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Prioritizing international agricultural research investments: lessons from a global multi-crop assessment

Diemuth E. Pemsl [a], Charles Staver [b], Guy Hareau [c,*], Arega D. Alene [d], Tahirou Abdoulaye [e], Ulrich Kleinwechter [f], Ricardo Labarta [g], Graham Thiele [h]

[a] Independent consultant, Seattle, USA
[b] Bioversity International, Montpellier, France
[c] International Potato Center (CIP), Lima, Peru
[d] International Institute for Tropical Agriculture (IITA), Lilongwe, Malawi
[e] International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria
[f] Federal Ministry of Food and Agriculture (BMEL), Berlin, Germany
[g] International Center for Tropical Agriculture (CIAT), Cali, Colombia
[h] International Potato Center (CIP), Lima, Peru; former Director of the CGIAR Research Program on Roots, Tubers and Bananas (RTB), Lima, Peru

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ABSTRACT

Investments in international agricultural research have proven very successful at an aggregated level over the past decades. Decision makers, however, face the tough question of how best to allocate limited public funds across increasingly diverse research areas to achieve the largest impacts. Simultaneously, donors demand more accountability from research institutions with regards to use of funds and resulting impacts on food and nutrition security, the environment, gender equality and poverty reduction. From 2012-2014, the CGIAR Research Program on Roots, Tubers and Bananas (RTB) undertook a systematic, quantitative ex-ante priority assessment across five key crops to inform its strategic research portfolio decisions. In-depth studies were conducted for cassava, banana, potato, sweetpotato, and yams with a harmonized methodological framework. The assessments comprised: 1) elicitation of major production constraints and research opportunities through global expert surveys; 2) identification of priority research interventions; 3) ex ante estimation of costs and benefits for two adoption scenarios using partial equilibrium economic surplus models; and 4) poverty impact simulations. Results suggest substantial, although variable benefits for all assessed potential research investments and provide a range of impact indicators (adoption area, number of beneficiaries, net present value, internal rate of return, and poverty reduction). The findings have since informed the research portfolio development of RTB and were critical for continued program funding in the second phase. This paper presents the methodology and results and then focuses on the policy implications and lessons learned to strengthen future priority assessments in agricultural research.

1. Introduction

Public investments in international agricultural research have proven highly successful at an aggregated level over the past decades (Maredia and Raitzer, 2010; Renkow and Byerlee, 2010; Pardey. et al., 2016, 2018; Alston et al., 2020, 2021). Decision makers, however, must allocate limited funds across increasingly diverse research areas, multiple commodities, and geographies with the goal of generating the largest development impacts. Identifying and implementing a rational, efficient approach to establish research priorities that is based on objective criteria and leads to strategic resource allocation despite the prevalent uncertainty is especially important in mission-oriented research fields such as health, energy, and agriculture. Improving on previous, more ad hoc, and informal decision-making practices is also called for by donors, who demand greater accountability from research institutions with regards to the use of funds and the impacts on sustainable development goals such as food security and healthy diets, gender equity, natural resource stewardship, and poverty reduction. Donors' interest also reflects the claim from constituents that public research effectively responds to societal demands (Wallace and Ràfols, 2015; Ciarli and Ràfols, 2019) and addresses the most important societal needs (Sarewitz and Pielke, 2007). Priority setting can also help prevent misalignment of different approaches within identified priority fields (Staver et al., 2020; Wallace and Ràfols, 2018). Following formal

* Corresponding author:
E-mail address: g.hareau@cgiar.org (G. Hareau).

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priority setting procedures improves both the quality and transparency of the complex resource allocation decisions typical for public research systems including (international) agricultural research (Stewart, 1995; Mills, 1998). This paper contributes to the priority setting literature by describing and evaluating a systematic, global, quantitative, multi-crop priority assessment in the agricultural sector.

For the past 50 years, agricultural research generating international public goods has been the mandate of the CGIAR[1]. A major reorganization of the CGIAR is currently underway with the aim to create a streamlined structure with updated research goals and a unified vision. The reform includes restructuring the entire research portfolio of the CGIAR under new initiatives pursuing major science and development goals and investment plans supporting implementation of the new research strategy (CGIAR, 2021). While the selection criteria and process have not been finalized, the needs for approaches and methods to inform decisions about the future research portfolio are apparent. Given that the new 'One CGIAR' will begin operating in early 2022, drawing on the lessons from previous prioritization experiences is highly relevant and timely (Barrett, 2020).

Different methodological approaches have been developed to support priority setting in international agricultural research (Gryseels et al., 1992; McCalla and Ryan, 1992; Kelley et al., 1995; Alston et al., 1995; Wiebe et al., 2021). These methods have been applied in ex ante priority assessments conducted for the CGIAR as a whole and at the individual Center level (see e.g., case studies in Raitzer and Norton, 2009), to help guide strategic research portfolio decisions. Usually, multiple objectives must be reconciled in addition to determining the most efficient use of research funds, including questions of equity across types of beneficiaries (incl. gender), crops or regions (ISPC, 2012; Alene et al., 2009a). Available methods to determine research priorities range from simple qualitative scoring exercises to highly complex simulation models estimating the functional relationship between inputs (research investments) and agricultural outputs while accounting for the underlying uncertainty (see e.g., Mills, 1998; and Braunschweig, 2000, for an overview of different priority setting methods). The quantitative approach described by Alston et al. (1995) estimates the economic surplus resulting from a research-induced supply shift and compares the resulting discounted benefits with the associated discounted costs in a cost-benefit analysis. This approach is approximately in the middle of the methodology spectrum in terms of complexity and resources required for execution. The resulting key indicators, net present value (NPV) and internal rate of return (IRR) on investments, have been common practice to support investment decisions for publicly funded agricultural research (Mills, 1997; Fuglie and Thiele, 2009), although they may not represent with precision the scale of livelihood changes occurring in society through research investments (Pardey et al., 2016; Rao et al., 2020). The use of additional indicators to assess multiple objectives (e.g., equity and efficiency) may require additional methods such as mathematical programming (Mutangadura and Norton, 1999).

Although setting priorities for public investments in research is common practice, for example in the health and energy sectors, and the economic surplus and cost-benefit concepts are founded on basic economic theory, their use for ex ante priority analysis has been more popular for the agriculture and fisheries sector. The methods discussed in this paper are also suitable for national research prioritization and were common practice in some large agriculture research organizations such as EMBRAPA in Brazil (de Andrade et al., 2002). However, its use has been more sporadic recently and sometimes other less data intensive and more ad-hoc procedures for defining national research priorities are preferred (Thornton et al., 2018). Recently, efforts to assess ex ante impacts of specific crop innovations (e.g., genetically modified crops) involving national institutions and scientists also relied on CGIAR programs as backstopping the methodological approach (IFPRI, 2020).

The work presented in this paper was undertaken by the CGIAR Research Program on Roots, Tubers and Bananas (RTB), which brings together five international research Centers[2], with more than 200 partners for research and development on banana, cassava, potato, sweetpotato, yam, and other minor roots and tubers. These crops, all "vegetatively propagated staple crops", are linked by similar breeding, seed, and post-harvest issues, and by the importance of women in their production, processing, and use (RTB, 2016). The priority assessment covering all five major RTB commodities was conducted with a harmonized core methodology to help guide priority setting decisions and resource allocation for a research portfolio of more than US$70 million annually.

The objectives of this paper are to: (i) document the motivation, process and methodology of the RTB priority assessment; (ii) share selected results to illustrate the nature of findings; (iii) describe how the results of the assessment have been used in support of strategic decision making and research policy; (iv) share lessons learned that are transferable to subsequent or similar exercises; and (v) identify key areas for more effective use of priority assessment in international agricultural research planning.

The paper is organized as follows. First, we describe the motivation for the RTB priority assessment, the analytical framework and tools used, and present an overview of the timeline and costs associated with implementation. Second, we present and discuss selected results across the five crop studies. We then examine how the study findings have been used and have since influenced decision making processes. We conclude by discussing major challenges and potential improvements and reflect critically on the process and methods of the exercise in terms of effectiveness and utility.

2. Methodology and Analytical Framework

RTB crops have policy relevance in most developing countries because they are grown and consumed by the poorest farmers and most food insecure people and because of the projected growth in the global supply, demand and trade of roots and tubers (Scott et al., 2000; Scott, 2021). Recognizing this role and the under-investment in research on these crops compared to major grains and cereals (Petsakos et al., 2019), the RTB program was created in 2012 to mobilize complementary expertise and resources, avoid duplication of efforts, and create synergies to increase benefits for smallholder farmers, consumers, and other stakeholders. As a condition for implementation and to secure funding for the program, the Fund Council - the governing body with authority over research program design and implementation - and the Independent Science and Partnership Council (ISPC) of the CGIAR, an independent scientific advisory entity, requested a rigorous priority setting exercise based on the expected impacts of investments in alternative potential research areas and to ensure alignment with the CGIAR strategic goals and targeted outcomes.

