisis with great impacts on food systems. The teams on the ground found ways to adjust and keep the research advancing, despite logistical challenges. Roots, tubers and bananas sustain local value chains which are less vulnerable to supply chain disruptions than globally traded cereals. During this challenging year, roots tubers and bananas have played a vital role: raising incomes, enhancing climate resilience, and improving nutrition, food security and gender equity.

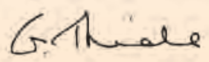


Some highlights this year include genomic tools to tackle complex bottlenecks in breeding, examining how to break through the 40% adoption ceiling for improved root, tuber and banana varieties, innovations to identify and manage banana bunchy top virus (a serious disease), giving consumers their say in defining future crop varieties, and how farmers can use ICT to take collective action to manage potato diseases.

As these stories show, RTB is a program that adds value to the work of its collaborating centers and partners, creating a critical mass that contributes to the many successful outcomes and impacts. RTB has brought together partners from around the world to ensure that root, tuber and banana crops benefit from the excellent research needed to raise productivity, adapt to climate change, and help women and men farmers improve the food security of their households. We thank all our partners and donors whose outstanding contributions have made these achievements possible and wish them success as they continue their work with One CGIAR.



Barbara H. Wells
CIP Director General



Graham Thiele
RTB Program Director

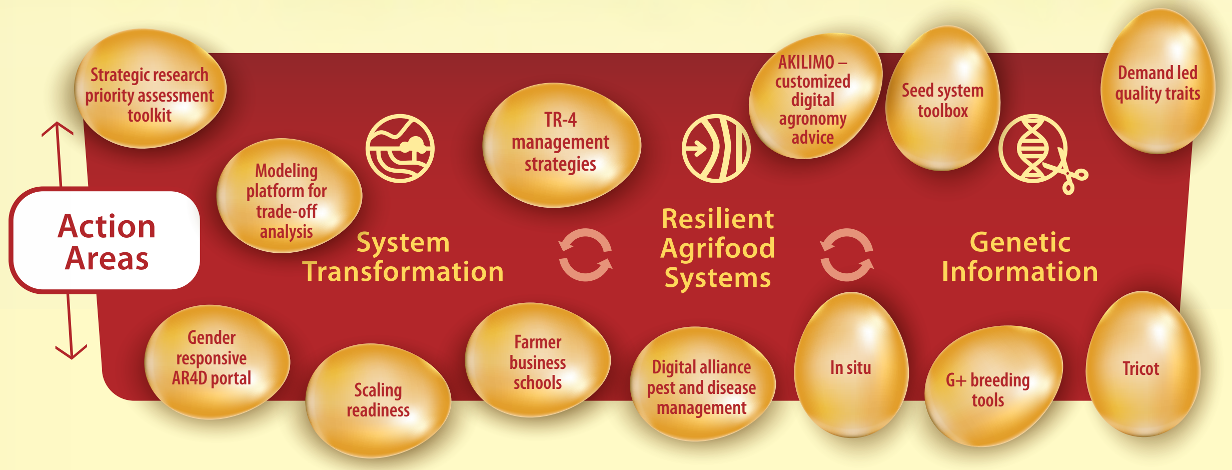
RTB AT A GLANCE

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 is a partnership collaboration led by the International Potato Center (CIP) implemented jointly with the Alliance of Bioversity International and 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 contributed to increase the benefits of the centers' research and interventions for smallholder farmers, consumers, and other actors in root, tuber and banana agri-food systems. RTB consolidates research in five interdisciplinary flagship projects (FPs), described throughout this report. Each flagship has a dynamic leader based in one of the centers. A flagship is a set of interrelated research 'clusters' with clear impact pathways through which RTB centers and their partners collaborate to achieve 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 is implemented through MEL, an online planning, monitoring, evaluation, and learning platform, collaboratively developed with several CRPs and centers. In 2020, RTB collaborated with 221 partners, primarily national agricultural research organizations, academic and advanced research institutions, private companies and nongovernmental organizations (NGOs). These partnerships play an increasingly important role in scaling ensuring that research benefits women and men alike and engages youth.

The contribution of RTB golden eggs to the One CGIAR structure for transforming global food systems



Source: One CGIAR research strategy 2030

RTB developed a set of collective knowledge assets through the RTB partnership collaboration in addition to crop-specific innovations that we call "golden eggs". These are available as an online resource for wider use. Golden eggs can be defined as frameworks, approaches, tools together with their community of developers and users that show the value-added of the RTB partnership collaboration. These golden eggs can contribute to an array of research for development activities with wide applicability for roots, tubers and bananas as well as other crops. The golden eggs in the transition to the One CGIAR framework will contribute to the UN's Sustainable Development Goals for 2030.

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 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

◂ **Plant samples in the gene bank, part of CIAT's Genetic Resources program, at the institution's headquarters in Colombia.** N. Palmer (CIAT)

ENHANCED **GENETIC** RESOURCES

Flagship Project 1

is developing cutting-edge science for faster and more efficient breeding of the crop varieties that consumers demand. Modern genetic science is overcoming the limitations of conventional breeding for vegetatively propagated crops. Plant breeders across the RTB program are developing new genomic tools in collaboration with top universities and research centers worldwide. "FP1 is not just using the most up to date genetic science, but also helping to further advance it," says Luis Augusto Becerra, FP1 leader and principal research scientist at CIAT.

Gender and social inclusion guiding more impactful breeding products

The Gender and Breeding Initiative (GBI) has piloted a set of G+ tools for gender-responsive breeding. The tools have been successfully piloted in several breeding programs and have attracted attention from breeders and social scientists in many CGIAR centers. The tools help multidisciplinary teams to share knowledge and collaborate as they address gender and social inclusion when setting breeding priorities for new crop varieties.

Cassava Traders at Market, Uganda. S.Quinn (CIP)

Gender inequality may hamper the adoption of new varieties, so breeding programs must understand what makes an innovation appeal to women and men. RTB, the CGIAR Excellence in Breeding Platform (EiB), and the CGIAR Gender Platform have jointly supported the Gender and Breeding Initiative GBI to develop the "G+ Tools" for gender-responsive breeding.

The G+ Customer Profile Tool describes the customer segments (demographic groups) who will be interested in a new variety. The customer segments may be based on occupation and gender, for example, male smallholders, female smallholders, or processors of both genders.

The G+ Product Profile Query Tool looks at the traits demanded by each customer segment. Is a specific trait (such as, short cooking time) "required", "nice to have", or "to be avoided"? This tool helps to define the traits that women and men need in a future variety, and traits that may cause harm.

The G+ tools guide a multidisciplinary team as they share knowledge and collaborate in advancing breeding products. In a pilot with cassava in Nigeria, in 2020, the tools helped the team to confirm the importance of focusing on gari and fufu (staple food products) in the breeding product profiles, while prioritizing small-scale women processors as a key customer segment.

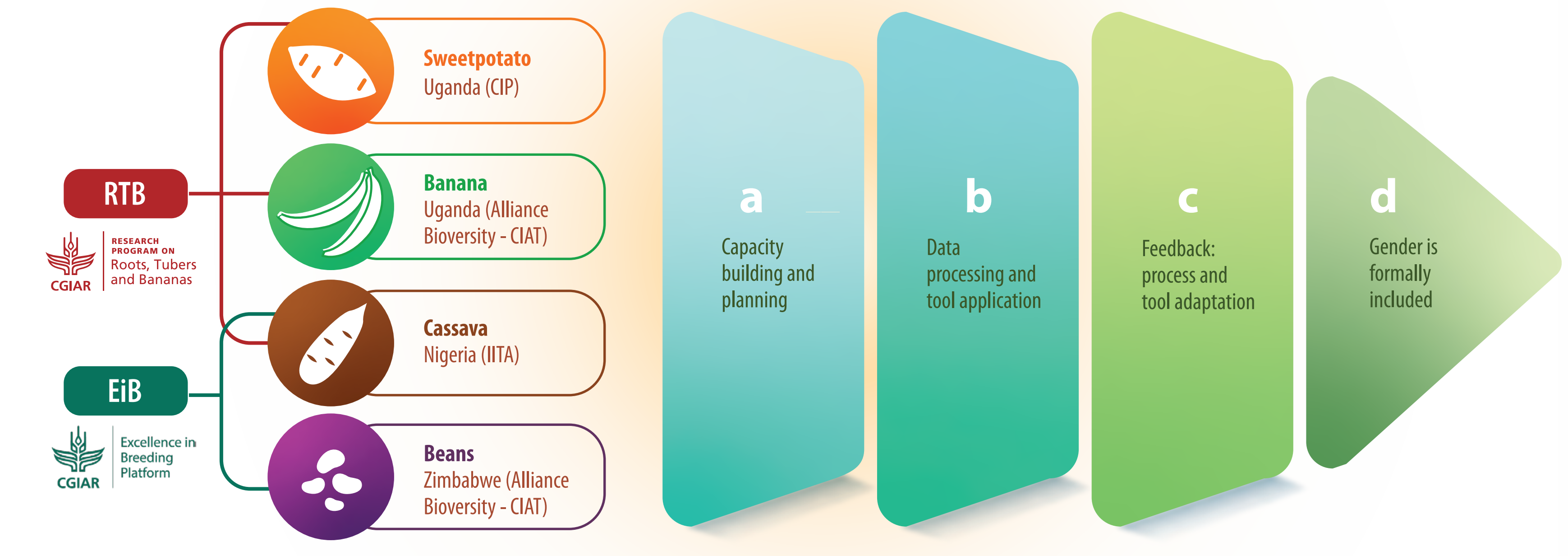
A recent product advancement meeting highlighted the need to evaluate drudgery experienced by women processors, and the softening of the root during fermentation. Breeding erect plants could harm women farmers, who do most of the weeding, because more weeds grow under erect plants.

In Uganda, sweetpotato is mainly grown by women, and most of it is eaten at home. The G+ tools validated the decision to target white-fleshed, quick cooking sweetpotato for home use, in addition to OFSP varieties with their improved nutritive content, and reconfirmed the importance of disease resistance and high dry matter content.

Also, in Uganda, the tools were used to identify the banana trait preferences of women and men. Some traits, such as ease of peeling, are important to many farmers, but especially to women. Many other attributes are important to both women and men:

- **Agronomic attributes,** e.g. adaptability to poor soils
- **Plant parts which can be used** for multiple purposes, e.g. banana leaves for use in food preparation or roots for medicines
- **Processing traits** related to value addition
- **Size and shape attributes,** e.g. uniform finger size, straight fingers for easier peeling, and compact bunches for easy transport

DISTRIBUTION OF CASES AND IMPLEMENTATION



A series of online workshops on the tools attracted plant breeders and social scientists from many CGIAR centers. "The workshops were really useful for bringing a diverse group of plant breeders and social scientists together. The participants agreed that defining customer segments and product profiles should not only be about the plants, and crop traits, but more about the people, and how they will benefit from the breeding products," said Vivian Polar from RTB. "These tools help to put gender and social inclusion at the heart of breeding."

These successful interactions during the online workshop with plant breeders and social scientists demonstrate that the G+ tools can address gender and social inclusion when setting priorities for new crop varieties.

Gender and social inclusion were systematically included in four real-world cases of plant breeding.

Women processors in Nigeria test cassava varieties made into prepared food. B. Teeken (IITA)

Choose the best and the worst out of three: Tricot simplifies variety testing with large numbers of farmers

The triadic comparison of technology options (tricot) crowdsources data from individual farmers, consumers or others to evaluate and rank three technology options. RTB is using this novel approach to test varieties in many farmers' fields at once and has piloted tricot with cassava and sweetpotato breeding programs in Africa. Tricot is so versatile that RTB is trying it with consumers, who taste and judge different varieties of cooked cassava and sweetpotato. Tricot takes advantage of user-friendly software to also capture variables such as location and climate. The method is a valuable way to inform product profiles for breeding programs, select varieties for release, promote new varieties for specific domains and identify traits that are likely to drive the adoption of promising varieties once released.

Citizen science crowdsources data directly from multiple users to improve the efficiency and accountability of agricultural research, using digital technology to gather and process data. The triadic comparison of technology options (tricot) is a novel citizen science method that facilitates farmer experimenters to evaluate crop varieties under real world conditions where each farmer ranks only three varieties. For each participating farmer, trial data, location and local climate are then captured on the online ClimMob platform, which allows data analysis. Consequently, tricot allows many more farmers to collaborate for varietal testing than was previously possible.

Tricot is a robust method to rank three options with farmers, processors or consumers. A farmer in Benue state (Nigeria) harvests her tricot trial. D. Owoade (IITA)

RTB has used tricot to test new cassava varieties in Uganda, Tanzania and Nigeria. The International Institute of Tropical Agriculture (IITA) and the National Root Crop Research Institute (NRCRI) did 320 trials with farmers across Nigeria. Cassava varieties were evaluated with mother-baby trials, where a large on-station trial, or "mother", is replicated by various farmers, who each test some of the options, in what are known as "baby" trials, using tricot.
IITA and NRCRI also evaluated processing with the household members who usually prepare these foods. Participants grew local varieties as a check and 15 improved ones and then processed the harvest into local foods (gari, eba and fufu).

The mother trials did not show significant differences in root dry matter, yet the baby trials showed that the landraces had significantly higher dry matter. This highlights the need to test new varieties under farmers' conditions, and tricot allows for large numbers of farms to be included in the testing. Although the baby trials showed that farmers ranked the landraces higher for gari and eba quality, the recently released improved variety Game Changer was ranked well for all the food products. Tricot trials are also being conducted in Uganda with the National Crops Resources Institute (NaCRRI) and in Tanzania with the Tanzania Agricultural Research Institute (TARI) and data is being analysed to help select the most farmer-preferred varieties in these countries.