The priority assessment began in 2012, immediately after the official start of the program, and delivered results in late 2014. Fig. 1 provides an overview of the timeline of the study.

A cross-center team developed the analytical framework for the

[1] As a global research partnership, CGIAR is the world's largest international agricultural research network, currently comprising 15 research Centers. At the outset, CGIAR research focused exclusively on improving productivity (mainly through breeding of staple crops), while today the CGIAR and its partners are committed to a food secure future based on equitable poverty reduction, enhanced food and nutrition security, and improved natural resource management (CGIAR, 2018). This much broader mandate adds tremendous complexity to research priority assessment (ISPC, 2012; Byerlee and Lynman, 2020).

[2] The International Potato Center (CIP), which leads RTB; Bioversity International; the International Center for Tropical Agriculture (CIAT); the International Institute of Tropical Agriculture (IITA); and the French Agricultural Research Centre for International Development (CIRAD), which also represents the National Research Institute for Development (IRD), National Institute for Agricultural Research (INRA), and Vitropic.

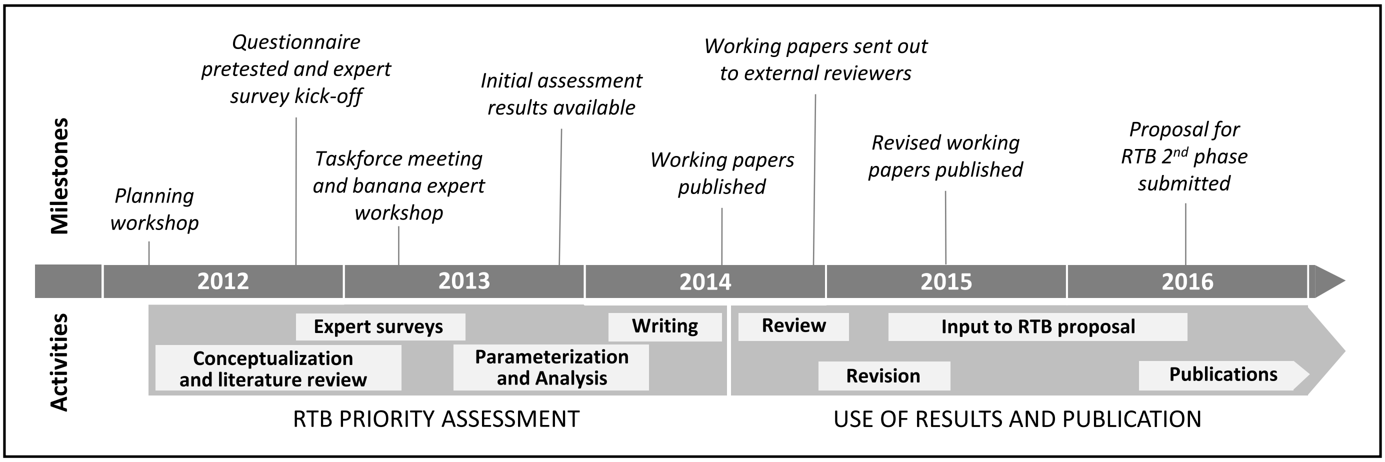

Fig. 1. Timeline and key activities of RTB Priority Assessment.

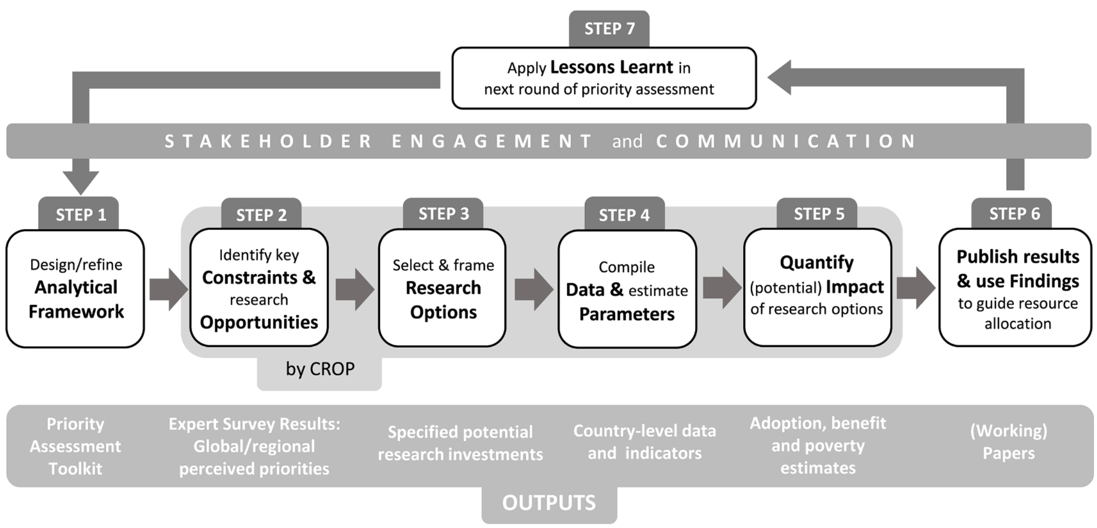

Fig. 2. Step-wise RTB Priority Assessment procedure.

assessment (Fig. 2). The initial design phase was followed by an elicitation of constraints from stakeholders, selection and description of potential research interventions, compilation of data and parameter estimation, quantification of potential impacts, sharing and utilization of findings, and finally the application of lessons learned. This final step loops back to the first to ensure that subsequent priority assessments build on the developed updated methods, data and results and benefit from lessons learned in the process. The engagement with stakeholders was a key part of the assessment and hence cuts across all steps.

Step 1: Design / refine analytical framework

The analytical framework of the RTB priority assessment is based on earlier analyses conducted at CIP (Collion and Gregori, 1993; Walker and Collion, 1997; Fuglie and Thiele, 2009), estimating benefits with a partial equilibrium economic surplus model and subsequent cost-benefit analysis. Based on a review of the relevant literature and priority setting exercises conducted by CGIAR Centers and other agricultural research organizations, we added an expanded production constraints analysis, a more in-depth stakeholder engagement, geo-spatial targeting, and a modified poverty impact dimension, included to address certain limitations of the economic viability indicators resulting from the cost-benefit analysis. We also explored options to incorporate gender (equity) and environmental impacts in the assessment, for example as weighting factors, but ultimately dropped these two categories since impacts were too location and context specific to be captured at the country level – the major level of analysis for the assessment.

For improved geo-spatial targeting, an online geographic information systems (GIS) tool was developed and used to visualize production, constraints and social indicators associated with root and tuber crops. Developing the platform and pulling data together, however, took much longer than expected, so the tool was not available for use in the initial targeting phase of the assessment as originally planned.

Step 2: Identify key constraints and research opportunities

Relevant production constraints and priority research opportunities were elicited from diverse national and local stakeholders through large-scale global expert surveys conducted either online or in person in 2012/13. A generic structured questionnaire was developed, and technical content was modified for each crop. The questionnaire contained open-ended questions on major constraints covering a broad range of topics in crop production and marketing (including social sciences and gender), tables in which respondents were asked to rate the importance of 70-90 different research opportunities using a five-point scale (from “not important” to “very important”), and some questions on personal attributes of the respondent. The research opportunities were selected based on literature review of yield loss factors, and production and marketing constraints, and consultation with CGIAR scientists.

The survey targeted national and regional experts for each crop from major production countries within the RTB geographical domain (Latin America, Sub-Saharan Africa, South and Southeast Asia and the Pacific). Two basic sampling strategies were applied: a) questionnaires distributed to participants of international crop-specific conferences; and b) online surveys. Potential respondents for the online surveys were identified through regional organizations, existing crop-networks or literature and internet search (e.g., staff of key organizations) and received personal email invitations. The surveys were also announced through newsletters and the RTB webpage, where links to the surveys were posted. The questionnaires and all accompanying communications were available in several languages (see Table 1) to facilitate participation of national partners. A detailed description of the survey design, sampling and implementation, can be found in the expert survey working papers for each crop (Abdoulaye et al., 2015; Creamer et al., 2014; Kleinwechter et al., 2014a and 2014b; Pemsl et al., 2014).

Step 3: Select and frame research options

Research options to be evaluated in the study were selected based on overall and regional scores from the expert survey (step 2) in consultation with experts and CGIAR Center scientists, considering the scope (and reach) of RTB's research activities to ensure a good match of assessed options with the (future) program portfolio. The selection procedure was slightly different for each crop. The banana research options, for example, were selected through a formal, consultative process during an expert workshop (see Pemsl et al., 2013), while the cassava and yam research options were selected based on regional stakeholder consultations. The potato and sweetpotato research options were selected in consultation with CIP scientists and closely aligned with research lines covered in previous assessments (Fuglie and Thiele, 2009) and with CIP's research portfolio.

Research options had to comply with the following criteria: i) the research creates a global public good in the form of a new, adoptable innovation addressing a key constraint or targeting a prime opportunity for the respective crop; ii) the potential impact from adopting the innovation is quantifiable using the selected methods; iii) impact would materialize within the 25-year assessment period; and iv) the research scope is within the RTB capacity and mandate, prioritizing the needs of (smallholder) farmers and other vulnerable groups in developing and transition countries. These criteria effectively result in the exclusion of certain types of research such as upstream and basic research as well as most types of social science research from this assessment. However, the exercise was not meant to assess or dictate RTB's entire research portfolio, but rather to identify and demonstrate the likely impact of high priority research. From the conceptualization phase, RTB management acknowledged that this study and its findings would only be one data point and source of information feeding into the program resource allocation process. Such "broadening out" of assessments can enhance both the rigor and accountability of priority assessments (Ely et al., 2014) and improve buy-in and likelihood of use of the results.

For each selected option, experts described the relevant constraint, proposed on-going research, the specific adoptable innovation, and associated benefits (e.g., expected yield increase, production cost changes, change in post-harvest losses, nutrition and health benefits), and the target domain (region, country and production system) for the innovation.

The selection process and description of the research options can be found in the crop specific working papers documenting the priority assessment (Abdoulaye et al., 2014; Alene et al., 2014; Hareau et al., 2014a and 2014b; Pemsl and Staver, 2014).

Step 4: Compile data and estimate parameters

The data used in the economic assessment are those required by conventional economic surplus analysis and the refinements applied in the study, and were collected from three general types of sources:

Online statistical databases

- FAOSTAT (http://faostat.fao.org/): crop production information (yield, area, price) by commodity and country; average of the most recent three years available (2010-2012, older data if necessary);
- World Development Indicators (World Bank, http://data.worldbank.org/indicator): data on poverty prevalence and (agricultural) gross domestic product (GDP) by country.

Published sources: Published sources were used to populate parameters wherever possible. This includes information on the geographical area where a constraint is present (current spread = share of production area affected) and the area at risk (likely future spread). Where research options corresponded with on-going projects, we consulted Center and project financial documents to obtain R&D costs; for new research, we used proposed budgets. To estimate the farm-level impact of technology adoption we reviewed published documents and combined this information with expert estimates for the model parametrization.

Expert estimates: For parameters without published information, we relied on estimates from panels of 2-4 experts with in-depth knowledge of the crops, respective technologies, and target areas. Expert estimates were used for farm-level impact of technology adoption (changes in yield, production costs, and post-harvest losses) for novel research interventions/technologies; for the future distribution of constraints, potential adoption area (the target domain); and for parameters defining the adoption profile (adoption lag, ceiling, and pace) for each technology and country[3]. We triangulated estimates with information found in the published literature. To address the common upward bias of experts due to overly optimistic adoption estimates, we conducted sensitivity analysis by computing a "lower adoption" scenario with a 50% reduced adoption ceiling compared to the expert estimate. Sensitivity analysis conducted for several parameters as part of the analysis for banana to test robustness of the results justified the choice of the adoption ceiling as the most critical parameter for scenario analysis.

Step 5: Quantify the potential impact of research options

The quantification of benefits starts with determining the target domain (i.e., the potential adoption area). Often the target domain is smaller than the total crop production area, either because the constraint (e.g., pest or disease) is not present everywhere, or the adoptable innovation is only suitable under certain conditions (e.g., agronomic practices designed for small-scale farmers or specific production systems or individual farmer and household characteristics).

We simulated adoption over time (the adoption curve) using the target domain and estimated parameters on adoption lag, pace, and ceiling. The largest adoption area reached within the assessed period is reported as one impact indicator, representing the reach of the research intervention. Following earlier practice, the adoption area was converted to the number of beneficiaries by using country specific estimates of average crop area per household and average household size (RTB, 2011).

To derive summary measures of the potential impact of research options we used an economic surplus (ES) model over a 25-year period (2014-2039). Given the limited international trade options for RTB crops in most producing countries, we assumed a closed economy and calculate the economic benefits at the national level. For each country included in the assessment, national crop production data and prices were used for the computation of benefits. We used a standard partial ES model as described by Alston et al. (1995) and applied by Fuglie and

[3] For banana, we disaggregated country level information by cultivar group, since yields, production systems, prices, and major constraints are significantly different (Pemsl and Staver, 2014).

Table 1
Importance scores of research opportunities by crop from global expert surveys.

	“Importance score” assigned by experts *(1 = not important, 2 = somewhat important, 3 = important, 4 = very important, 5 = extremely important)*				
	Mean		**Regional means**		
Highest ranked research opportunities by crop	ALL	s.e.	LAC	SSA	A/P
Banana *(survey period Jan – Mar 2013; N = 523; online survey only; 3 languages: EN, SP, FR)*					
Breeding for high yield	4.21	0.04	4.14	4.40	4.05
Management of fungal leaf disease (excl. resistant varieties)	4.11	0.04	4.40	3.88	3.85
Breeding for resistance to fungal leaf diseases	4.11	0.04	4.45	3.82	3.85
Strategies to improve soil fertility (micronutrients and fertilizer)	4.08	0.04	4.18	4.18	3.82
Improved phytosanitary and physiological quality of planting material	4.01	0.05	4.04	4.07	3.92
Cassava *(survey Jun 2012 – Jun 2013; N = 343; online, expert visits & conference surveys; 4 languages: EN, SP, FR, PR)*					
Assessment of cassava based innovation systems	4.43	-	4.41	-	-
Improving shelf life of cassava roots	4.25	-	4.20	4.10	4.33
Phenotypic/molecular screening of landraces in search of high-value traits/new sources/tolerance/resistance to stress	4.21	-	4.63	3.97	4.04
Developing cassava products for industrial applications (flour, starch)	4.20	-	4.39	4.05	4.10
Breeding for high yield	4.16	-	4.18	4.02	4.28
Potato *(survey period Sept 2012 – Jun 2013; N = 411; online & conference surveys; 5 languages: EN, SP, FR, RU, CN)*					
Late blight control and management	4.71	0.04	4.63	4.77	4.78
Breeding for late blight resistance	4.60	0.05	4.56	4.52	4.67
Breeding for drought tolerance/water use efficiency	4.51	0.05	4.56	4.34	4.60
Breeding for earliness	4.49	0.04	4.48	4.66	4.49
Improving production & distribution of elite planting material (formal)	4.45	0.05	4.31	4.42	4.67
Sweetpotato *(survey period Sept 2012 – Jun 2013; N = 216; online & conference surveys; 3 languages: EN, SP, CN)*					
Improving planting material quality (e.g. elimination of diseases)	4.35	0.05	4.29	4.71	4.16
Pro-vitamin A (beta-carotene) (breeding)	4.28	0.06	4.21	4.70	4.03
Breeding for high yield	4.26	0.06	4.21	4.61	4.10
Improving production & distribution of elite planting materials (formal)	4.21	0.05	4.21	4.46	4.10
Sweetpotato virus disease (SPVD) management	4.18	0.07	3.93	4.63	4.00
Yam *(survey period Sept 2012 – Jun 2013; N = 216; online, expert visits & conference surveys; 2 languages: EN, FR)*					
Improving shelf life of yam tubers	4.30	0.07	4.50	4.24	-
Improving soil fertility (micro-nutrients, fertilizer, org. matter)	4.17	0.07	4.17	4.10	-
Improving small scale processing for human consumption	4.13	0.07	3.80	4.13	-
Improving technologies for farmer-based production and distribution of planting materials (informal)	4.10	0.07	4.50	4.13	-
Disease management (yam mosaic disease)	4.06	0.08	3.40	4.24	-

Notes: Languages: EN – English, SP – Spanish, FR – French, PR – Portuguese, RU – Russian, CN – Chinese; Regions: LAC – Latin America and Caribbean, SSA – Sub-Saharan Africa, A/P – Asia and Pacific; *Potato*: Responses for A/P are predominantly from China (N = 117; 66% of A/P responses) *Sweetpotato*: Responses for A/P are predominantly from China (N = 53; 53% of A/P responses)
Yam: N = 7 (3% of total sample) for LAC, rest from SSA with 66% of total sample from West & Central Africa.
Source: Compiled by the authors based on expert survey results as reported in Abdoulaye et al. (2015); Creamer et al. (2014); Kleinwechter et al. (2014a, 2014b); Pemsl et al. (2014)