Getting the food characteristics right can help break through the barrier for adoption of improved root, tuber and banana varieties. RTB and partners have further innovated with tricot to evaluate cooked food with consumers in markets and centralized locations (such as schools) besides farmer households.
Consumer preferences for 21 advanced breeding materials of sweetpotato were tested in Ghana, and for six released varieties in Uganda. 1,433 participants each tasted three sweetpotato varieties and explained which ones they preferred and why. In general, consumers liked the same varieties, whether they were tasted at home or at a central location.
In Ghana, consumers preferred a white-fleshed, high dry matter clone in the breeding pipeline (PG17136-N1), thus helping inform trait prioritisation in the breeding program. Ugandans preferred Ejumula, an orange-fleshed, high dry matter landrace followed by NASPOT 13, a variety released in 2013.

"Using the tricot method in consumer trials gave us a practical, and replicable way to reconfirm that breeders had some varieties in the pipeline that would be highly acceptable to farmers and consumers," says Kwabena Acheremu, CSIR Savanna Agricultural Research Institute.

Farmer participation is valuable in agricultural research. Innovations tested under real farm conditions should ideally be primed for rapid upscaling. However, participatory research can be expensive, and not always easy to replicate or to quantify. Tricot may help to make it more feasible to bring the perspectives of farmers, processors and consumers into plant breeding and other topics of agricultural research.

The sweetpotato varieties were cooked in coded pots for the centralised tasting. Each consumer was then given samples from 3 randomly selected pots. M. Nakitto (CIP)

Genomics and bioinformatics to breed for high-yielding, biofortified sweetpotato

Genomic tools and strategies developed for polyploid genomes such as those of sweetpotato, potato, banana and yam, are helping to tackle complex bottlenecks in sweetpotato breeding. This includes storage root bulking (for higher yields) and breaking the negative correlation between starch and beta-carotene (provitamin A) content for orange-fleshed sweetpotato (OFSP). Low starch content in OFSP varieties is a major bottleneck to adoption in sub-Saharan Africa, where consumers like starchy sweetpotatoes. So, thanks to these new developments, breeders will be one step closer to breed high-yielding, biofortified OFSPs that are high in starch, suitable for wide adoption. Lessons learned from this work may be applicable to breeding for other polyploid crops.

OFSP (orange-fleshed sweetpotato) varieties are often percieved as "watery" and rejected by African consumers,who prefer a dry, starchy sweetpotato. This is unfortunate, as OFSP is rich in beta-carotene, which our bodies use to make vitamin A. For years, researchers have suspected that there was a negative link between the genes involved in producing starch and beta-carotene. Previous breeding efforts concentrated on selecting high-yielding clones with lots of beta-carotene (i.e. dark orange roots) by crossing parents with high beta-carotene with adapted, high starch content parents. However, because of the negative genetic association, these efforts resulted in biofortified sweetpotato varieties that were low in starch.

▲ **Because of their genetic structure, dark orange sweetpotatoes like this one are high in vitamin A, but they also tend to not be starchy enough.** D. Gemenet (CIP)

▶ **Decentralized vine multipliers preparing sweetpotato vines for sale. Geita Region, Tanzania.** K. Ogero (CIP)

Decentralized vine multipliers preparing sweetpotato vines for sale. Geita Region, Tanzania. K. Ogero (CIP)

Recent work by RTB geneticists shows that the genes for starch and beta-carotene are more closely linked than had been suspected, which will make them more difficult to separate. By crossing an OFSP with a white-fleshed sweetpotato, and mapping the genes of their offspring, the RTB team demonstrated that the two genes involved in starch and in beta-carotene synthesis are located near each other on the sweetpotato genome. One of these genes, *phytoene synthase* (PSY), is involved in beta-carotene synthesis, while the other, *sucrose synthase* (SuSy), has to do with making starch.

A third gene, called *Orange*, is on a different region of the genome, but it acts with the PSY and SuSY genes to inhibit starch production while making more beta-carotene (or vice versa). As a further twist, *Orange* and PSY act together to influence the production of either starch or beta-carotene, so that more of one means less of the other.

Besides starch and vitamin A, farmers also want sweetpotatoes that yield more

RTB's sweetpotato genomics team is learning why orange-fleshed sweetpotatoes tend to have low starch. D. Gemenet (CIP)

Dorcus Gemenet (molecular breeder and geneticist) and Jolien Swanckaert (sweetpotato breeder for East and Central Africa) meet with sweetpotato seed multipliers in Rwanda, who explain that vitamin-rich sweetpotatoes also need to be high in starch. D. Gemenet (CIP)

The negative association between the genes for starch and beta-carotene complicates breeding for these traits in a single sweetpotato variety. "It has been frustrating at times, but now that we understand more about how these three genes work, and where they are located, this will help breeders to design genome-assisted breeding approaches to create OFSP with more starch, and greater public acceptance," says Dorcus Gemenet, a molecular geneticist previously at CIP in Kenya.

Besides starch and vitamin A, farmers also want sweetpotatoes that yield more. When farmers harvest sweetpotatoes to eat at home, they usually just dig up a few roots at a time. The mature roots are removed from the plant and the immature ones are left in the soil to continue growing. Sweetpotato roots that keep growing even after the plant has reached maturity, are said to have "continuous storage root formation and bulking," a trait that results in higher yields and a longer harvest time.

Recent RTB work with genome-wide association (GWAS) identified 34 genes associated with continuous storage root formation and bulking. Another seven were involved in the opposite trait of discontinuous root formation and bulking (the roots stop growing when the plant reaches maturity). Now that geneticists have mapped the locations of the genes involved in root growth, it will be easier to select for them early on in breeding efforts.

Except for cassava, other root, tuber and banana crops are polyploid; they have more than two sets of chromosomes. This complexity can make the crops difficult to breed, so advanced bioinformatic tools have been developed for carrying out genomic analysis in the polyploid sweetpotato. "Mapping these candidate genes for sweetpotato will also be useful for other polyploid crops," explains Astére Barayenya at Makerere University, who collaborated on the work with scientists at CIP, ILRI and other partners. "We hope that our work with sweetpotato genomics will shed light on more efficient ways to breed other vegetatively propagated crops."

Genomics sheds light on origins of Guinea yam

Understanding the genetic diversity of yam is crucial for improving this important crop. When researchers at IITA and partners analyzed the genome of the Guinea yam (*Dioscorea rotundata*) by sequencing 336 accessions of yam, including its wild relatives (*D. abyssinica* and *D. praehensilis*), they found that the domesticated Guinea yam is probably a hybrid of these two wild yams. Although the wild relatives are unsuitable for agriculture, they are a rich source of genes not found in domesticated yams. Gene banks have few accessions of wild yams, so collecting and conserving these species will be important for future breeding of Guinea yam.

Future improvement of yams like these, seen here in a market in Benin, will depend on collecting and conserving their wild relatives. R. Terauchi (Iwate Biotechnology Research Center and University of Kyoto)

POSSIBLE ORIGIN OF GUINEA YAM

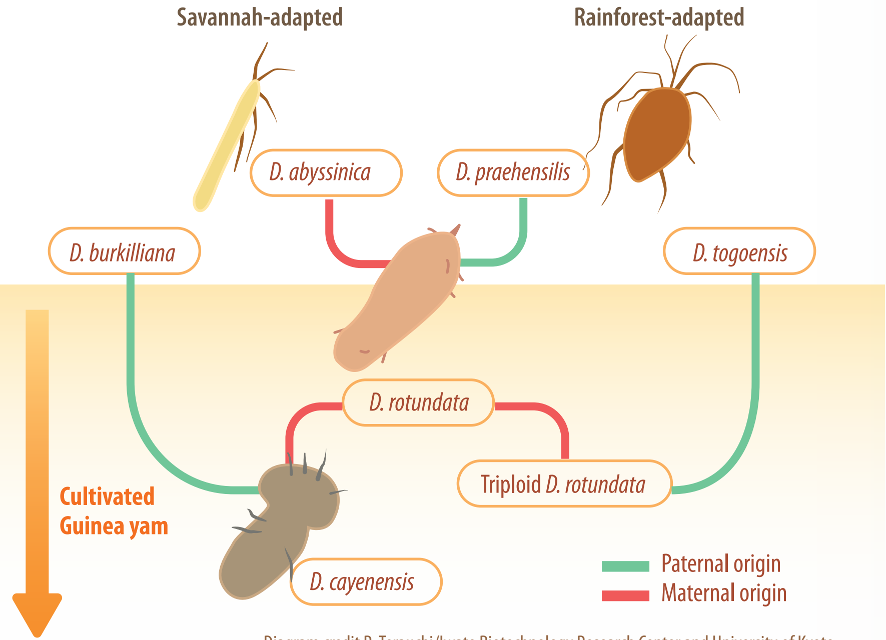


Diagram credit R. Terauchi/Iwate Biotechnology Research Center and University of Kyoto

R. Terauchi (Iwate Biotechnology Research Center and University of Kyoto)

Sweetpotato's wild relatives may help the crop adapt to climate change

At least some plants have genes for a certain kind of "memory." A young plant exposed to a stress (like drought) may be better prepared for similar trouble later in life. Researchers in Peru withheld irrigation water to induce a memory of drought in 59 accessions of the sweetpotato's closest wild relatives. Later on, some of these wild sweetpotato relatives responded to drought through different mechanisms, such as producing more green leaf area, keeping their leaves alive for longer or keeping their leaves cool by opening their stomata (a bit like sweating) although this mechanism deserves further research. If wild sweetpotato relatives can remember how to adapt to stress, breeders may be able to use these traits to help the cultivated sweetpotato resist drought and adapt to climate change.

Taking a leaf's temperature. Wild sweetpotatoes may remember how to stay cool. F. Guerrero-Zurita (CIP)

Older plants have learned to adapt to drought. F. Guerrero-Zurita (CIP)

An artificial drought induces a kind of memory in young relatives of the sweetpotato. F. Guerrero-Zurita (CIP)

Paulina Matamoros Escobar, a custodian farmer from Chopcca (Huancavelica, Peru), showing the landrace Morado Gaspar. S. De Haan (CIP)

Conserving crop diversity on farm

RTB scientists are developing baselines of crop diversity and providing support to farmers who conserve vulnerable landraces. Baselines (of which varieties are grown and where) are necessary to identify vulnerable varieties and track their status. The baselines use citizen science to monitor crop diversity in farmers' fields from gene to landscape. RTB scientists are standardizing procedures for supporting *in situ* conservation, including payment to farmers who conserve crop diversity, and strengthening farmers' organizations.

Ex situ ("off-site") conservation keeps varieties in gene banks or in seed vaults. *In situ* ("on site") conservation maintains crop diversity in farmers' fields. Farmers still conserve most of the world's crop diversity, as they have done for millennia. Plant breeders rely on this genetic material to improve tomorrow's crops to meet stresses like climate change and invasive pests and diseases.

In situ conservation relies on the support of robust baselines, which include data on which varieties are grown and where. Like a census, the baseline includes local names and a genetic fingerprint for the varieties, showing which ones are common and which are endangered. Farmers' crop diversity is dynamic, being lost and added to over time. Baselines document this diversity, its distribution, and use. The International Potato Center (CIP) and the Alliance of Bioversity and CIAT (the Alliance) have established guidelines on how to conduct the baselines.

Since 2013, scientists at CIP have developed baselines for potato landraces in several hotspots, including the Yauli-Paucara microcenter in Huancavelica, Apurímac and Tayabamba, Peru and on the Bolivian Altiplano. NGOs, universities and regional governments gathered large datasets on crop varieties, which are gradually being released as baselines. On 19 July 2021, the Yauli-Paucara baseline will be officially launched by the Regional Government of Huancavelica. These baselines will allow researchers to return to the same hotspots in the future to monitor change.

Mix of potato landraces from Huancavelica, Peru. S. De Haan (CIP)

Young farmers in Chopcca selecting seed for a biodiversity seed fair (Huancavelica, Peru). S. De Haan (CIP)

Exchange between Quechua and Yanesha farmers. S. De Haan (CIP)

In the Pasco region in central Peru, CIP, AGUAPAN (Association of Guardians of the Native Potato) and its NGO partner Grupo Yanapai have been conducting a baseline for potato with Quechua-speaking farm communities. Meanwhile, the Alliance is completing a baseline with cassava in Yanesha communities in the Amazon region of Pasco. In both experiences, crops of global importance (cassava and potato) are being managed in their center of origin by indigenous peoples.

CIP and the Alliance have experimented with novel models for benefit sharing and payment for environmental services in Peru. The CGIAR has a role to play to develop models of benefit sharing, because all its gene banks are in centers of crop origin. AGUAPAN is an initiative supported by the private sector in 100 rural communities in seven regions. The initiative provides direct monetary benefits to households, called "potato landrace custodians." AGUAPAN is governed by farmers themselves, conserving among them at least 1000 landraces.

Tubers of the frost-tolerant landraces. C. Bastos (CIP)

These interventions hosted an exchange between researchers and Yanesha and Quechua leaders in 2019 during the AGUAPAN annual assembly to discuss farmers' rights, place-based governance of genetic resources and the importance of baselining to protect biocultural heritage.

Ex situ and *in situ* conservation approaches are complementary, in part because the immense diversity in farmers' fields is practically unmanageable in gene banks. Dynamic, *in situ* conservation is resilient against changing climates, conserving traits that are strongly farmer-preferred, as well as adaptive traits. For example, frost resistant landraces like *Puqya* and *Manua* are now being planted over wider areas with increased probability of frosts like Huancavelica.

"The next step is to scale these conservation approaches and establish an Andean-Amazonian network of in situ observatories, and to apply citizen science to monitor diversity more often and with increased agility." says Stef de Haan of CIP. These efforts will help to establish an online decision support system for documenting the conservation status of landraces in the field and in the hands of farmers. These tools can then be applied to other crops in diversity hotspots identified by RTB researchers, and in the centers of origin for cereals, legumes, vegetables and other crops.

A student from Daniel Alcides Carrión National University (Peru) evaluating leaf shapes of cassava. E. Delaquis (the Alliance)

Daniel Alcides Carrión National University student helps conduct a baseline in a varietal garden in a Yanesha community, Peru. E. Delaquis (the Alliance)

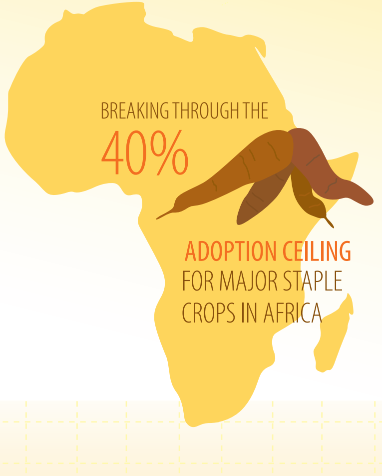
ADAPTED PRODUCTIVE VARIETIES AND QUALITY SEED

Flagship Project 2

is about breeding better crop varieties and improving seed systems. FP2 supports RTB's plant breeding teams to create the varieties that are demanded by male and female farmers and consumers. FP2 also strengthens the seed systems so that farmers receive quality seed of new varieties. "We make sure that farmers are partners in plant breeding. Now breeders are aware of the specific demands of different stakeholder groups for the root, tuber and banana varieties of the future," says Maria Andrade, FP2 leader, plant breeder at CIP, and World Food Prize winner.

Breaking the adoption ceiling of modern varieties

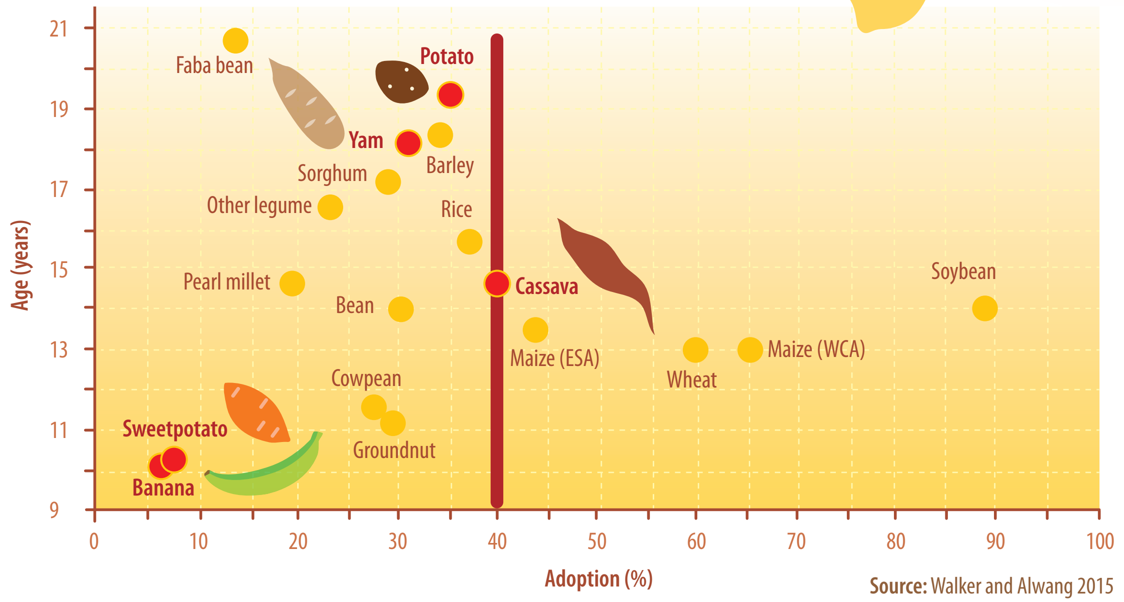
In Africa, the adoption of modern varieties of roots, tubers and bananas rarely surpasses 40% of their potential, a major reason is insufficient attention paid to the crop traits that farmers and other consumers want. Understanding these preferences, and addressing them through breeding programs, can help break through the 40% ceiling and contribute to improved smallholder livelihoods. Fortunately, new breeding tools make this more feasible; breeding programs are seriously committed to capturing real demand and change is underway with the RTBfoods project and in RTB breeding programs.



A team of RTB scientists recently reviewed adoption studies of modern varieties of RTB crops. This revealed that the average adoption rates in sub-Saharan Africa are below 40% of the crops' area, as though there were an invisible ceiling. One major reason for the invisible ceiling has been the insufficient attention by breeding programs to understanding how consumer preferences shape demand and drive adoption. This is especially important in sub-Saharan Africa where farm households are consumers as well as producers, and because men and women play different roles on the farm and may differ in their preferences. Fortunately, work is underway with RTB breeding teams to incorporate these preferences in new varieties (product profiles) which gives us every reason to hope that we can break through the invisible ceiling (see story in this annual report on RTBfoods).

◄ Sharifa Juma digs terraces to stop soil erosion. G. Smith (CIAT)

ADOPTION AND VARIETAL AGE MODERN VARIETIES IN SUB-SAHARAN AFRICA 2010



Source: Walker and Alwang 2015

More than 44 new banana (and including plantain) varieties were released in East Africa by 2016. But the area planted in these varieties is only about 6% of the total, even though many modern varieties are high-yielding and disease-resistant. Studies showed that adoption was low mainly because new varieties usually failed to meet consumer demands for a specific product type (e.g., for cooking, or as fresh fruit).

In Nigeria, cassava fared better, as modern varieties were adopted on 46% of the crop's area. Those varieties tended to be high-yielding, which was important as cassava became a commercial crop in the late twentieth century. However, it was also clear that widely adopted varieties were also good for making gari (a food in high demand). Other local varieties meet consumers' preferences for specific cassava products such as a snowy white color for making abacha, a grated cassava product

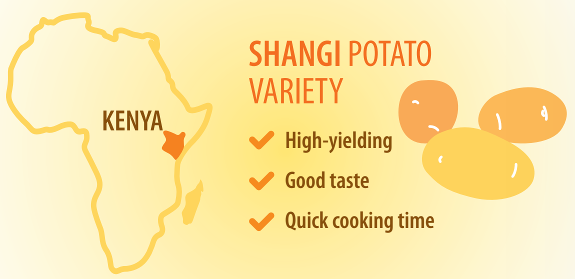
In the case of sweetpotato in Uganda, adoption surveys did not examine the importance of quality traits. However, CIP plant breeder Robert Mwanga, who also co-authored the study, explained that "during participatory plant breeding, we found out that many of the attributes that farmers look for were consumer traits, including the attractive color of roots, 'sweet' roots when cooked, and mealy and non-fibrous texture. So, targeting these traits is important if farmers are going to adopt our varieties."

A snowy white cassava is best for making abacha. Charity Ofozie Ugo processing abacha in Ohokobe Afaraukwu in Abia State Nigeria. T. Madu (NRCRI)

In Côte d'Ivoire, consumers generally prefer guinea yams (*Dioscorea rotundata*), because they make a good pounded yam. Nevertheless, many farmers have adopted land races of water yam (*D. alata*), introduced from other regions as a cheaper alternative. Again, a key factor in adoption was a quality preference, and the varieties that were adopted made an acceptable pounded yam, unlike many water yam varieties.

Potato in Kenya has shown particularly rapid varietal change. In recent years, the Shangi variety, likely a farmer selection from CIP breeding lines, has been adopted by most farmers. Sophie Sinelle, of Syngenta Foundation, co-author of the RTB review paper, explains: "in Kenya we found that farmers do like high-yielding potato varieties, but adoption is driven by a combination of consumer and market demand preferences which you can find in Shangi variety, earliness to be the first on the market, and culinary qualities such as taste and quick cooking time."

As Graham Thiele, lead author and director of RTB, concludes, "a central finding is that despite some recent work there is still a dearth of information to capture and address gender differentiated consumer preferences and procedures to ensure that this information can be addressed effectively by breeding programs."



Farmers Gladys Nkirote (left) and Doris Kagendo (right) proudly holding harvested tubers of Shangi variety in Kamurampa village, Meru County, Kenya. Doris bought 50 kg from decentralized seed multiplier Cecinta Nduru. R. Jumah. (Farm Input Promotions Africa Ltd.)

A new project, RTBfoods, an integral part of RTB, is working to break through the adoption ceiling. RTBfoods does improved surveys of consumer demand for roots, tubers and bananas. Then RTBfoods translates consumer criteria (like good taste and stretchability of pounded yam) into properties that breeders can recognize, such as starch and fiber content. "While there may not be a gene for tasty or stretchy, RTBfoods is researching the interaction of genes and the environment to help breeders produce these traits in varieties that consumers will value," says Dominique Dufour, who leads RTBfoods at CIRAD.

Woman showing Shangi potato variety. Wakulima market. Nairobi, Kenya. A. Balaguer (CIP)

Innovations in early generation seed show promise to get new varieties into farmers' hands faster

Early generation seed (EGS) is the starter material for producing commercial seed of new varieties. EGS is the key to a healthy, economically viable seed system. RTB has supported the development of new technologies that make it possible to produce EGS faster, making improved varieties available sooner, as shown by experiences from cassava in Nigeria, sweetpotato and potato in East Africa, and yam in West Africa. Healthy and productive seed for farmers starts with top quality EGS.

Commercial seed is produced from early generation seed (EGS), where RTB is giving a lot of attention. RTB is supporting systems that get top quality EGS of new varieties into the hands of commercial seed producers faster and more efficiently, thus building value chains that improve the yields and the livelihoods of many root, tuber and banana farmers.

RTB has supported the development of rapid multiplication techniques (RMTs) that are accelerating the multiplication and bulking up of EGS to provide disease-free starter material using molecular detection protocols. This is important, because once a variety is selected for release, and farmers want it, it can take years to multiply it in the field and make seed available.

In Nigeria, semi-autotrophic hydroponics (SAH), used in Latin America to multiply potato seed, was adapted by IITA and the Nigerian National Root Crops Research Institute (NRCRI) for cassava. By quickly multiplying cassava cuttings in small trays, more seed can be produced, cutting costs from a dollar for breeder seed to ten cents for SAH plantlets. Additionally, SAH can achieve a 50-fold multiplication in the quantity of EGS in 15 weeks compared to 30 weeks for the previous method.

Stokman Rozen a private company in Kenya training private-sector and national program technicians from Kenya, Madagascar and Uganda to produce apical cuttings. Apical cuttings being multiplied are Unica, a CIP variety. M. Parker (CIP)

Sustainable early generation seed business analysis tool (SEGSBAT) helps to analyze financial performance of early generation seed (EGS) businesses run by specialized seed producers, such as NARS and private companies. The tool includes coverage of *in-vitro*, breeder, and foundation seed classes. The supply of EGS is often a bottleneck to improving formal seed systems.

IITA researchers successfully adapted SAH from Latin America for rapid multiplication of top quality cassava seed in Nigeria. IITA SAH technicians displaying healthy SAH cassava plantlets. H. Nitturkar

In East Africa, the International Potato Center (CIP) and partners developed and introduced new RMTs for potato to private companies and the public sector including: sand hydroponics, aeroponics (growing roots in the air), and rooted apical cuttings (shoots cut from plantlets are transplanted into plugs). In Kenya, private seed companies like Kisima Farm and Stokman Rozen are using rooted apical cuttings to produce commercial seed quickly, on a large scale, while training other companies to produce the cuttings.

IITA's Yam Improvement for Income and Food Security in West Africa (YIIFSWA) project has developed new techniques for producing EGS. The Temporary Immersion Bioreactor and vivipak systems are being shared with national agricultural research centers to produce clean starter material for breeder and foundation seed, while private seed companies in Nigeria and Ghana are producing foundation seed with aeroponics and hydroponics and single node vine cuttings. This EGS is then being made available to seed yam growers WHO are producing commercial seed tubers with another RMT, the adaptive yam minisett technique. See the box on yam minisett, opposite.

Margaret McEwan, Senior Scientist and Seed Systems Specialist at CIP explains. "We have been able to learn across crops – for example hydroponics in potato has been adapted to sandponics in sweetpotato. Agricultural economists have determined the cost of production for different technologies using the Sustainable Early Generation Seed Business Analysis Tool (SEGBAT), from the seed systems toolkit. Understanding the unit cost of production and developing marketing strategies are critical components of the sustainable sweetpotato EGS business plans which we have supported with public and private sector organizations in 11 countries in sub-Saharan Africa."

These experiences show that RMTs can bring healthy seed of improved varieties to farmers sooner. Lowering the cost of EGS also lowers costs throughout the system. Quality is easier to manage and certify at early stages, so certification should focus on EGS, rather than on farm level certification. RMTs need to be used with the right marketing and pricing strategies. With the proper incentives, private companies can produce EGS for root, tuber and banana crops, which will lead to greater varietal adoption.

35 tubers from one apical cutting. Shangi variety, Kenya. M. Parker (CIP)

Getting more for less with seed yam

At harvest, West African yam farmers keep up to 30% of their tubers to plant the next season, so many yams that could be sold or eaten must be saved as seed. A seed tuber can weigh over a kilogram, but it can be cut into minisetts: 30 to 90 gram pieces. If planted three weeks earlier than usual (with irrigation if necessary), minisetts can produce seed yams at a seed-to-crop ratio of 1:30, instead of 1:3. A hectare of yam planted with 30-gram minisetts yields almost as much as one planted with 90-gram pieces, while saving an additional ton or two of seed. However, farmers were wary of the smaller sizes. The most skeptical farmers were invited to participate in demonstrations, where the minisetts (treated with chemicals to prevent pests) produced good seed yam. The expected productivity increase for the adapted yam minisett technique is about 25%, and it should be promoted more widely.