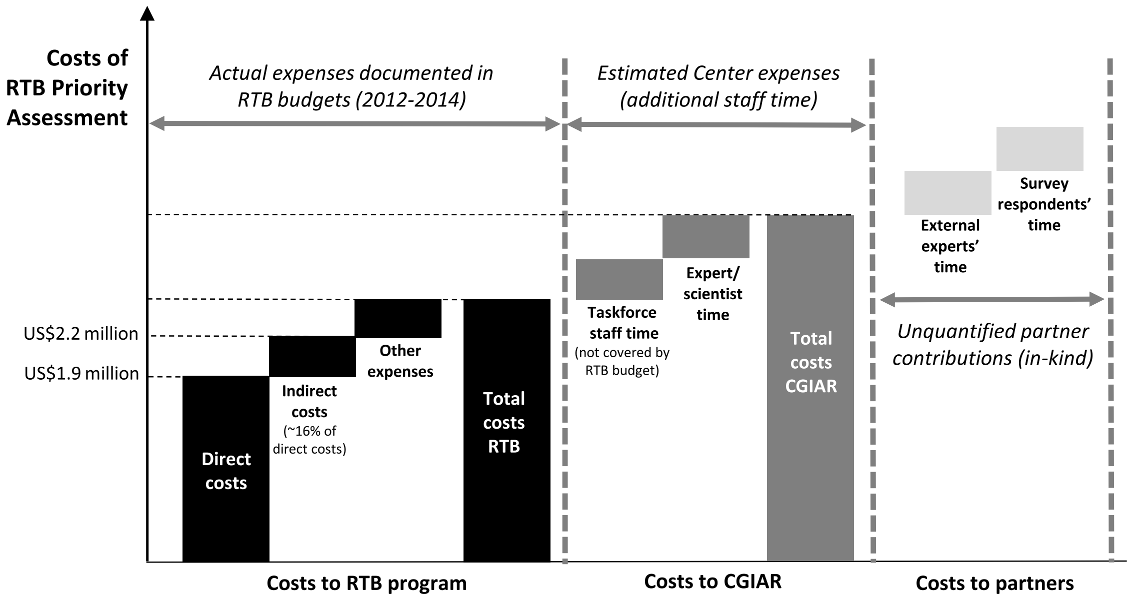

Fig. 3. Estimated costs of RTB priority assessment (2012-15).

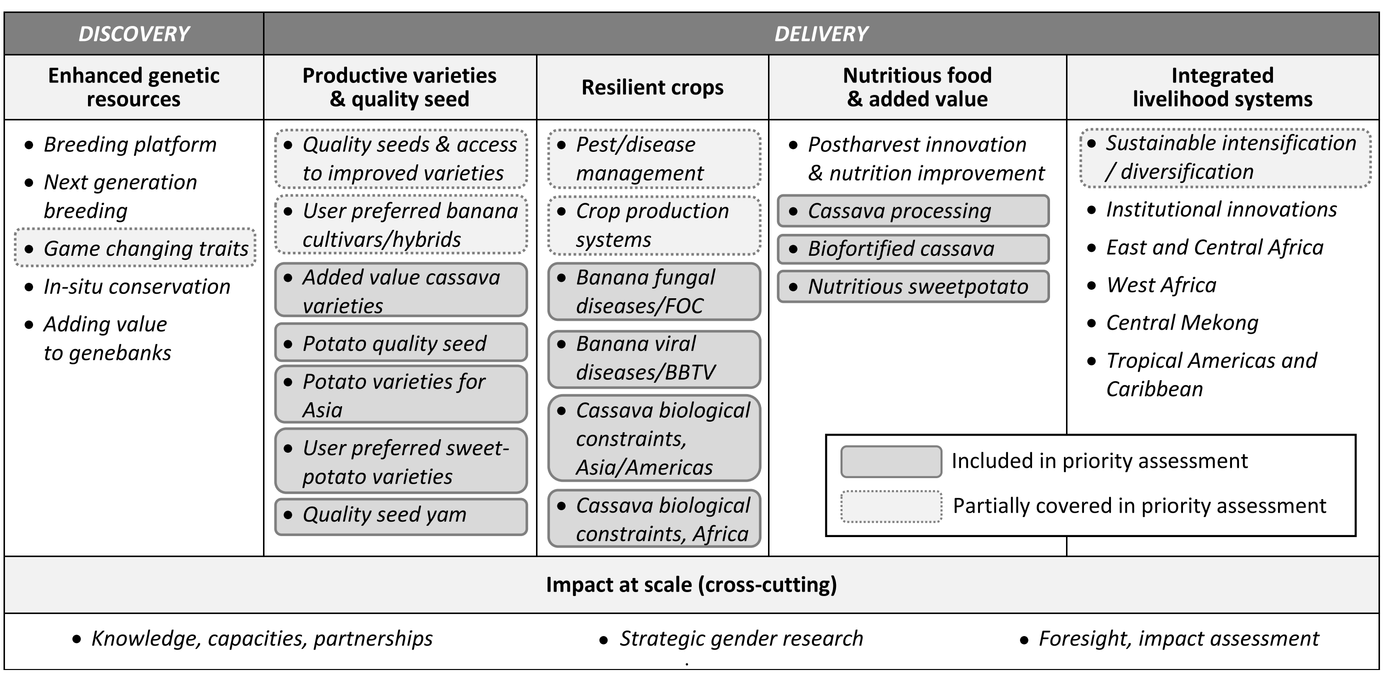

Fig. 4. Congruence of priority assessment with overall RTB research portfolio.

Thiele (2009) and Alene et al., 2009b. To derive the net present value (NPV) of the benefits, aggregated annual costs were deducted from annual benefits and then discounted (with a conservative discount rate of 10%). Comparing the costs with the net benefits yields the internal rate of return (IRR) on the investment. Production and consumption of RTB crops is projected to continue growing in the near future (Scott, 2021) despite positive income changes in target countries that may shift consumption away from staple crops. The low demand elasticity used in the model (0.5) accounts for this projected trend and its drivers.

Returns on research investments typically comprise not only financial benefits but also impacts on human health, gender equality, agro-ecosystems and natural resources, which are harder to express in monetary terms (ISPC, 2012). The health impacts resulting from nutritional improvements, for example from bio-fortified crops such as orange-fleshed sweetpotatoes with higher beta carotene content (Bouis and Saltzman, 2017), are not captured in the ES model. We computed these health benefits following the Disability Adjusted Life Years (DALY) approach described in Stein et al. (2005). The DALY approach has become the standard model to assess health benefits of biofortification (Lividini et al., 2018). Once quantified, health impacts can be added to the economic surplus results before computing IRR and NPV (see Hareau et al. (2014b) and Fuglie (2007) for details).

Some selected research options have (long-term) benefits on the agro-ecosystem and natural resources (e.g., increased populations of natural enemies of crop pests; pesticide reduction; reduced erosion due to improved agronomic and management practices). The RTB assessments, however, only captured the impact from increased yields and reduced production costs while additional (positive) externalities were not quantified.

We attempted to include metrics on gender impacts resulting from the adoption of innovations, but quantifying these effects across cultural settings, production systems and location-specific social context was infeasible with the applied methodology. To meaningfully include these effects, the model would have to be more (spatially) disaggregated – which was out of reach for this global, multi-crop exercise due to data limitations for other parameters. A group of gender experts initiated follow-up focus group discussions and case studies in multiple locations to improve methods and tools facilitating the inclusion of gender impacts in subsequent assessments.

The estimated R&D costs for research options to CGIAR were doubled for the cost-benefit analysis to account for (in-kind) contributions of national partners. Additionally, dissemination costs based on the marginal annual adoption area were set at US$50 per hectare for improved varieties and US$80 per hectare for knowledge-intensive innovations such as crop or pest management practices, following the approach in Fuglie (2007).

In addition to computing NPV and IRR, we estimated potential impacts on poverty reduction to address the equity dimension of research priority setting (Byerlee, 2000; Alwang and Siegel, 2003; Fan et al., 2005; Alene et al., 2009a). Improving on the method to simply weight benefits with the poverty headcount used in earlier exercises (Fuglie and Thiele, 2009), we first estimated the marginal impact on poverty reduction of an increase in the value of agricultural production using poverty reduction elasticities of agricultural productivity growth. The reduction in the total number of poor was then calculated by considering the estimated economic benefits as the additional increase in agricultural production value (Alene et al., 2009b). We applied the regional elasticities proposed by Thirtle et al. (2003) who found that a 1% growth in agricultural productivity reduces the number of rural poor by 0.72% in Africa, 0.48% in Asia, and 0.15% in Latin America and the Caribbean.

Step 6: Publish results and use findings to guide resource allocation

One intended output of the priority assessment was to share methods, results and lessons learned with a wide group of stakeholders in the form of web updates, downloadable reports and presentations in meetings and conferences. The methodology and results of the priority assessment were documented in 10 working papers: an expert survey report and a strategic research priority assessment report per crop[4]. Each report was reviewed by two external experts and revised according to the feedback and comments received. The reports were available online soon after study completion (Fig. 1), with the objective of quickly making the information accessible to obtain feedback from stakeholders and encourage use of the results. Progress and results of the assessment were also shared via RTB and Centers' webpages and social media outlets, and through numerous presentations at workshops and conferences. Presentations targeted RTB audiences as well as wider stakeholder groups (e.g., regional banana networks) and the larger scientific community. In addition to this synthesis paper, each crop team developed a plan to publish the crop specific applications and results in peer-reviewed journals.

Another key objective of the priority assessment was to generate information that supports and strengthens the development of RTB's future research portfolio. The assessment was hence scheduled so that results were available as input to strategic portfolio and resource allocation decisions for the development of the RTB 2nd phase proposal.