Freshly cut minisetts spread out to dry after being treated with fungicide and insecticide to prevent pest attacks. B. Aighewi (IITA)

Less is more. These yam minisetts are small pieces of seed tuber that are high-yielding, and they save seed that can be sold as food. B. Aighewi (IITA)

Adapting regulatory seed frameworks to RTB crops: unlocking a major bottleneck to broader impact

Seed systems for vegetatively propagated crops (VPCs) are often governed by laws designed with cereal crops in mind. As a result, rules and guidelines may be less suited for VPC seed, which is bulky, perishable, and prone to spreading diseases. VPCs need seed regulations designed specifically for vegetative planting material. For example, VPC seed regulations should emphasize quality testing and certification for early generation seed (EGS) more intensively than for lower seed classes. Targeted, evidence-based policy recommendations are helping to improve regulatory frameworks for VPCs in Tanzania, Rwanda, Nigeria, and Vietnam.

In many countries, seed quality assurance systems, including testing and certification protocols, are based on technical experience with cereal and pulse crops. Vegetatively propagated crops (VPCs) have distinct types of planting materials, which means that this experience is often unsuitable to the design and implementation of VPC-specific seed quality assurance systems. To ensure that quality VPC seed production and distribution are subject to appropriate rules and regulations, RTB teamed up with the CGIAR Research Program on Policies, Institutions, and Markets (PIM) to conduct a qualitative analysis of seed policy and practice, focusing on cassava in Nigeria, potato in Kenya and potato and cassava in Vietnam.

Results from the RTB-PIM study indicate that across all three countries, VPC seed quality assurance systems are not only too stringent but are also difficult to implement and monitor. This can be prohibitively costly for many seed producers, leading to the continued movement of seed through informal channels. These channels—often vibrant, bustling local market exchanges—rely on trust among seed producers, traders, and farmers that are developed through long-term relationships. As such, there are good reasons to maintain and strengthen informal channels, while also strengthening the formal system in an integrative and supportive manner.

The Alliance of Biodiversity and CIAT is working with the Agricultural Genetics Institute in Vietnam in maintaining, evaluating, multiplying, and distributing CIAT CMD Resistant and Elite Clones under the cassava program. T. Chinh (Alliance of Bioversity International and CIAT)

Unfortunately, informal channels work better at local scales. Wholly unregulated, large-scale, long-distance seed trade, including cross-border movements of seed, can contribute to the spread of pests and diseases, as experienced with cassava mosaic disease (CMD) in Vietnam. Seed systems at a local scale may not be able to keep pace with government strategies to expand production while managing new threats such as climate change and emerging pests.

VPC seed quality assurance systems need to strike a careful, but sensible balance between permissive rules at a local level and stricter regulations at the national and regional levels. At present, however, few countries have found this balance, with most still promoting strict and centralized quality control regulations that no one can comply with.

The alternative is a more permissive regulatory regime with decentralized production systems, grassroots capacity development, market surveillance, and quality assurance systems that integrate internal quality assurance (managed by seed producers) with external quality assurance (managed by government regulators).

Tanzania may have found the balance between over-regulation and none. New seed regulations were introduced as part of a larger upgrade of the cassava system. Farmers were not used to buying cassava seed, which they sourced from local farms. From 2013, IITA and Mennonite Economic Development Associates (MEDA) worked closely with the Tanzania Official Seed Certification Institute (TOSCI) and the Tanzania Agricultural Research Institute (TARI) to develop a network of seed inspectors and entrepreneurs as part of a BMGF-funded project, 'Building an Economically-Sustainable Seed System in Tanzania for Cassava' (BEST Cassava). BEST Cassava set up the Cassava Seed Growers' Association, to help seed entrepreneurs coordinate inspections from TOSCI. By 2020 new regulations for potato, sweetpotato and cassava covered all seed classes, from breeder to quality declared seed (QDS), a seed class one step below certified seed. TARI, TOSCI, MEDA and IITA formed a cassava advocacy team that encourages district councils to promote the production and processing of commercial cassava. The team trains farmers to make more money from cassava, by using disease-free, certified seed.

Cassava breeder seed of CBSD-resistant variety Mkuranga1 being multiplied in a screenhouse of the Tanzania Agricultural Research Organization (TARI), at Kibaha near to Dar es Salaam, Tanzania. J. Legg (IITA)

The Tanzania experience was valuable for Rwanda, where viral diseases had severely impaired cassava production. In 2017 the IITA-led Cassava Brown Streak Disease (CBSD) Control Project supported the development of cassava seed standards, with an emphasis on inspections to guarantee that cassava seed is disease-free, with a preference for disease-tolerant varieties. Regulations also allow QDS. These standards were approved by the Rwanda Standards Board (RSB) in 2018. Rwanda was able to act quickly, within a year, because of the example set by the successful model piloted in Tanzania.

Where there are few threats from plant health problems, a more permissive, seed regulation policy makes sense. However, major pest and disease threats can be managed in part by enforcing seed quality control. International borders are a critical point to apply strict quality control to minimize the risk of long-distance spread of pests and diseases of VPC seed. More permissive and cost-effective seed policies remove a key bottleneck to broader adoption of quality seed of improved varieties.

RESILIENT ROOTS, TUBERS AND BANANAS

Flagship Project 3

develops and supports the strategies and tools needed to keep root, tuber and banana crops healthy and productive. Pests and diseases continue to evolve and to emerge in new countries, such as banana bunchy top disease across Africa and cassava mosaic disease in southeast Asia. "FP3 is improving its user-friendly apps that farmers and extensionists can use with an inexpensive smart phone. We are also combining satellite images with drone photography to create digital technology that smallholders can use to manage crop pests and diseases," explains James Legg, FP3 leader, and scientist at IITA.

Better pest management by understanding gender differences

Interdisciplinary teams of scientists across the CGIAR's Roots, Tubers and Bananas Program (RTB) studied how women and men perceive and manage pests and diseases differently and how this matters in the adoption of crop protection technologies. Without considering gender, innovations will not reach all farmers. A gender perspective can enhance the design and scaling of pest and disease management technologies.

Understanding gender can help design better pest management programs. Women farmers often have their way of seeing and managing pests, that may differ from those of men.

Men may have attended more years of formal schooling, where they learned to read and speak the national language. Training for women may require a female facilitator who can create a comfortable environment for women, by speaking in the local language.

Women work longer hours than men, so there is a need to avoid new technologies that demand more labor. Labor-saving techniques, like pheromone traps, can be used.

◄ Harvesting banana. (CIP)

Even when men and women grow different crops, they can interact in unforeseen ways. For example, in the East African highlands, men usually manage the banana crop, while women oversee the climbing beans that grow up the banana plants. If only men learn to control banana *Xanthomonas wilt* by removing the diseased stems, they may uproot the women's bean plants. Therefore, women need to be involved in banana disease management training, even if they are not directly in charge of banana production. Based on these findings, the teams working on banana disease management are developing new strategies to ensure that women receive training, even if they are not directly in charge of banana production.

Female banana-farmers, like this widow in Isingiro district, Uganda, have their own needs, assets and knowledge. A.Rietveld (Alliance)

Pests can even lend themselves to different management strategies, according to the gendered division of labor. For example, in southern Ethiopia, men control millipede pests in sweetpotato by planting early, because men do the plowing, while women hand kill the pests while inspecting the fields.

In Southeast Asia, where cassava is a cash crop of the poor, widows have less money than other farmers and are less inclined to invest in clean seed to manage disease. Some programs are now offering specific support to female-headed households to understand their attitudes towards clean seed, and to help them overcome constraints so they can use it.

INTERDISCIPLINARY TEAMS OF SCIENTISTS across the CGIAR's Roots, Tubers and Bananas Program (RTB) studied how women and men perceive and manage pests and diseases differently and how this matter in the adoption of crop protection technologies.

Pheromone trap for potato tuber moth in a potato field in Kabale, Uganda. J. Okonya (CIP)

"RTB research and interventions have shown that technologies for crop protection are widely available, but appropriate approaches to introduce these technologies are missing. Understanding gender norms and relations is a first step to increase adoption of the technologies," explains Nozomi Kawarazuka, RTB gender cluster leader.

By looking deeply at the world of men and women, we learn to see the people behind the crops, with their own needs, assets and knowledge. Men and women farm differently. They have different access to cash, information, labor and land. They may grow different crops and have different tasks on farm. These and other differences give women farmers their own perspective on crop pests and diseases. This understanding is helping to develop and share technologies that respond to the needs of female and male growers of root, tuber and banana crops, so that everyone can improve their pest and disease management.

▸ **Training trainers in OFSP production, multiplication, pests and diseases management in Kasungu.** E. Abidin (CIP)

Weathering the storm with sweetpotatoes and other root crops

As a ground hugging crop that produces food underground, the sweetpotato is ideal for resisting the ravages of tropical storms. And thanks to its short cycle, planting the sweetpotato after extreme weather events has helped farmers bounce back from shocks like Cyclone Idai in Mozambique and Typhoon Ompong in the Philippines. Sweetpotato varieties are also being bred and released for salt- and drought-resistance, making the sweetpotato an important crop for adapting to climate change.

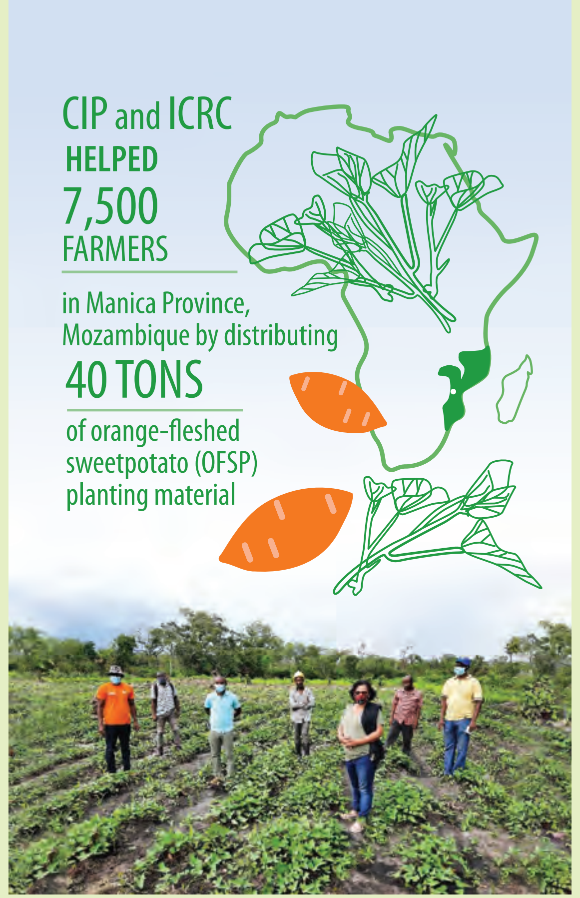
Extreme weather events (such as typhoons) are increasingly frequent. For example, Buzi district in central Mozambique was struck by Cyclone Idai in March 2019, only to be devastated in December 2020 by Cyclone Chalane. Around the world, storms are becoming more destructive, likely because of climate change. Typhoons and cyclones damage crops in the coastal tropics, threatening food security as a smaller harvest means there is less to eat and less to sell. Washed out roads and bridges make it harder to get to market to sell the produce that is available, so farmers lose the income they need to buy school supplies, medicines and certain foods.

Crops like the sweetpotato, whose product grows underground, resist strong winds and heavy rain better than do above-ground crops and trees. The ground hugging sweetpotato vines largely escape damage from typhoons and cyclones, allowing rural households to still harvest some food to eat and to sell. And because the sweetpotato matures quickly, resource-poor families can plant it after a storm and start to produce food soon. Two months after planting, families can begin to eat the plant's nutritious leaves, and after three months, the high-calorie, vitamin-rich sweetpotato roots are ready to harvest. The sweetpotato requires less

Houses flattened by cyclone Chalane on December 30, 2020. Sweetpotatoes help families recover from such disasters. T. Issa (SADE)

management and fertilizer than many crops, which also makes it an ideal investment after a disaster, when time and money are often scarce.

Cyclone Idai, which hit southern Africa on 15 March 2019, left more than 1,000 people dead and caused $2 billion worth of damages, including widespread crop loss. A collaboration between the International Potato Center (CIP) and the International Committee of the Red Cross (ICRC) helped 7,500 farmers in Manica Province, Mozambique, by distributing 40 tons of orange-fleshed sweetpotato (OFSP) planting material. The high-yielding, CIP-bred OFSP varieties distributed by the Red Cross are rich in vitamin A, which is vital for healthy child development. Now USAID is helping CIP to rebuild the seed system in Sofala, benefitting 40,000 households.



Farmers, local agriculture authorities and the CIP team inspect this sweetpotato multiplication plot in Buzi, Mozambique. Just a week after Cyclone Chilane, the crop is recovering quickly. E. Agostinho and A. Naico (CIP)

Super Typhoon Ompong made landfall in Luzon on 15 September 2018, and wreaked havoc across the northern Philippines. Eighty-two people were killed, and 800,000 households were affected. There was at least $493 million damage, just to agriculture. Even after taking a beating from the typhoon, most sweetpotato plants were still green and healthy; 97% of rice farmers reported losses, but only 14% of sweetpotato growers. Rice farmers lost on average 51% of their standing crop, but sweetpotato growers saved all but 8% of their crop. Other root crops, like cassava, taro and yam, also fared better than cereal crops.

"The sweetpotato by nature stands up to stormy weather, but climate change is also making drought more common. RTB is also breeding sweetpotato varieties that are drought-tolerant and also tolerant to salinity. This helps to make the sweetpotato doubly able to meet the challenges of a changing climate," says Maria Andrade, of CIP.

Sweetpotatoes grow close to the ground, so they largely escape storm damage, and can soon produce food for isolated, rural families. N. Abdul (CIP)

Global cooperation fights a potentially devastating banana pandemic

A potentially devastating banana disease (Fusarium TR4) is now spreading across the tropics, threatening the livelihoods of smallholders and large commercial farmers alike, especially growers of Cavendish, the main variety of dessert banana. There have been efforts to understand and control this devastating disease, but a real solution will require international cooperation across many disciplines. In 2020, RTB supported a virtual symposium and a masterclass to share information on how TR4 spreads, how to diagnose it and insights into future control methods.

A virulent strain of a soil-dwelling fungus known as Fusarium Tropical Race 4 (TR4) is threatening the world supply of bananas, and the livelihood of millions of farmers. TR4 kills the banana plant by attacking its vascular system. Disease management is complex, as the fungus persists for decades in infected fields and there are no fully effective strategies for managing TR4.

The pathogen spreads easily through spores, in contaminated soil and planting material. The spores even cling to farmers' shoes and farming equipment. First identified in Taiwan in 1967, TR4 spread to other Asian countries by the early 2000s.

◄ **Sampling a diseased banana in northern Mozambique. Surveys like this help to map the spread of TR4.** G. Blomme (Alliance)

Since 2014, the disease has expanded quickly across the greater Mekong Delta, especially in Laos and Vietnam. TR4 also emerged in 2013 in Mozambique, and was more recently identified on Mayotte, an island in the Indian Ocean. In August 2019, TR4 was reported in organic banana plants in La Guajira, Colombia, while in April 2021, TR4 was spotted in northern Peru, also on an organic banana farm. So far, the Colombians have managed to contain TR4 in the department of La Guajira, although the pathogen has spread from two farms to ten. The Cavendish variety, which dominates the market for dessert bananas, is widely grown as a monocrop, facilitating the spread of the disease. However, TR4 is also starting to gradually spread into smaller-scale, more diversified banana farming systems in various Asian countries.

TR4 kills the banana plant by attacking its vascular system. M. Dita (Alliance)

Internal symptoms of Fusarium wilt, TR4 affecting Cavendish bananas in Colombia. M. Dita (Alliance)

The Alliance of Bioversity and CIAT and the International Institute of Tropical Agriculture (IITA), with the support of RTB, held a two-day virtual mini-symposium which presented a state-of-the-art overview of research on this disease. In addition, a virtual Masterclass for anyone interested in the pathogen, diagnostic tools, control strategies and the impact was organized by The Alliance and IITA in the framework of ProMusa and RTB.

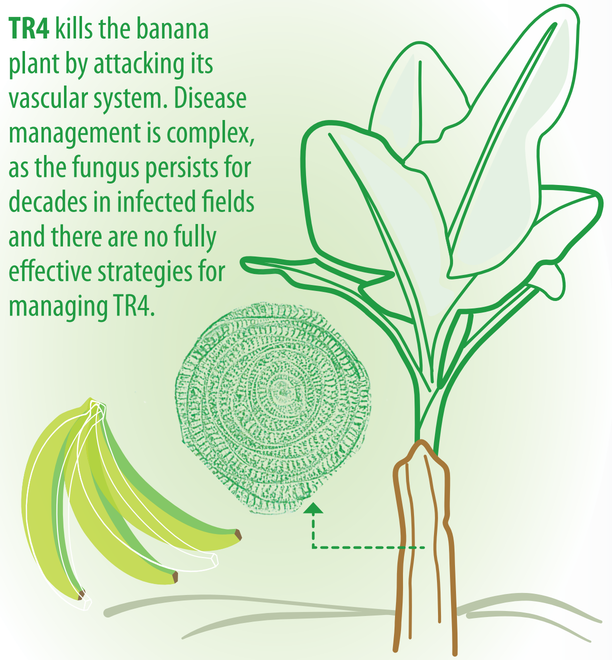
During the Masterclass, banana researchers from across the globe presented current knowledge on *Fusarium* spread, epidemiology and control. At the virtual symposium, novel research insights were communicated. For example, how to detect viable *Fusarium inoculum* from environmental samples, or insights in the survival and treatment of *Fusarium* in water. In addition, weevils and nematodes were reported to contribute to disease spread and infection intensity. The symposium also presented new tools to detect and map TR4.

The symposium discussed biocontrol approaches, including use of the beneficial fungus *Trichoderma* to control TR4. The substrate left over after harvesting cultivated mushrooms could be applied to the soil to stop the spread of the disease. Groundcover root flavonoids and phenolic acids may also help stop the fungus in the soil. Researchers in China have identified beneficial bacteria closely related to the well-known Bt. Two of these *Bacillus* bacteria are now being screened to find the best strains for biological control of TR4. Colombian scientists are testing ammonia-based soil disinfectants to eliminate the pathogen from locations where infected mats had been removed.

FUSARIUM TROPICAL RACE 4 (TR4)

Is a virulent strain of a soil-dwelling fungus.

TR4 kills the banana plant by attacking its vascular system. Disease management is complex, as the fungus persists for decades in infected fields and there are no fully effective strategies for managing TR4.



The key option to mitigate the impact of *Fusarium* is through the use of resistant or highly tolerant germplasm. Some promising genetic material is currently available and is being used, and many other banana types are being screened for resistance. Therefore, conventional breeding, in addition to GM and CRISPR, will most likely widen the pool of resistant germplasm in the years to come.

"The rapid spread of TR4 threatens food security across the tropics on three continents. The banana also creates lots of jobs, including many for women and youth, from farming to packing houses to retail sales. It's heartening that the world's experts have been able to start working together to develop the technologies that will solve this crisis," says James Legg, leader of FP3, which helped to sponsor the symposium.

Female banana exporter in Uganda. (CIP)

Leaves turn yellow on a diseased plantain plant. A Fusarium Race 1 affected Bluggoe plant in northern Mozambique. G. Blomme (Alliance)

Alliance for Banana Bunchy Top Disease Control in Africa

The banana bunchy top virus (BBTV) has now spread to 16 African countries, threatening the livelihoods of 70 million banana farmers and imperiling the diversity of the varieties they grow. RTB has coordinated the Alliance for Banana Bunchy Top Disease (BBTD) Control in Africa. This unique initiative aligned international, multi-stakeholder teams to combat this dangerous disease. The BBTD Alliance has fostered cutting-edge research for development (R4D), established practical solutions so farmers can once again produce bananas for food and income. The Alliance has also helped to build capacity among national programs in the detection, surveillance, and control of BBTD.

The banana bunchy top disease (BBTD), caused by the banana bunchy top virus (BBTV), is spreading across sub-Saharan Africa. Since the disease was first reported in the Democratic Republic of the Congo (DRC) in the 1960s, the virus has invaded 16 countries, and it endangers a crop grown by 70 million households. The virus spreads through planting material and by an insect vector, the banana aphid. This disease stunts the plant which stops producing fruit. Sometimes all the fruit is lost in a single season. When BBTD strikes, the recommendation to farmers is to eliminate infected banana mats and replace them with healthy suckers. However, smallholders hesitate to destroy large parts of their banana gardens, especially if some of their plants are still bearing bunches.

Where BBTD strikes, it increases the demand for clean planting material while making it more difficult to find seed of local landraces. This threatens the diversity of well-adapted landraces.

There is a strong premium for collective action as farmers need to act together to prevent disease from spreading to their community and to prevent reinfection after replanting. Collective action also facilitates training, allows for peer support, information exchange and fidelity to control options.

Banana mat with advanced symptoms of BBTD. The banana aphid can spread the virus from this unproductive mat to healthy ones. As farmers take seed suckers from this plant, they unwittingly spread the disease to new fields. L. Kumar (IITA)

Bunchy Top Alliance research team checking for banana aphids. L. Kumar (IITA)

Bunchy top symptoms are subtle (green leaves with yellow margins and shortened petioles). These fresh leaves may look healthy, but they are too small and too close together. This mat may yield nothing and needs to be eliminated and replaced with healthy plants. L. Kumar (IITA)

STOP BUNCHY TOP

THERE IS A STRONG premium for collective action as farmers need to act together to prevent disease from spreading to their community and to prevent reinfection after replanting

Nigerian Agricultural Quarantine Services (NAQS) inspectors reviewing the BBTV surveillance app to find and report diseased plants to control the spread of the disease. L. Kumar (IITA)

Because BBTD can easily cross borders, management requires international cooperation. In 2011, RTB set up an interdisciplinary, multi-national Alliance for Banana Bunchy Top Disease Control in Africa, coordinated by IITA, the Alliance of Bioversity International and CIAT, with CIRAD and national research partners (Benin, Burundi, Cameroon, Congo Brazzaville, DRC, Ghana, Malawi, Nigeria, and Zambia), the FAO and the Inter-African Phytosanitary Council (IAPSC), and research partners from Australia (University of Queensland), Asia, Europe, India, Kenya, UK (University of Cambridge) and the USA.

The BBTD Alliance developed new knowledge and management technologies, while building capacity, and supporting national partners and farmer organizations. Ten graduate students conducted research on disease management and epidemiology, diagnostic tools, disease-resistant banana varieties, and remote surveillance with satellite and drone images. Seed entrepreneurs, extension agents, farmers and plant health inspectors were trained to diagnose the disease in the field, rogue infected plants and produce clean planting material. Trainees learned to recognize the early symptoms of BBTD, and to understand that the virus can only be stopped by eliminating diseased plants. The countries joined to contain the spread of BBTD across the continent, thanks in part to annual workshops for sharing knowledge and technologies.

The BBTD Alliance taught disease management at pilot sites, using farmer field schools (FFS) to collaborate with farmer experimenters. Consistent removal of diseased mats (roguing) based on early farmer-detectable disease symptoms was found effective in maintaining BBTD levels below 1% in Malawi, Benin and Burundi trials, and supporting the production of low-risk seed for expansion. Gender analysis shed light on power dynamics within the households and communities to ensure that women and men farmers benefited equitably from the FFS. Farmers learned to multiply clean seed and they were linked to tissue culture and other sources of healthy planting material. An experiment with farmers in seven countries showed that BBTD could be managed with timely rogueing to produce healthy planting material.

The early detection of BBTD when it spread to Togo, and the eradication of the virus there, is the first case for halting the spread of an invasive virus in sub-Saharan Africa. Demonstrations and hands-on training helped Togolese partners to eliminate the disease. Farmers, extension workers, policymakers, and donors saw firsthand how BBTD was managed in Benin, Cameroon, Malawi, and Nigeria. In 2020, RTB developed an online training course on disease recognition and eradication.

Studies examined the gendered access to information and resources in Benin, Cameroon and Nigeria. For example, in Cameroon, men had a greater say in decision-making over farm resources and information services, even when women were more involved in actual seed and site selection. Men also had greater access to clean seed than women. "Getting healthy planting material is crucial for managing bunchy top, and if women cannot access clean seed, they are at a disadvantage. Projects across Africa will have to ensure that women have equal access to healthy planting material," says Lava Kumar of IITA.

Getting ready for surveillance and eradication of BBTV infected banana plants. L. Kumar (IITA)

Identification of banana diseases and their spread using remote sensing and smartphones

Using the Tumaini AI-powered smartphone app to ground-truth aerial diagnoses. B. Omondi Aman (Alliance)

The Alliance of Bioversity and CIAT is using drone imaging in combination with open-source satellite images to identify bananas in mixed crop landscapes in eastern Democratic Republic of Congo and in southern Benin. Once banana plants are identified, researchers use advanced algorithms and machine learning to distinguish healthy plants from those affected by BXW (banana *Xanthomonas* wilt) or BBTD (banana bunchy top disease) with over 90% accuracy. Future research is needed to better distinguish BXW from *Fusarium* wilt and other health problems that turn leaves yellow. The Tumaini AI-powered smartphone app can be used to ground-truth these aerial diagnoses, allowing researchers to develop and further improve machine-learning models to detect banana diseases early, and prevent outbreaks.

Figure from Selvaraj et al. shows aerial drone images narrowing in on the disease, and the contrast between healthy and diseased plants. B. Omondi Aman (Alliance)

Using the Tumaini AI-powered smartphone app to ground-truth aerial diagnoses. (Alliance)

NUTRITIOUS FOOD AND VALUE ADDED

Flagship Project 4

harnesses the nutritional potential of roots, tubers and bananas, expanding their use sustainably, and adding value through post-harvest innovation. "At FP4 we have an exciting partnership with RTBfoods that is helping us to turn our crops into nutritious foods that farmers and consumers love," says Tawanda Muzhingi, FP4 leader and food scientist at CIP.

Iron fist potatoes, integrating nutrition and agriculture in social protection programs

A Zero Anemia project in Peru is linking agriculture with nutrition in coordination with a variety of public social protection programs. The mothers of young children visiting health clinics for checkups receive vouchers for seed of potatoes that are high in iron. The women and their families learn about growing these potatoes, so children and pregnant women eat more of them. Nutritionists share recipes that are adapted to local food preferences while explaining that eating iron-rich potatoes contributes to reducing anemia.

Social protection programs can be a way to scale food-based nutrition solutions linked to agricultural innovation. Potato has great potential for reducing iron-deficiency. A recent study published in the Journal of Nutrition demonstrated that iron from yellow fleshed potatoes has a high absorption in the human body, contributing 30% of the iron requirement of women on fertile age. It is expected that iron biofortified potatoes can contribute over 50% of the dietary iron requirements in places where it is a major staple such as the Andes.

◄ **A women farmer of La Libertad.** Asociación Pataz

Iron biofortified potatoes can help prevent anemia, but only if people grow them and eat them as part of a diverse diet. A pilot project in Peru, Zero Anemia, is combining nutritional education with seed vouchers for "Iron Fist" potatoes. As part of the project, the International Potato Center (CIP) and its partners (Asociación Pataz and Institute for Nutritional Research) are studying the practices, knowledge, motivation, and attitudes surrounding complementary feeding of children aged six to 36 months. The seed vouchers are distributed through health centers to mothers with young children. To participate, women must be potato farmers, registered with two Peruvian government social programs: Juntos ("together"—targeting poor households) and Cuna Más ("crib and more"—for mothers with kids under three-years-old).