Step 7: Apply lessons learned in future priority setting/assessment

The payoffs to this large-scale, global assessment and the effort involved in harmonizing the methodology across crops would increase further if lessons learned are applied in the next cycle of priority assessment and contribute to improved priority setting. The development of the new research portfolio of the 'One CGIAR' system certainly will require a harmonized approach, tools, and metrics for the selection of research priorities. Moving from one-off exercises to institutionalized processes that build on the compiled information, findings and lessons learned from each cycle of ex ante and subsequent ex post assessments and associated stakeholder consultations will increase the quality and usefulness of priority assessment exercises in support of research priority setting (see e.g., Ndjeunga and Bantilan, 2009). For that purpose, we provide the key lessons from the RTB assessment in the final sections of this study.

Costs of conducting the priority assessment

RTB invested US$2.2 million in direct costs in the priority assessment between 2012 and 2014 that covered the overall coordination cost and crop specific team costs. These included operational costs, staff time of the taskforce members, and indirect costs as well as additional costs incurred for staff and travel, support of taskforce meetings, and other expenses (e.g., consultant fees). Centers contributed their own resources mainly for additional staff time of taskforce members and of scientists contributing to selection and framing of research options and parameter estimates. The final cost category are in-kind contributions of partners and other stakeholders, who contributed time to participate in surveys and workshops and provided feedback. We did not attempt to quantify all costs, but the waterfall graph in Fig. 3 visualizes the different cost categories. The objective of building capacity in all RTB Centers and implementing this study through a peer group of taskforce members resulted in improved priority setting skills and culture in all Centers. The time invested in capacity building accounted for a substantial share of the total costs.

3. Selected Results and Highlights of Findings

In this section we present selected results, to demonstrate the type of information and indicators produced and to show the effectiveness of the approach for research priority assessments in a global, multi-crop setting.

The first block of results relates to the identification of key constraints and research opportunities through large-scale, global expert and stakeholder surveys (step 2 in Fig. 2). The number of respondents for the five crop surveys combined was N = 1,709 (Table 1 shows the breakdown by crop), with participants from a wide range of countries in all RTB focus regions. Most respondents were scientists from national agricultural research organizations with a wide variety of disciplinary backgrounds.

The open-ended questions on major constraints to crop production and marketing were, as expected, answered with widely varying levels of specificity (e.g., from naming a certain fungal disease to just stating "pests and diseases" in general). The main purpose of these questions was to ensure that no major constraints were omitted, so answers were carefully checked against the list of research opportunities provided. No significant gaps were uncovered, so the compiled lists were considered comprehensive. Table 1 shows the top 5 ranked research opportunities for each crop together with averages scores for the entire sample and disaggregated regional results for Latin America and the Caribbean, Sub-Saharan Africa, and Asia/Pacific. While some constraints are universally important across regions, others received high scores in only one/some region(s) reflecting regional but not global relevance. For example, late blight in potatoes was assigned very high importance across all regions, while fungal leaf diseases (mainly *Mycosphaerella*) in banana were top of the list only in Latin America and the Caribbean (Table 1). While regional means are included in the table for yam, the sample consists almost entirely of responses from Sub-Saharan Africa, where most

[4] Methods, tools and working papers are available online: https://www.rtb.cgiar.org/strategic-research-priority-assessment-toolkit/.

production is located. Although respondents were not forced to rank research opportunities and could assign unlimited “extremely important” scores, there are clear differences in the perceived importance across research opportunities. The highest ranks have average scores well above 4 (representing rankings between ‘very important’ and ‘extremely important’), while the lowest rank received mean scores of 2.69 (banana), 2.58 (cassava), 2.89 (potato), 2.73 (sweetpotato), and 2.56 (yam). The statistical significance of differences in mean scores can be seen in the standard error column in the table. As an example, the 95% confidence intervals were ±0.14 for potato mean scores and ±0.19 for sweetpotato scores.

In addition to being used in the selection of research options, the importance scores obtained through the expert surveys were used to gauge the crop-specific alignment between the RTB research portfolio and stakeholder perceptions of key constraints and opportunities. The results showed that almost all constraints considered to be of great importance by stakeholders were addressed through RTB research (Fig. 4).

The second block of results is obtained from the identification of research options and model parameters (steps 3 and 4 in Fig. 2). For all five crops combined, 37 research options were assessed, but for brevity, we only show results for the top three performing options per crop. Of all assessed research options, 54% focused on breeding, 24% addressed pest or crop management, 14% targeted seed systems, and 8% were post-harvest related.

The key parameters for the assessment that were estimated by experts are the scope and spread of the constraint, quantitative estimates for the expected farm level impacts (e.g., yield increases, or loss prevented) and the likely adoption (Table 2). The adoption and impact parameters were elicited separately for each target country; thus, the

Table 2
Parameter estimates for selected research options included in the priority assessment.

Top ranked research options by crop	**Present Value of total R&D costs 2014-2039** (US$ million)[1]	**Probability of success** (%)	**Regions: # countries targeted**	**Research lag** (years)	**Adoption lag** (years)	**Maximum adoption rate** (% of area)	**Yield increase** (%)	**Input cost change** (%)
Banana (total of 12 research options assessed)								
BXW management: cultural practices	24.3	50 - 80	SSA:14	3	7 - 8	7 - 60	90	20
Recovery from banana bunchy top virus (BBTV)	22.2	50 - 80	SSA:18, Asia:4	3 - 7	8	5 - 45	80	40
Resistant plantain (RELEASE)	6.7	30 - 80	SSA:8, LAC:9, Asia:1	7	8 - 15	2 - 46	70 [2]	40
Cassava (total of 10 research options assessed)								
High-quality planting material production and distribution systems for improved varieties	53.9	50-80	SSA:24, LAC:12, Asia:9	1 - 4	5 - 12	20 - 50	30 - 50	5 - 25
Sustainable crop and soil fertility management	47.7	75-80	SSA:24, LAC:12, Asia:9	1 - 5	6 - 12	20 - 50	15 - 56	5 - 30
High-yielding, drought-tolerant varieties and increased water-use efficiency	47.7	65-80	SSA:24, LAC:12, Asia:9	5 - 8	12	8 - 90	15 - 35	10 - 20
Potato (total of 6 research options assessed)								
Late Blight resistance	54.5	80	SSA:13, LAC:4, Asia:15	2	10	10 - 60	12 - 32	-5, -2
Virus-resistant varieties	27.3	70	SSA:12, LAC:3, Asia:12	2	10	0 - 55	40	-5
BW-resistant varieties	13.6	50	SSA:10, LAC:3, Asia:9	10	10	0 - 60	10 - 30	0
Sweet potato (total of 4 research options assessed)								
Orange-flesh sweet potato (OFSP)	81.8	60-80	SSA:17, Asia:5, Haiti	1 - 2	10	10 - 70	20	1 - 3
Weevil-resistant varieties	13.6	50	SSA:17, Asia:5, Haiti	5	10	30 - 60	10 - 30	1 - 3
SPVD-resistant varieties	13.6	50-80	SSA:17, Asia:5, Haiti	1 - 5	5 - 10	20 - 40	10 - 40	1 - 3
Yam (total of 5 research options assessed)								
Clean planting materials and agronomic practices	24.3	75	SSA:5, Pacific:1, LAC:2	5 - 10	12 - 15	30 - 50	50	25
Improved varieties with complementary ICM	21.4	75	SSA:5, Pacific:1, LAC:2	5 - 10	12 - 15	10 - 30	40	20
Yam pest and disease management options	17.5	80	SSA:5, Pacific:1, LAC:2	3 - 8	10 - 15	25 - 40	30	10

Notes: Research costs accrued before the assessment period were treated as sunk costs and not included. Parameter estimates were done at the country level – the numbers displayed show the range from lowest to highest estimate.

[1] Discounted with 10% interest rate to reflect present cost value. For the analysis, these costs are matched with additional costs of the same magnitude (1:1) at the NARS level.

[2] For this research option, there was also a 25% reduction in post-harvest losses.

Source: Compiled by the authors based on RTB priority assessment results as reported in Abdoulaye et al. (2014); Alene et al. (2014); Hareau et al. (2014a, 2014b); and Pemsl and Staver (2014).

Table 3
Results of RTB priority assessment – adoption, beneficiaries, economic benefits and poverty impacts (lower adoption scenario).