Iron Fist Potatoes calendar featuring best practices in nutrition and agronomy. F. Pinedo, (Asociación Pataz, La Libertad)

In the first year, one hundred and forty-two households redeemed their vouchers for 10 kg of biofortified seed potatoes. The project included a communication campaign targeted at both men and women, so that everyone would understand the nutritional benefits of these potatoes, and how to grow them.

The bags of seed included three new CIP clones, biofortified through conventional breeding, and two commercial landraces, Bretaña and Huevo de Indio, all high in iron. The seed potatoes were delivered by the "Papas Puño de Hierro" (Iron Fist Potatoes) campaign by government extension agents in collaboration with municipal governments, in coordination with local actors.

The mothers received the seed before the planting season (November and December 2020), along with a flyer and a calendar describing how to grow and prepare these iron-rich potatoes.

Extensionists monitored the crop and gave farmers technical assistance. During the harvest of May–June 2021 the clones will be further evaluated for yield and their acceptance by the families. A cooperative of seed potato growers will multiply the varieties for coming seasons, which is essential for further scaling.

"Many farmers who grow potatoes suffer from anemia, especially women and children, because they need more iron in their diets," explains Ronal Otiniano from Asociación Pataz, adding "Native potatoes are high in iron, but Zero Anemia is part of an effort to breed potatoes that are biofortified to have even higher levels of iron, to improve the nutritional impact."

Scaling the potatoes involves some innovative nutrition messaging. The project has written dietary guidelines with healthy recipes for young children. The project also produced a song and video about the iron fist potatoes, with local singer Kenty José. The song aired on radio stations in the districts of Curgos and Julcán.

Since almost all food starts on farms, it's natural that agriculture and nutrition go together, although this often is not the case in practice. Zero Anemia is helping to make it happen and the plan is to link with social programs for broader scaling.

Fighting anemia with seed and knowledge. An extension agent shares iron-rich seed potatoes, and a flyer about growing and eating them. C. Villanueva (Asociación Pataz, La Libertad)

Breeding for better nutrition: Iron-rich potatoes and sweetpotatoes to combat anemia

In developing countries, almost half of young women and children under five suffer from anemia, caused by a lack of iron in their diets. While beans and certain vegetables are iron-rich, the iron in potatoes and sweetpotatoes is easier for the human body to absorb, because these crops are low in plant compounds (like phytates ad phenolic acids) that inhibit iron absorption.

An RTB study In Malawi concluded that women could get 18% of the iron they needed by eating iron-biofortified, orange-fleshed sweetpotato (OFSP) over two weeks.

In a study in Peru, RTB recently found that iron absorption from a yellow-fleshed potato variety is significantly higher than that in a purple–fleshed, iron-biofortified potato. High polyphenol levels in the purple fleshed potato were likely the major inhibitors of iron absorption. Iron absorption from a yellow–fleshed, biofortified clone is expected to be as high as from the yellow-fleshed variety.

Potatoes that are rich in iron can help alleviate the suffering of women and children who suffer from anemia. Bertha Azursa Clemente and her son with biofortified potatoes in Huancavelica, Peru. S. Fajardo (CIP)

Gabriela Burgos, nutritionist at CIP explains *"Peruvian women could obtain 33% of their daily iron needs from the yellow-fleshed potato variety and probably more than 50% of their needs from an iron-biofortified, yellow-fleshed potato clone. So, it could be a key food to promote in the Government's Zero Anemia Program".*

FP2 leader and senior sweetpotato breeder for Africa, Maria Andrade, testing out a meal during nutritional trials of sweetpotato. J. Low (CIP)

These studies give promise that roots and tubers can make a key contribution to meeting women's iron needs, considering their greater potential for biofortification, because potato and sweetpotato are amenable to conventional breeding to increase their iron and zinc content.

Consumers have their say: assessing and breeding for preferred quality traits of roots, tubers and cooking bananas

The CIRAD-led project, RTBfoods, is finding innovative ways to satisfy consumer demand for new crop varieties. The approach organizes consumer preferences for quality characteristics into "product profiles" for food types and translates them into physical properties and genetic traits that plant breeders can measure and select for. Technologies like near-infrared spectroscopy (NIRS) help to measure those properties quickly to rapidly screen for them in a breeding program.

The people who grow, prepare, and eat foods made from root, tuber and banana crops have strong preferences, but breeding for the textures and flavors they like can be elusive. This is a major reason why the adoption of improved varieties is rarely higher than 40% of the crop's area, as discussed earlier in this report.

CIRAD, a strategic partner of RTB, is leading a Bill & Melinda Gates Foundation funded project, RTBfoods, which is providing solutions. Teams working with food product profiles across all five crops use various tools to identify the qualities consumers want. Some of these preferred qualities translate into physical properties that breeders can select for. The findings will be used to screen for those traits early in the breeding cycle. If this process is completed, there's great promise to create improved varieties which many people will like, leading to enhanced adoption.

A special 2020 issue of the *International Journal of Food Science and Technology* highlights a comprehensive method developed by RTBfoods to define the food "product profile", that is, the end-users' preferences for a specific food product:

STEP 1 **Literature review and key informant interviews** identify the state of knowledge and knowledge gaps in food science, gender, and markets, to focus research.

STEP 2 **Gendered food mapping exercises**, using statistically robust methods in communities to determine the qualities of varieties needed by men and women.

STEP 3 **Demonstrations with champion processors** to evaluate varieties during food preparation.

STEP 4 **Consumer taste tests** for foods made from different crop varieties.

STEP 5 **A food product profile** defining quality characteristics important for women and men along the food chain.

The special issue presents eight different product profiles which can have transformational impact on breeding work. However, RTBfoods realizes that defining the food product profile is just the first step in a process that moves breeding forward:

1. Define the food product profiles.
2. Link food product profiles to properties, like starch, pectin, and moisture, that can be assayed in the lab.
3. Develop tools to rapidly screen for these properties early in the breeding cycle.
4. Integrate the traits that consumers want into breeding programs.
5. Evaluate the new varieties with consumers.

Pairwise **ranking of fufu (fermented cassava) prepared and ranked by successful, small-scale processors in Osun State, Nigeria.** D. Dufour (CIRAD)

Champion processors in Osun State, Nigeria evaluate varieties of cassava to see which one makes the best fufu using different cooking techniques. D. Dufour (CIRAD)

In Nigeria, IITA and partners crafted food product profiles by identifying traits of importance to rural consumers of pounded yam, a dough made from boiled tubers. People preferred pounded yam that is: stretchable, moldable, sticky, smooth, and moderately soft.

RTBfoods is pioneering methods to link such preferences with properties that breeders can screen for. For example, color preference in yam is easy to predict, and studies are ongoing to develop assays for stretchability. In cassava, water absorption and changes in relative density during boiling correlate with quick cooking time, which is important for cassava consumers. An operator can process up to 100 samples per day using these objective criteria.

Near infra-red spectroscopy (NIRS) quickly reads the infrared-light spectrum of uncooked (or cooked) lab samples of potato, sweetpotato, yam, cassava, or banana to simultaneously and quickly screen for diverse properties in a breeding program, such as starch, fiber or beta-carotene content as well as other compounds that could be of special interest, such as tannins or cyanogenic compounds.

"Breeders used to make crosses and then spend years selecting the best hybrids. NIRS will let breeders discard the unpromising offspring in the first seasons, to narrow in straightaway on the best candidates," says Emmanuel Alamu of IITA.

Meeting consumer preferences for boiled and pounded yams in new varieties

Yam is a cherished food in West Africa. It is eaten boiled, roasted or fried, but especially as pounded yam (a slightly adhesive dough made by peeling, boiling, pounding and kneading). New yam varieties will only be successful if they can be used in these favorite recipes. In Nigeria consumers look for a pounded yam that is white and has a certain texture (easily stretched and molded, smooth and moderately soft). Second, pounded yam must have a pleasant aroma and taste (not bitter). In Benin, where boiled yam is a popular street food, consumers want tubers that are easy to peel, white or yellowish when boiled, sticky, crumbly, with a sweet taste and a pleasant smell. Boiled yams should not be too dark, or hard to the touch. Identifying these criteria precisely will help breeders to select the right lines for the next generation of improved yams.

Boiled yam pieces are crushed and pounded in a mortar by two pestles simultaneously to produce a smooth and stretchable paste. B. Teeken (IITA)

Pounding new yam hybrids in CNRA, Bouaké, Côte d'Ivoire. D. Dufour (CIRAD)

IMPROVED LIVELIHOODS AT SCALE

Flagship Project 5

helps take innovations to scale by developing and implementing tools and approaches that benefit more efficient and equitable scaling of the broad spectrum of RTB and CGIAR innovations. The RTB Scaling Fund provides a unique space to nurture the scaling of RTB innovations with our partners and to *"practice what we preach"* says Marc Schut, FP5 leader and senior innovation and scaling scientists with IITA and WUR.

The Scaling Fund: improving the scaling readiness of innovations

Researchers often face challenges as they translate their research into innovations for use at a large scale. Since 2018, the RTB Scaling Fund supported rooted apical cuttings (RAC) and seven other projects in Africa and Latin America to bring promising innovations into use. The projects used Scaling Readiness, a step-by-step approach to critically assess the readiness to scale innovations, and implement strategies aimed at resolving bottlenecks for scaling. The Scaling Fund was successful in advancing selected innovations and also contributed to improving the Scaling Readiness approach.

Model apical cutting of potato with simple leaves. M. Parker(CIP)

Research for development organizations struggle to find the best approaches to scale their innovations. Researchers often work more on the technical side of their innovations than on marketing, policy, communication and the rest of the enabling environment. FP5 is designing strategies to take innovations to scale, with mechanisms like the RTB Scaling Fund.

Since 2018, RTB has sent out several calls for concept notes on innovations seeking Scaling Fund support. An independent panel assessed the scaling readiness of those innovations. Each year, the innovations with the highest scores received funding. Since 2018, three batches of projects have been funded, for two years each (Table 1).

◄ FIPS VPA Cesinter Nduru in her dehaulmed seed potato plot of Asante variety. This is to ensure the root tuber grows to the recommended seed size in Murinya village, Kibirichia ward. R. Jumah (CIP)

Table 1. Overview of the eight Scaling Fund Projects awarded and implemented between 2017 and 2021

RTB Scaling Fund Batch		
2018-2019	**2019-2020**	**2020-2021**
1. Scaling Single diseased-stem removal (SDSR) for BXW banana disease in Burundi, eastern DR Congo, Rwanda and Uganda	1. Orange Fleshed Sweetpotato (OFSP) Puree for safe and nutritious food products and economic opportunities for women and youths in Kenya, Uganda and Malawi	1. TRICOT - Scaling RTB crop variety validation and diffusion using farmer citizen science in Ghana and Rwanda
2. Conserving sweetpotato roots to produce planting material known as Triple S in Ethiopia and Ghana	2. Scaling approach for flash drying of cassava starch and flour at small scale in Nigeria, DR Congo and Colombia	2. Scaling AKILIMO – A Digital fertilizer recommendation service in Nigeria, Tanzania and Rwanda
3. A technology for turning cassava peels into an ingredient of animal feed in Nigeria	3. Scaling Rooted Apical Cuttings in Kenya and Uganda	

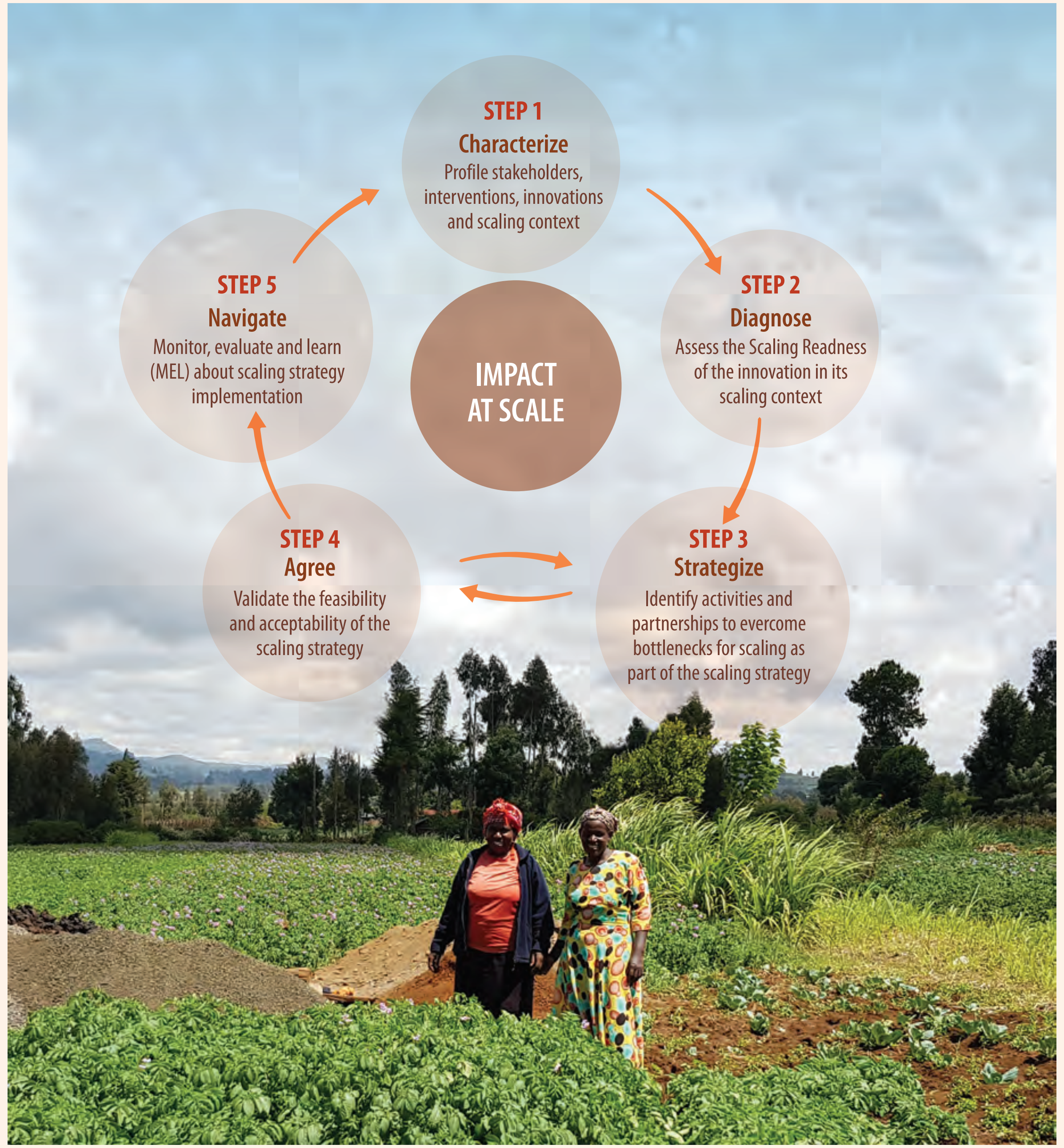


Figure 1. Scaling Readiness proposes a step-wise approach to operationalize innovation system thinking in support of the development, implementation and monitoring of better-informed scaling strategies (Sartas et al. 2020)

The Scaling Fund does more than award money to winning projects. RTB's FP5 team also guides project leaders as they design scaling strategies based on the Scaling Readiness Approach, monitoring their progress, and drawing lessons to inform critical thinking about scaling. Scaling Readiness provides concepts, practices and tools to guide decision-making on scaling of innovations. It supports the design of context-specific innovation packages. The approach assesses each innovation in the package for its readiness to contribute to development outcomes. This provides a basis for identifying the bottlenecks for scaling and developing and implementing strategies to overcome them.