Top ranked research options by crop	Adoption Area (million ha)	Number of beneficiaries (million HH)	(million persons)	Net Present Value (US$ million)	Internal rate of return (%)	Poverty Reduction (million persons)
Banana						
BXW management: cultural practices	0.64	3.22	15.67	1,982	72	1.61
Recovery from banana bunchy top virus (BBTV)	0.40	2.02	9.67	1,337	61	0.64
Resistant plantain (RELEASE)	0.45	1.70	7.57	1,111	64	0.25
Cassava						
High-quality planting material production and distribution systems for improved varieties	3.38	6.73	33.08	7,585	416	2.10
Sustainable crop and soil fertility management	3.27	6.43	31.72	8,284	210	2.66
High-yielding, drought-tolerant varieties and increased water-use efficiency	3.99	7.89	36.49	3,025	61	2.00
Potato						
Late Blight resistance	0.77	2.11	9.47	2,303	68	0.35
Virus-resistant varieties	0.36	0.87	3.83	1,909	82	0.31
BW-resistant varieties	0.64	1.72	7.85	253	29	0.20
Sweetpotato						
Orange-flesh sweetpotato (OFSP)*	0.67	3.00	14.60	563	35	0.48
Weevil-resistant varieties	0.72	2.94	14.11	363	41	0.36
SPVD-resistant varieties	0.48	1.96	9.41	673	116	0.34
Yam						
Clean planting materials and agronomic practices	0.68	2.39	17.72	570	37	0.18
Improved varieties with complementary ICM	0.43	1.58	11.74	2,026	60	0.66
Yam pest and disease management options	0.43	1.60	11.85	412	43	0.10

* Including health benefits from adoption of OFSP (DALY method) substantially increases benefits: NPV: US$1,298 million, IRR: 51% (lower adoption scenario).
Source: Compiled by the authors based on RTB priority assessment results as reported in Abdoulaye et al. (2014); Alene et al. (2014); Hareau et al. (2014a, 2014b); and Pemsl and Staver (2014).

table shows ranges (lowest-highest estimate) where applicable. Research options differ in terms of total R&D costs, duration, and remaining years of research. Moreover, some research options are a continuation of on-going investments, while others constitute new, potential future research investments. The resulting difference in the research lag is an important determinant of the economic performance. The probability of success is a combination of the expected probability that the described research outputs will be available (on time) and the likelihood that in-country dissemination activities will take place and lead to adoption. The change in yield varies from 10-90%, with the high-end estimates representing the avoidance of (almost) total yield loss that would likely occur without the research intervention, due to e.g., diseases such as *Xanthomonas* wilt on bananas (BXW). Production cost changes range from -5% (with resistant varieties replacing other, more expensive control measures) to 40% due to higher prices for improved seed/planting material and/or increased use of other inputs (fertilizer, labor).

Research options have different target geographies, reflecting the regional importance of the crop, the prevalence of the respective constraint, as well as the strategic interest and capacity of RTB to get involved (e.g., focus on countries and regions with high levels of poverty and/or weaker national research programs). Although not displayed in Table 2, the country level data for crop production area, yields, prices, poverty levels and agricultural value added were obtained from sources such as FAOSTAT and World Development Indicators.

Of the two adoption scenarios analyzed, we only display the lower adoption scenario results (with 50% reduced adoption ceiling) in this paper.

The final block of results is the quantification of the potential impact of the research options (step 5). In Table 3 we include all computed performance indicators and show that (1) expected adoption areas are large, ranging from several hundred thousand to almost four million hectares representing an estimated 3.8 to 36 million persons impacted; and (2) all options have large positive net present values. Even the lowest performing research options per crop, based on the indicators used, still resulted in positive returns on the research investment with internal rates of return of 13% for yam, 23% for banana, cassava, and potato, and 35% for sweet potato. When comparing research options using the listed performance indicators (other than IRR), it should be kept in mind that the size of the underlying investment (R&D costs, Table 2) varies substantially.

Our estimations show that all research options could potentially reduce poverty. Assessing research options based on this performance indicator leads to a different ranking compared to the traditional economic indicators, since impacts on poverty reduction are larger in countries with higher levels of poverty. The potential for impact through nutritional improvement of crops (for example orange-fleshed sweetpotato) is a dimension of great importance especially in less well-off households. Including health benefits in the economic assessment can largely increase the overall benefit estimate.

The relatively high positive return for research on improved agronomic practices (e.g., crop and soil fertility management for cassava; cultural practices in BXW management for banana; clean planting materials and agronomic practices for yam) was somewhat unexpected given that production system problems have been regarded as typically location specific. Since they also depend on the delivery of inputs and information intensive improved management, they have been considered difficult to scale. A key change was big data approaches and cell phone apps which can generate and analyze site-specific data on agronomic constraints to increase the accuracy and reduce the cost of scaling agronomic recommendations hence offering increased chances for impact.

The assessment confirmed the continued importance of research addressing key diseases with high potential for devastating losses (e.g., BXW and BBTV for banana, cassava mosaic disease (CMD) and cassava brown streak disease (CBSD); late blight and bacterial wilt for potatoes, weevils and viruses for sweetpotato). In the case of bacterial wilt in potatoes, this major production constraint has potential for very high payoffs, although the rates of return on investments are low because of the longer research lag required to produce an adoptable innovation (i. e., resistant varieties).

In subsequent assessments, separating the contribution of clean (i.e., pathogen free) seeds and planting material from the effect of improved varieties might help to shed additional light on the relative importance of each. The potato study found that the expected adoption rates used in previous studies (Fuglie, 2007) were too optimistic and had to be adjusted downward based on ex post studies focusing on actual adoption rates of improved varieties. This further stresses the need for a continuous learning cycle with regards to priority assessment and the need to integrate different approaches and sources of information (Step 7, Fig. 1).

4. Policy Implications

Outcomes and policy implications of the RTB priority assessment (steps 6 and 7, Fig. 2) can be grouped under four conceptual categories: i) accountability and access to funding, ii) how research priorities are established, iii) institutionalizing priority setting, and iv) collaboration and capacity building. For each of these categories, we outline the key achievements of the study. Challenges and suggestions for improving priority setting in international agricultural research are presented in the next section.

To determine policy influence, we analyze how different stakeholders have used the assessment and how its results have influenced their decision making (Table 4). Since the priority assessment was commissioned by RTB in response to a donor request, the first-level (next) users of the information are the donors who requested the study and RTB program management. The implementing Centers, and their research managers, are considered second-level users. The third group of users comprises other CGIAR Centers, CGIAR Research Programs, and national partners involved in agricultural research and development.

4.1. Accountability and access to funding

RTB responded to a direct request from donors and from the Independent Science and Partnership Council of CGIAR (ISPC) to conduct a rigorous ex ante priority assessment as a precondition for continued funding. Failure to comply could have had implications, with the loss of credibility and possible consequences in second phase funding.

The commitment to strategically explore alternative research options and the ability to complete this large-scale exercise with a harmonized methodology across multiple crops and regions in a joint effort by the member Centers has earned RTB considerable credibility in the CGIAR agricultural research and donor community. The study team has repeatedly been contacted by staff from other CRPs inquiring about methodology, tools and guidance for conducting similar assessments. The exercise also set a standard for systematic priority assessment at the Center and CRP level, which may impact the expectations and requirements for evidence-based research portfolio decision making in the CGIAR going forward.

While Raitzer and Kelley (2008) found little correlation between benefits documented in ex post impact assessment studies and subsequent donor funding decisions, the priority assessment had direct and almost immediate funding implications for RTB. The priority assessments findings were used in the RTB 2nd phase proposal (submitted in mid-2016) and contributed to the 'A = excellent' rating received and the CGIAR System Organization decision to support a second phase with an increased level of funding (ISPC, 2016).

An external evaluation of the RTB program was commissioned by the

Table 4
Evidence of use/influence of RTB priority assessment results by user level.

1st Level Users: *CGIAR and RTB management*	2nd Level Users: *RTB member Centers*	3rd Level Users: *Others*
ISPC (Independent Science and Partnership Council of CGIAR) mentions priority assessment in proposal review; credits RTB for being only CRP with rigorous, large scale priority assessment; priority assessment was pre-condition for second phase RTB approval and contributed to decision to increase funding for the program. **IEA (Independent Evaluation Arrangement of CGIAR)** acknowledged the importance of the priority assessment and strongly encouraged use of results. **RTB management** used compiled data, parameters and results of priority assessment to set targets for second phase and track progress towards achieving them; considered priority assessment results to assure its research priorities line up with key constraints; consulted and analyzed priority assessment results to confirm and justify its research portfolio and funding decisions.	**Bioversity International** senior management referenced results during portfolio discussions; contributed priority assessment parameters and results to FAO-led Global Fusarium (FOC) Initiative and priority assessment is cited in a resulting policy brief. **CIAT- International Center for Tropical Agriculture** gathered more information for cassava constraints and priorities in Asia since region was underrepresented in the original exercise; impact assessment team is working to expand priority setting to cover other research fields (e.g., rice and ecosystem services). **CIP - International Potato Center** continued priority assessment work e.g., completing bio- fortified potato assessment; in 2017, research areas had to be prioritized due to reduced funding and decisions were justified partly with priority assessment results. **IITA - International Institute of Tropical Agriculture** leadership requested presentation on (results of) priority assessment and access to all generated information. **Scientists from implementing Centers** have used priority assessment information and results in proposals to strengthen their funding applications (e.g., Bioversity proposals for BBTD, Bacterial and Fusarium wilt to RTB in internal competitive calls).	**Other CRPs / CGIAR Centers** inquired about methods and tools used in priority assessment to inform their own exercises; PA approach and results presented in meetings of the Standing Panel on Impact Assessment (SPIA) of the CGIAR. **GLDC (Grain Legumes and Dryland Cereals Agri-food Systems)** cited the priority assessment several times in 2nd phase proposal (GLDC, 2016) and modelled own priority setting after RTB priority assessment process and methods. **Scientific community** - Cassava priority assessment methodology and results published in peer-reviewed journal (Alene et al., 2018). - Projection of banana losses due to Fusarium (FOC) presented and published (Scheerer et al., 2018).

Independent Evaluation Arrangement (IEA) of CGIAR and completed in late 2015. The evaluation team was briefed on the priority assessment, reviewed available documents, and interacted with involved scientists. In the final evaluation report, several recommendations made reference to the priority assessment: a) recommending further use of priority assessment results to determine RTB's research portfolio and to ensure funds are directed at the highest priority programs (recommendations 3 and 4); and b) suggesting a "clear strategy of how priority and impact assessments will be linked over time, and how the results from ex-post assessments, complementing ex-ante assessment, will inform program planning" (recommendation 14; CGIAR-IEA, 2015). We will further discuss this issue in the section on 'institutionalizing priority setting' below.

4.2. Setting research priorities

The priority assessment taskforce specifically avoided the term 'priority setting' when labeling the study, acknowledging that while results inform portfolio decisions, other important criteria play a role in setting research priorities (Braunschweig et al., 2001). The study, however, directly influenced RTB resource allocation decisions (Table 4). RTB management used the results for relevance and effectiveness to ensure its research portfolio was addressing key constraints and to inform and justify portfolio decisions. RTB also had a considerable share of discretionary funding, around 25% of total funding (RTB 2020 Annual Report, page 70) that, based on the results of the study, was strategically allocated to cover the research areas of the program that might have been left out without sufficient resources from restricted donor funding. Furthermore, data and results were used to set quantitative targets for the research program (e.g., technology adoption, beneficiary numbers, poverty reduction, beneficiaries with improved dietary/health status), thus improving program design, monitoring and evaluation systems.

Highlighting research lines in the overall RTB research portfolio that are (partially) matched by one or more of the research options shows that the priority assessment covered most of RTB's delivery research (Fig. 4). The priority assessment did not address RTB's discovery or upstream research for which impact pathways are longer, less direct, and more complex, and hence benefits are harder to quantify with the methods used and establishing credible attribution is generally more difficult. The study also excluded regional programs, which are better assessed using a different methodology e.g., congruence analysis matching regional investment levels with measures of importance of RTB crops. Finally, cross-cutting policy and socio-economic research was not covered since it would be better served by methods reflecting the indirect nature of impacts on beneficiaries.

At the second user level, senior management of the implementing Centers was supportive and involved in the study. Anecdotal evidence suggests that results were considered when making portfolio decisions. For example, in 2017, CIP justified decisions about which research areas to prioritize in response to reduced donor funding based on priority assessment results, amongst other criteria. This use of quantified ex-ante priority assessments to inform resource redirection and consolidation in times of downsizing is among the expected outcomes.

Scientists from RTB member Centers were important users of the study and have cited priority assessment information such as compiled (production) data, parameter estimates and results to support and strengthen proposals when seeking research funding (see examples from Bioversity International in Table 4).

Most implementing Centers have continued their priority assessment efforts. CIP has conducted priority assessments with consistent methods for over 20 years, with evidence that results have directly impacted investment decisions in some cases (e.g., correcting underinvestment in Africa and sweetpotato). In most cases, results were used to justify the existing research portfolios (Fuglie and Thiele, 2009). The other Centers have done less systematic priority setting in the past. However, two of them have engaged in follow up ex ante studies after completing the RTB priority assessment to evaluate additional research options (Bioversity International: Fusarium on banana (Scheerer et al., 2018); IITA: Yam (Mignouna et al., 2020)). Bioversity International has supplemented the priority assessments with additional sensitivity analysis and a deliberate banana stakeholder engagement along all steps of the assessment including an elicitation of stakeholder feedback on parameter estimates and results and a toolkit webpage[5] explaining all steps of the methodology.

4.3. Institutionalizing priority setting

The RTB priority assessment has contributed to the long-term goal of institutionalizing priority setting, which may serve as an example for future approaches of research initiatives under the new One CGIAR. The effort was the first experience in conducting ex ante assessments to help guide priority setting for a multi-center, multi-crop CGIAR program. Subsequent assessments will benefit from the developed methods and tools, and from the lessons learned. In the past, CIP was the only Center that had periodically conducted systematic ex ante assessments and now this model has expanded to all Centers in the RTB program. This spillover comprises the tools and processes developed, and the awareness and capacity built through the engagement and participation of many staff. RTB management directly promoted and engaged with the process, has used data and results to support decision making and funded follow-up ex post studies for selected research. CIP, having gone through the priority assessment cycle before, used results of ex post studies to adjust ex ante parameter estimates that were too optimistic. This is an example of how applying lessons learned and integrating different methodological approaches and sources of information improves the accuracy and usefulness of priority assessments. Together with the willingness to learn from findings as well as identifying gaps, this completes the first full loop of an ideal priority setting cycle (Horton and Mackay, 2003).

4.4. Collaboration and capacity building

The priority assessment fostered collaboration and built capacity in several ways. First, the exercise brought social scientists from different Centers together around a shared task and methodology to provide comparable metrics across crops. Establishing such a community of practitioners provides a strong, collaborative base going forward and sets an example for cross-Center cooperation and integration, much in line with the concept of the ongoing CGIAR reform. The established taskforce was the basis for the RTB social science research program and its focus on foresight, ex ante and ex post impact assessment. The program established two major objectives: to generate high quality inputs for research planning to RTB, CGIAR centers, advanced research institutions and other partners, and to provide rigorous evidence of the long-term impacts of investment in specific agricultural research. The objective of building capacity in all RTB Centers and implementing this study through a peer group of taskforce members also resulted in improved priority setting skills and culture in all Centers, reducing the costs of conducting similar studies in the future.

The priority assessment started out with an ambitious stakeholder engagement model, which envisaged stakeholder participation and input at every step. More than 1,700 participants from numerous countries and with a wide range of backgrounds responded to the expert surveys to identify key constraints and opportunities. The banana study team piloted additional engagement models by experimenting with "real-time" stakeholder feedback through an e-Forum, developing an e-learning tool describing the priority assessment method through

[5] https://www.rtb.cgiar.org/rtb-bananaresearchpriorities/knowledge-toolkit/.

explanatory videos and web-scripts[6], and reached out to the 523 participants of the initial banana expert survey both online and in regional network workshops to collect feedback on parameter estimates and the overall study process. The results of the priority assessment were shared with the scientific community in several workshops, conferences, and journal publications (Alene et al., 2018; Mignouna et al., 2020; Staver et al., 2020).

Collaboration for the priority assessment extended beyond the social science groups as natural scientists (breeders, agronomists) were also involved. Most resource persons framing research options and estimating parameters were CGIAR scientists, but numerous experts from universities and national research institutions contributed. Substantial capacity building in terms of explaining the methodological framework and clearly defining the parameters and their use was required, since most scientists had never been involved in such an exercise.

Despite these efforts in collaboration and capacity building and the awareness that national agricultural research systems (NARS) are important next users of the priority assessment results, convincing evidence that results or tools were used or have influenced decision making at that level is scant. Priority setting in national organizations has long been known as a complex process and a "bumpy procedure" where political and scientific motivations exist, and financial resources and economic expertise are often limited. Establishing a direct causal relationship between priority analysis and resource allocation of next-user institutions follows a long and complex impact pathway that is very difficult to track (Dalrymple, 2006).

Regional CGIAR spending as a share of developing countries public agricultural R&D has been increasing, while the share compared to total R&D spending has decreased due to the increasing influence of private spending (Alston et al., 2020). Even in Sub-Saharan Africa, CGIAR spending only represents just over 10% compared to developing countries own public R&D spending, and less than 3% in all other regions (Agriculture Science and Technology Indicators (ASTI), 2012). This does not, however, limit the value of the exercise, but to the contrary shows the potential of improving R&D portfolio efficiency if similar priority assessment approaches were to be implemented by the NARS. The team shared methods, particularly for the banana case, tools and results with national partners in order to promote the approach. However, we have no evidence of this exercise influenced any NARS funding decision so far.

5. Challenges and Improvement of Priority Assessment

We identified three categories of challenges regarding the implementation and use of the priority assessment to help set research priorities. We discuss these challenges below, and then identify areas of improvements for future exercises. The scope of these challenges goes beyond this study and is thus relevant for decision-making processes about any research portfolio in agricultural research.

5.1. Strategic and decision making challenges

Quantitative analyses are one of several sources used by managers and planners of research institutions to set priorities. However, the translation of priority assessment results into portfolio decisions is not a simple formula. Quantitative priority assessment exercises are intended to provide guidance to decision makers and resource allocation does not usually directly mirror the quantitative analysis conducted (Stewart, 1995). Nonetheless, systematic *a priori* thought on procedures for the best use of ex ante assessment to guide funding decision making could improve their use and usefulness.