One of the projects supported in Year 2 was for rooted apical cuttings (RACs), an innovation based on exploiting the yield potential of juvenile planting material to start bulking seed in the field. RACs are distributed to seed producers to plant in the field to bulk quality seed to quickly disseminate novel varieties. The innovations in the package comprise:

RAC method: Cuttings are taken from plantlets in the screen-house and transplanted into plugs of substrate. The cuttings take root and grow into vigorous plantlets which can be planted in the field

Robust market-demanded variety: Tolerant to disease, heat and water stress

Tissue culture: Starter material for cuttings and must be in place where cuttings are to be produced

Farmer producing seed potato on farm in a nursery plot from apical cuttings from a rural nursery. M. Parker (CIP)

Farmer producing seed potato. (CIP)

Seed system model: An integrated complex of seed producers from tissue culture to commercial seed and service providers and other stakeholders

Packaging: Economically viable options for packaging material and transport of rooted apical cuttings

Capacity building: Developing capacity of stakeholders in the technology and in seed production. Nurseries and seed producers are backstopped until they can operate independently

Investment feasibility: Ensure that the various innovations are economically feasible for users

The RACs innovation package was assessed using the concepts of Innovation Readiness and Innovation Use. Innovation Readiness is the demonstrated capacity of an innovation to fulfill its contribution to development outcomes in specific locations. Innovation Use indicates the level of use of the innovation or innovation package by the project members, partners and society (Table 2).

Table 2. Summary definition of levels of innovation readiness and use (Sartas et al. 2020)

Stage	Innovation readiness	Innovation use
1	Idea	Intervention team
2	Basic Model (testing)	Direct partners (rare)
3	Basic Model (proven)	Direct partners (common)
4	Application Model (testing)	Secondary partners (rare)
5	Application Model (proven)	Secondary partners (common)
6	Application (testing)	Unconnected developers (rare)
7	Application (proven)	Unconnected developers (common)
8	Innovation (testing)	Unconnected users (rare)
9	Innovation (proven)	Unconnected users (common)

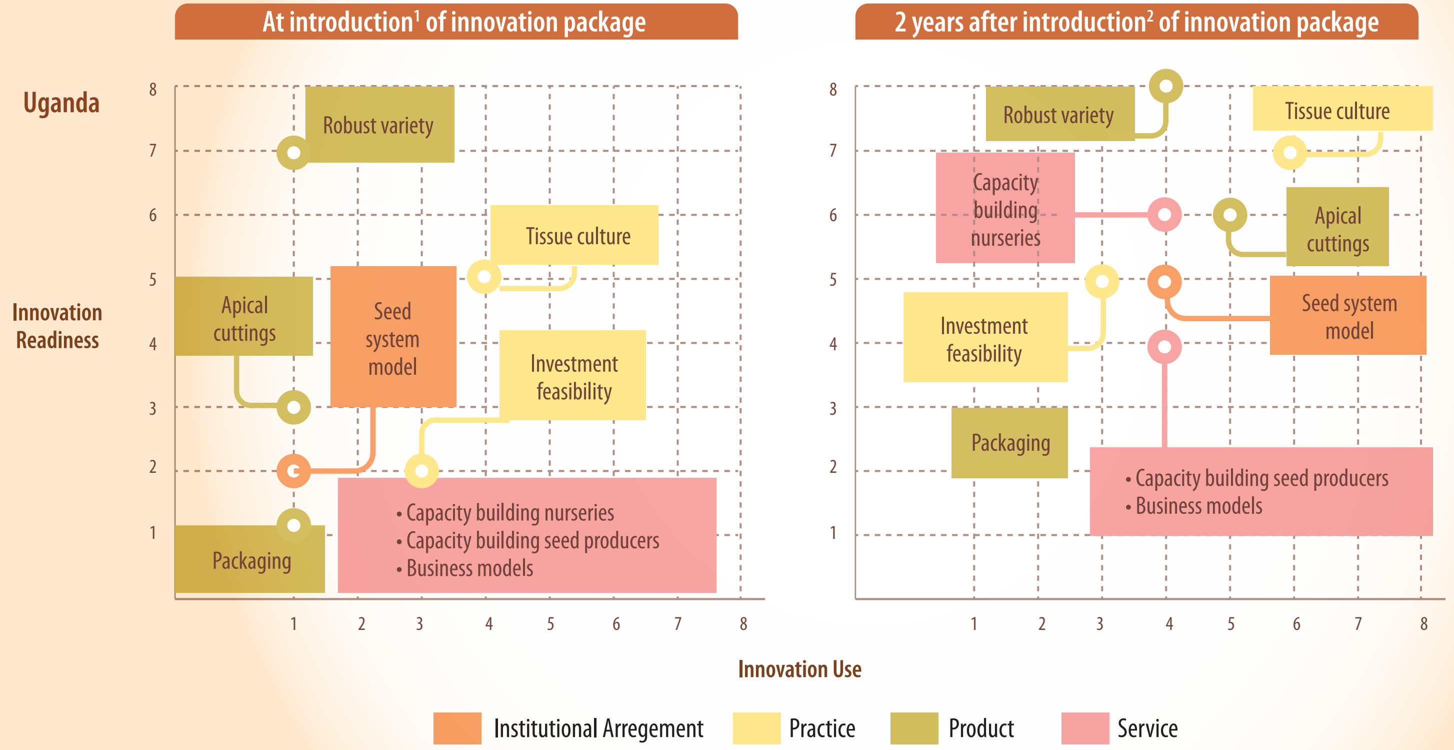
Over two years, the project improved the scaling readiness of the RAC innovations, especially with two critical bottlenecks: packaging and capacity development (Figure 2). Monica Parker who led the project explained that "the cuttings were accepted by users so quickly that they were being used incorrectly. The plantlets looked more like stem cuttings than high-yielding apical cuttings. This is being corrected through communication and various training events."

Parker observes that "Scaling Readiness helps researchers to understand that innovations do not scale themselves. The Scaling Fund supports a project as it anticipates obstacles, and then overcomes them."

The application of the Scaling Readiness approach with these projects enhanced scaling, but implementing the projects also improved the approach itself. Building on this work, the FP5 team has now published guidelines, and an article describing its theoretical underpinnings with more thorough outcome studies underway.

Apical cutting of potato. (CIP)

Figure 2. Readiness and use of the RACs innovation package at project start and finish in Uganda



The scores represent contributions from partners Kenya: National Potato Council of Kenya (platform), Stokman Rozen Kenya (private business), Farm Inputs Promotions Africa (NGO) and International Potato Center; and Uganda: KaZARDI and BugiZARDI (NAROs), Agromax (private sector), Self Help Africa (NGO) and International Potato Center

[1] At introduction of RTB Scaling Fund project, January 2019

[2] Following 2 years of RTB Scaling Fund project

Modelling farming systems to optimize interventions

FarmDESIGN is a model that helps to find the right balance between income, nutrition and soil health. An innovative application of the model in combination with a forward-looking partial equilibrium multi-market economic model, IMPACT, allows for analyzing various scenarios of future drivers of change. Complex interactions between biophysical and socio-economic spheres are explored and drivers like climate change, disease outbreaks, shifts in consumer demand or scaling of innovations are assessed and their possible impacts on ecosystems and livelihoods can be quantified. Modelling farms (in partnership with Wageningen University & Research) in Uganda, Kenya and Vietnam have shown that greater agrobiodiversity (such as growing more crops to eat at home) can increase the farm's resilience, improve the soil and put healthier food on the table. The model clarifies certain trade-offs. For example, a more diverse farm (with less land in cash crops) may not make the most money, but it may be better at adapting to a changing climate and to managing emerging pests and diseases.

Banana farmers in Uganda. S. Schumacher/ (Wageningen University & Research)

Encouraging farmers to take collective action to manage plant disease

Farmers may not be motivated to cooperate to manage a crop disease unless they understand how it spreads from one farm to another. Building avenues of cooperation, through apps and through local organizations, can also help motivate farmers to work together, as shown by an experience in Ethiopia.

Managing plant diseases often requires that farmers act as a group, but collective action needs to be carefully organized. As part of an EVOCA research program supported by RTB, a study on the management of potato late blight and bacterial wilt in Ethiopia highlighted coordination problems among potato farmers. Farmers misunderstood the causes of the diseases and how they spread. More than 90% of the surveyed farmers did not know that late blight and bacterial wilt are contagious. Each family tried to manage the diseases alone. So, the only group action was among the seed-producing cooperatives: perhaps only 5% of the potato growers.

In the seed potato cooperatives, the government set up a monitoring system where a farmer committee-imposed sanctions on those who failed to properly manage potato diseases. For example, the committee could reject farmers' seed potato, forcing them to sell it at low prices as ware (table) potato. But farmers who only produced ware potatoes disregarded the regulations and the committees had limited technical capacity to detect and manage diseases. Farmers also thought that the committees were biased towards their relatives and friends, adding to the mistrust from members who had their seed rejected.

Farmer committee members checking for adherence on collectively agreed disease management practices. E. Assefa (Wageningen University & Research)

Overcoming such problems requires that farmers reach an agreement on how to act, when, and how to monitor diseases, and how to set sanctions. EVOCA met with communities to teach them disease diagnosis based on visual recognition of symptoms, and management. Through this action research, the communities, especially the ware potato producers, came to understand that diseases are not simply induced by temperature or humidity, but by pathogens and that they are infectious, so they are a community problem. This motivated the cooperatives to include more farmers from the villages, to propose new ways of collaborating. Previously farmers had inspected their fields, but now they agreed to form teams of three neighbors for early morning joint disease scouting, with a monitoring committee to follow up on the scouting teams. When researchers suggested sanctions on those who did not manage diseases properly, the farmers feared that penalties could lead to conflicts. But when they realized that some farmers ignored agreed disease surveillance and management practices, they did impose sanctions, such as fines for missing team field scouting, or failing to report disease appearances.

As they worked together, the farmers realized that sanctions alone were not enough. Some farmers confided that they could not spray their fields because they could not afford fungicides. Other farmers decided to help them pay for fungicides, rather than risking an outbreak from unsprayed fields.

A three-day-long game experiment with potato-growing farmers showed how ICT can foster cooperative behaviors. Farmers received smartphones with an internet-based group communication application and training to use the device. They were allowed to communicate for three days in groups on individual and collective fungicide spraying. There were also control groups that did not communicate. Comparing farmers in these two groups showed that communication improved farmers' level of cooperation in managing the disease and avoiding free riders.

Extensionists should not only give advice, but also organize groups and use social media strategies. Knowing that a disease is contagious, understanding its cause, symptoms, and how it spreads helps motivate farmers to band together to manage it. Facilitated learning can help farmers design their monitoring systems. Organized farmers can then use ICT to share information about disease incidence, and about who is managing the disease well and who is not.

Government extension workers and potato researchers from a local agricultural research center actively supported this action research. After witnessing farmers' enthusiasm, an extension agent stated: "Farmers are engaged in this work; maybe they are more motivated because they are in charge." Berga Lemaga of CIP added: "Such an approach should not only be limited to disease management, but also extended to the adoption of all technical and social innovations that help boost potato production to impact food and nutrition security and increase its contribution to the national economy." Much more engagement is needed to stimulate change in Ethiopia's highly centralized research and extension system. To contribute to this effort, EVOCA is developing practice briefs and is planning a workshop with key stakeholders to get the message across.