Our priority assessment studies covered the RTB research portfolio linked to unique CGIAR comparative advantages in breeding, seed, pest and disease management and agronomy, making up over 70% of the total portfolio. The omission of certain portfolio areas (such as emerging challenges, discovery research, cross-cutting social science research, and regional livelihood system programs; see Fig. 4) which were not suitable for quantitative assessment with the selected methods limits the application of the results in guiding overall program-wide resource allocation. Final RTB research portfolio decisions were based on additional information and evidence (this included expert opinions, other research/publications, or supplementary quantitative and qualitative indicators) external to this priority assessment study and under the discretionary power from RTB management. As a result, the actual portfolio reflected a broader set of research areas and options than the ones assessed through the quantitative methods. For example, social sciences, gender and scaling topics, which have longer pathways to impact but are essential for the success of the entire portfolio, took prominent feature as one of the 5 flagship components of the program structure.

A large share (about 75%) of RTB's funds come from a considerable number of individual donor agencies, each with their own funding priorities. These bilateral funds are normally tied to a specific program or activity thus curtailing the program managements flexibility to reallocate resources across the portfolio to shift priorities in terms of crops, research lines and geographic focus.

Finally, the uncertainty around the future configuration of the research program and its funding makes it hard to establish a continuous priority assessment framework with cycles integrating ex ante, foresight and ex post impact assessment.

5.2. Methodological challenges

Despite initial efforts, impact dimensions such as gender equality and environmental sustainability were not included in the assessment due to resource constraints (mostly time, but also taskforce expertise), suitability of methods used and the location and context specific nature of these impacts. If these impact dimensions are not included, however, decision makers need to integrate them into their decision process in some other, likely less structured, and systematic way.

Appropriate parameter estimates are crucial since they largely determine the assessment results. The procedure to estimate parameters (e.g., adoption, farm-level impact, constraint prevalence and future spread) could be formalized, and more systematic and uniform across research options and crops. We found that scientists and research managers have limited experience in estimating parameters for new research and the task was particularly challenging since ex post/other studies that could provide guiding values only existed for some parameters.

Though research options for each crop can be meaningfully ranked based on the indicators obtained through the priority assessment (or compound indexes), the results are not (very) suitable for cross-crop comparison and numbers don't add up to a total impact due to the way research options are selected and framed (e.g. widely varying sunk costs, double-counting due to overlapping target domains and the fact that some research options were not framed as substitutes but rather as complementing each other). As stated under the previous section, these quantitative results are only one source informing investment priority decisions. Furthermore, the study did not attempt to optimize the portfolio across crops. Since different teams were involved for each crop study, this would have implied trying to assess the potential bias in crop experts' parameter estimates. Historical allocations to mandate crops by center also played a role in funding decisions.

5.3. Operational challenges

We found that high quality, recent data even for basic parameters such as crop yields and prices are not readily available across all crops and locations, and disaggregated information e.g., by variety, or

[6] http://www.rtb-bananaresearchpriorities.org/.

production/eco-system that could improve the accuracy of the model results were not available for most countries. This was the main reason the spatial targeting effort could not be implemented to meet the time deadline for the quantitative assessment.

Coordinating and harmonizing the process and activities for this study was time consuming and costly (e.g., convening the group for meetings and even calls across different continents/time zones). In addition, cross-Center collaboration can be challenging due to the existing funding and reporting structure as well as potentially competing interests in securing bilateral funding for individual Centers. The creation of a unified 'One CGIAR' may help to ensure common standards in the estimation of parameters and coefficients to streamline portfolio assessment across Centers and research programs.

Not surprisingly, the timely sharing of progress and results to diverse stakeholders dispersed over different countries and regions, speaking a variety of languages, and accessing multiple communication channels requires incredible effort and substantial resources. This proved to be a serious operational challenge that required more time and resources than were at hand. Once project activities were completed, no champions (or additional funding) were assigned to take on this communication challenge and as a result, the final communication and outreach effort fell short of initial expectations.

5.4. Improvements addressing identified challenges

Improving priority setting in international agricultural research and overcoming the challenges listed above, requires repeatedly conducting and constantly improving such exercises based on the feedback gathered from the implementing team, contributing resource persons, and the wider stakeholder group. In addition to publishing assessment results, sharing lessons learned through studies addressing weaknesses in methods and data, carefully establishing roles and expectations of all stakeholders, and increasing familiarity with and trust in ex ante assessment's purposes and methods can help to institutionalize priority setting processes. Establishing a culture of impact requires substantial investment in terms of time and resources and is a dynamic process (Blundo-Canto et al., 2019). We hence suggest incremental and 'no-regret' activities that simultaneously serve multiple objectives and can help reduce costs of subsequent assessments. Specifically, we recommend:

- Developing and discussing the **'theory of change' and uptake pathways** of priority assessment findings with key stakeholders and targeted users of information (RTB, donors, Centers, and NARS). Eliciting feedback from these stakeholders on their experience with this study (including study process and engagement, compiled information and performance indicators) will foster learning and help in developing well-matched results formats. Engaging with different users can also guide improved and more targeted communication strategies to ensure findings are accessible to decision makers in a timely manner, in accessible formats and through suitable channels.
- A better **integration of all impact assessment related efforts** (incl. ex ante, foresight and ex post impact assessment studies as well as project and program M&E work) can create synergies, maximize learning and help lower overall costs. One example is a more strategic approach to data collection, e.g., by taking advantage of ongoing data collection efforts and adding-on specific questions to cover information gaps identified in the priority assessment (e.g., spatial disaggregation), and working towards centralized data storage and careful curation to make data more accessible (e.g., investment in shared CGIAR data base).
- **Methodological advancement** such as improved mixed methods approaches, to cover those research areas not easily addressed by economic surplus modeling and to account for additional impacts such as gender equity and environmental sustainability. This will likely require increased spatial granularity of the model and disaggregation by e.g., geographical region, type of farming system, socio-cultural setting, or market conditions. High quality data collected for M&E purposes can help in addressing this issue. Strengthening partnerships with advanced research organizations can help to advance methodology and tools for better inclusion of additional impact dimensions.

6. Conclusion

Numerous factors contribute to the increasing need for systematic priority setting to guide resource allocation in international public agricultural research. The trend of poverty reduction in recent years (World Bank, 2018) may be reversed by for example the widespread COVID pandemic and climate change effects, making it even more important to carefully select and justify research priorities to maximize the impacts of invested funds.

The RTB priority assessment presented here was a broad, systematic, quantitative ex-ante study conducted to guide decision making in public international agricultural research. While the applied methods are not new, taking them to scale (by conducting surveys in multiple languages, using a harmonized methodology across five crops and four Centers, and taking a global perspective), and incorporating multiple objectives by analyzing poverty effects and regional benefit allocation as well as economic efficiency, represents a substantial advancement over previous efforts. We also experimented with ambitious targeting and stakeholder engagement processes, which - though not fully implemented as planned - helped to ground-truth the selection of research options, resulted in a high level of stakeholder awareness, and yielded important lessons learned. The study shows how research managers, policy makers and donors can engage with a wide range of stakeholders to increase participation in the definition of the global research for development agenda.

The results of the five crop studies have informed RTB portfolio decision making and are being used in target-setting for research outcomes and impact.

Moreover, the developed methods and tools can serve as a foundation for systematic priority assessment exercises and continuous improvement and broadening of the methodology. Some areas, such as working with a higher spatial resolution (rather than analyses at the country level) and accounting for effects of climate change will result in a more accurate assessment of potential research impacts.

Incorporating additional impact dimensions such as gender equality and environmental sustainability will make the results more useful in setting research priorities but is much more challenging from a methodological standpoint and will require innovative new tools and advanced methods developed through inter-disciplinary collaboration.

The large efforts required for compilation of data could be substantially reduced by harmonized, forward looking data collection and storage solutions. This will enable routine (much quicker and less expensive) priority assessment studies to address new challenges. The rapid spread of some devastating plant diseases such as Fusarium TR4 in banana and CMD and CBSM in cassava over the past years have shown how quickly priorities can change, stressing the importance of periodic re-assessments of research priorities.

We conclude that large research organizations such as the CGIAR would benefit from systematic and integrated priority assessment cycles that are repeated and constantly adjusted over time, with deliberate learning incorporated into each loop. This will strengthen frameworks and processes, contribute to institutional memory and capacity building, and increase relevance of priority setting for decision making while reducing its costs.

CRediT authorship contribution statement

Diemuth E. Pemsl: Conceptualization, Formal analysis, Writing – original draft, Visualization, Writing – review & editing. **Charles**

Staver: Conceptualization, Writing – original draft, Writing – review & editing. **Guy Hareau:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. **Arega D. Alene:** Conceptualization, Formal analysis, Writing – review & editing. **Tahirou Abdoulaye:** Conceptualization, Formal analysis, Writing – review & editing. **Ulrich Kleinwechter:** Conceptualization, Formal analysis, Writing – review & editing. **Ricardo Labarta:** Writing – review & editing. **Graham Thiele:** Conceptualization, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors have declared that no conflicts of interest exist.

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