Farmers learn to manage potato disease by working together, for example planting healthy seed potato. E. Assefa (Wageningen University & Research)

Knowledge Products cumulative

PUBLICATIONS

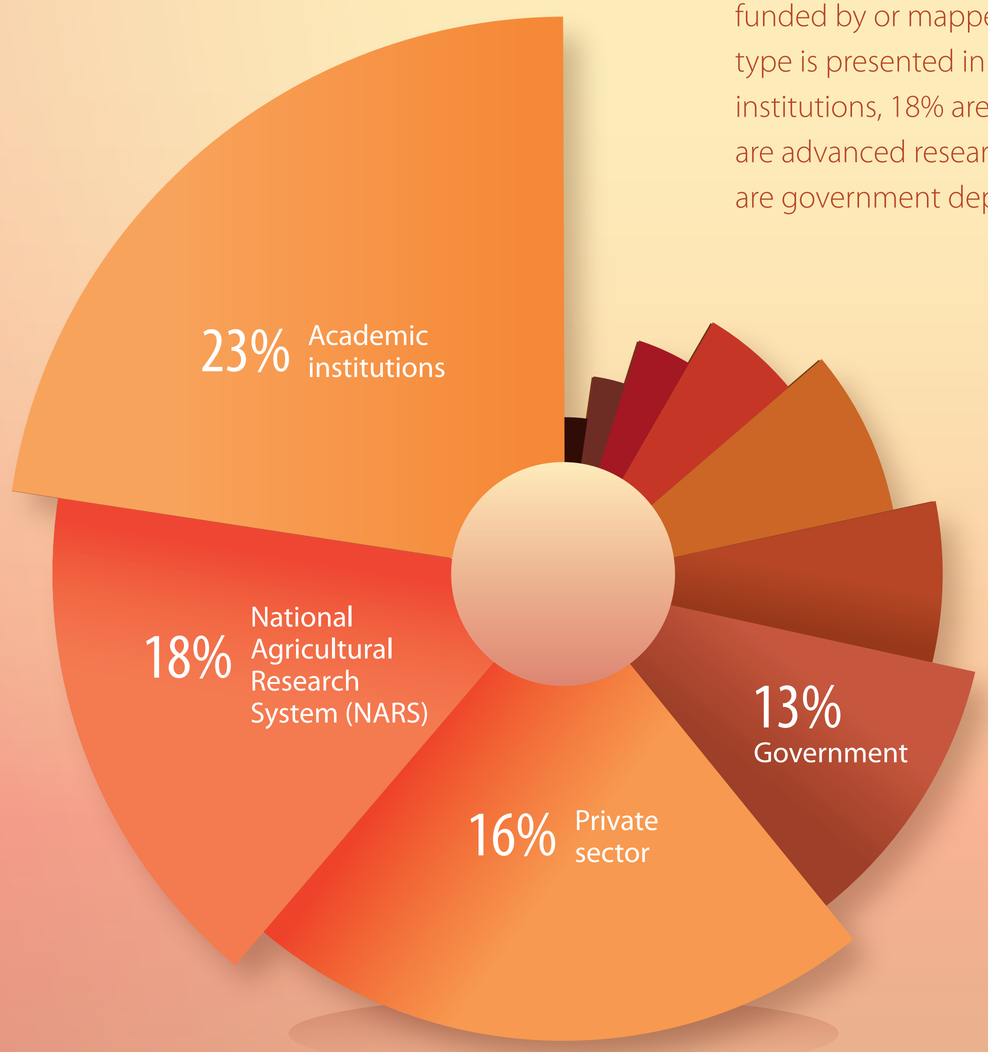
- **682** Peer-reviewed journal articles published
- **600** Publications in ISI journals
- **583** Open access journal articles

CGSPACE

- **371,679** Publications downloaded
- **482,839** Publications views

Partners

In total, 211 organizations have contributed to the results presented in this annual report. Our partners have contributed to at least a scientific article reported under RTB and/or have implemented a joint project or initiative funded by or mapped under RTB. The distribution of partners by organization type is presented in the graph below. Out of our partners, 23% are academic institutions, 18% are from a national agricultural research system (NARS), 8% are advanced research institutions, 16% are from the private sector and 13% are government departments at the national and subnational level.



- 10% Non-Governmental Organizations (NGO)
- 8% Advanced Research Institutions
- 3% CGIAR Center/Program
- 3% International Development Organizations
- 2% Regional and sub-Regional Organizations
- 2% Financing Institutions (including Foundations)
- 1% International Agricultural Research Centers
- 0.5% Farmers (individual or group)
- 0.5% Community Based Organizations (CBO)

Donors

2BLADES Foundation

AAH • Action Against Hunger

Australia ACIAR • Australian Centre for International Agricultural Research

Austria ADA • Austrian Development Agency

Belgium DGDC • Directorate General for Development Cooperation

BMGF • Bill & Melinda Gates Foundation

Comoros • Ministere de l'Energie, de l'Agriculture, de la Peche et de l'Environnement

CORNELL • Cornell University

EC • European Commission

France CIRAD • Centre de coopération internationale en recherche agronomique pour le développement

Friedrich Alexander • University Erlangen-Nuremberg

Germany GIZ • Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH

Government of India

Government of Japan

Government of Switzerland

IBRD • International Bank for Reconstruction and Development

ICIPE • International Centre for Insect Physiology and Ecology

IFAD • International Fund for Agricultural Development

Ireland • Irish Aid

McCAIN • Foods Limited

MEDA • Mennonite Economic Development Associates

NCSU • North Carolina State University

Netherlands NWO • Netherlands Organisation for Scientific Research

Perú MINAGRI • Ministerio de Agricultura y Riego del Perú

QUT • Queensland University of Technology

SFSA • Syngenta Foundation for Sustainable Agriculture

Spain AECID • Agencia Española de Cooperación Internacional

Uganda NARO • The National Agricultural Research Organisation

United Kingdom FCDO • Foreign, Commonwealth & Development Office

United States USAID • Agency for International Development

Financial Report

The total 2020 budget for RTB was USD 90.8M, USD 20.5M (23%) from W1&2, and USD 70.2M (77%) from W3, bilateral and RTB participant centers' own funds. The initial W1&2 budget was USD 19.0M. During the year the following risk mitigation measures were taken to reduce the COVID-19 impact on implementation: i) review the budget allocated to travel/workshop ii) reorient towards activities that would be more feasible to deliver, iii) reduce the overall budget allocated due to uncertainty of funds from donors. The final allocation was USD 18.1M. Additionally, RTB had USD 2.5M from carryover from 2019. Hence, the total budget for RTB in 2020 was USD 20.5M.

CGIAR Funding Windows

- Windows 1&2: funds are provided by the CGIAR to RTB for allocation across the agreed 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 by a Donor to a center using the centralized CGIAR trust funding facility. The Projects are mapped into RTB when they are consistent with the RTB portfolio.
- Bilateral: funds are contracts directly negotiated and signed between a center and a donor. The Projects are mapped into RTB when they are consistent with the RTB portfolio.

2020 Expenditure

RTB total expenditure in 2020 was USD 69.5M, or 77% of the budget, of which USD 17.6M (25%) was from W1&2, and USD 51.9M (75%) from W3, bilateral and centers' own funds. W1&2 expenses reached 86% execution of the final budget and W3, bilateral and centers' other own expenditure, reached 74% execution. The RTB flagships have an average execution of 87%. No flagship overspent.

The chart below shows the W1&2 budget and expenditure by flagship and the Program Management Unit (PMU) expenditure of USD 1.3M.

Flagship 2020 W1&2 Budget vs Expenses

(USD Millions)

Flagship W1-2	Budget									
	Bioversity International	CIAT	CIP	IITA	CIRAD	WUR	Partners	Add. Funds	PMU	Total
FP1 : Enhanced Genetic Resources	0.76	0.91	1.49	0.67	0.30	-	0.13	0.21	-	4.48
FP2 : Productive Varieties & Quality Seed	0.51	0.47	2.19	0.67	0.02	0.08	-	0.28	-	4.23
FP3 : Resilient Crops	0.83	0.46	0.69	1.37	0.08	-	-	0.37	-	3.81
FP4 : Nutritious Food & Added Value	0.17	0.50	0.65	0.53	0.24	-	0.08	0.11	-	2.27
FP5 : Improved Livelihoods at Scale	0.59	0.58	0.85	1.09	0.02	0.38	-	0.17	-	3.68
CRP Management & Support Cost	0.04	0.07	0.08	0.08	-	-	-	0.06	1.75	2.07
TOTAL	2.90	3.00	5.96	4.41	0.67	0.46	0.20	1.19	1.75	20.54

Flagship W1-2	Expenses									
	Bioversity International	CIAT	CIP	IITA	CIRAD	WUR	Partners	Add. Funds	PMU	Total
FP1 : Enhanced Genetic Resources	0.76	0.80	1.38	0.67	0.28	-	0.12	-	-	4.01
FP2 : Productive Varieties & Quality Seed	0.51	0.40	1.98	0.71	0.02	0.07	-	-	-	3.70
FP3 : Resilient Crops	0.83	0.42	0.61	1.32	0.08	-	-	-	-	3.25
FP4 : Nutritious Food & Added Value	0.17	0.49	0.63	0.46	0.17	-	0.08	-	-	2.00
FP5 : Improved Livelihoods at Scale	0.59	0.46	0.70	1.08	0.00	0.29	-	-	-	3.12
CRP Management & Support Cost	0.04	0.05	0.08	0.08	-	-	-	-	1.27	1.52
TOTAL	2.90	2.63	5.37	4.31	0.56	0.36	0.20	-	1.27	17.61

* Add. Funds: corresponds to the final confirmation of funds by the Foreign, Commonwealth, and Development Office (FCDO), SMO transferred an additional as supplemental W1 to ensure RTB received at least 90% of the planned budget and Scaling Funds 2nd Year.

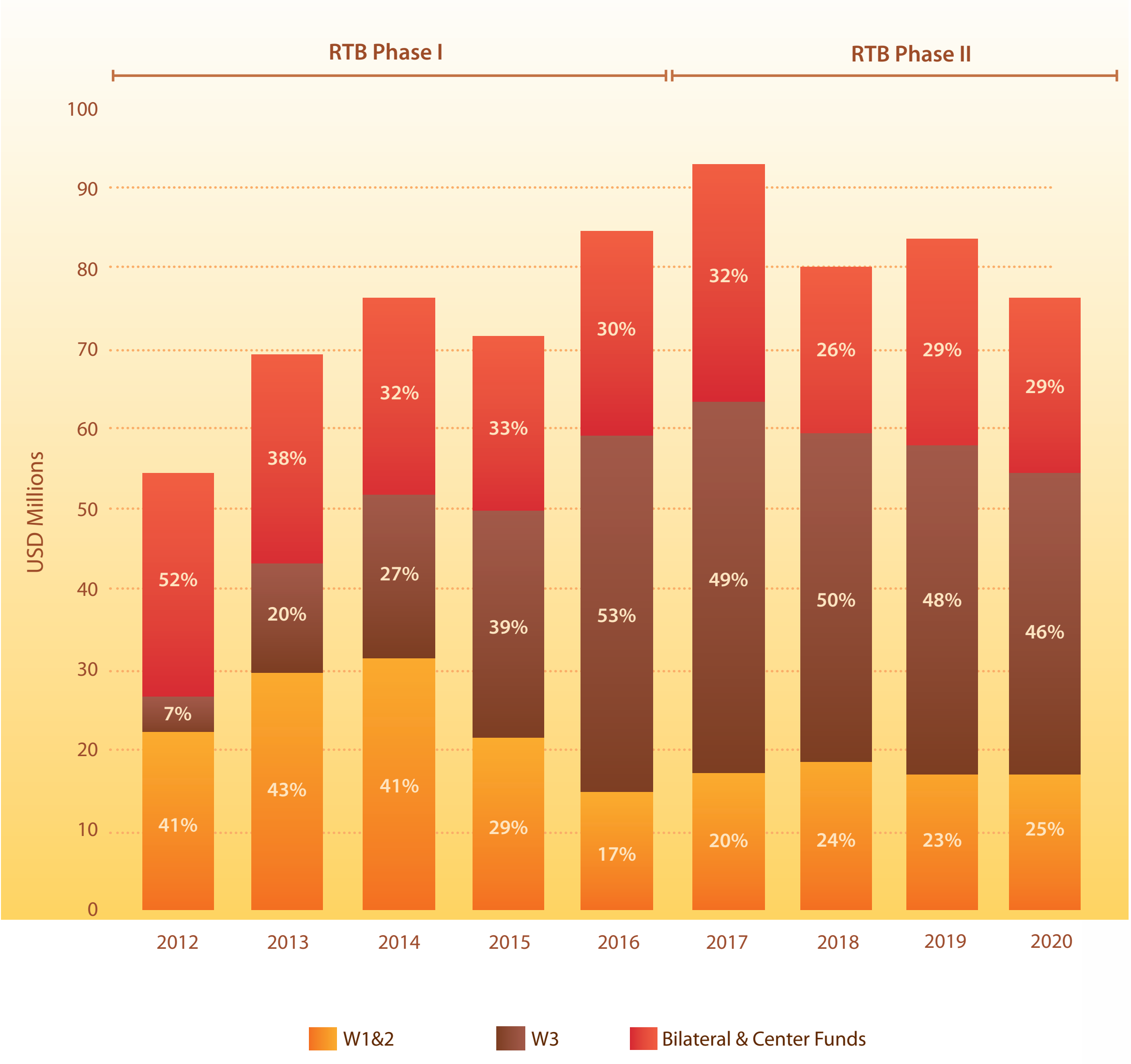
RTB 2012 -2020

The distribution of budget by funding sources shows a relatively stable contribution of W1&2 over the two-last years with a reduction of USD 1.0M from USD 21.5M in 2019 to USD 20.5M in 2020.

The implementation rate in 2020 was 77%, a decline from 2019 (87%) and 2018 (85%). This was mainly because of the challenges of Covid-19, the late confirmation of W1-2 funds from Foreign, Commonwealth, and Development Office (USD 0.63M) and SMO additional supplemental W1 (USD 0.26M) funding that was not feasible for program participants to spend before the end of the year.

The cumulative expenditure reached USD 682.0M over the nine years of the program (USD 191.3M from W1&2, and USD 490.7M from W3, bilateral and center funds).

RTB expenditure: 2012 to 2020



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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