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Managing complexity and uncertainty in agricultural innovation through adaptive project design and implementation

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ABSTRACT
The recent shift towards agricultural innovation systems recognises that agricultural development is complex and must involve multiple actors. This makes innovation through a project framework inherently challenging. This article draws lessons from a project that fostered post-harvest innovations in Uganda. First, a two-stage design allowed scoping out business cases with partners to identify potential innovations. Second, stakeholders used the Participatory Market Chain Approach (PMCA) to flexibly develop the innovations. Third, flexible funding made it possible to seize new opportunities along the way. Fourth, the project was attentive to surprises in implementation and encouraged reflection.

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Introduction

Over the past three decades, agricultural research has made a commendable paradigm shift towards being more participatory and less rigid, but many projects are still designed and implemented with little flexibility or adaptive management. The new paradigm emerged as a critique of the classical top-down linear approach in which scientists created technology for extensionists to transfer to farmers. The top-down approach had limited success in the complex, high-risk, heterogenous environments where most smallholders work and in which demand for technologies is embedded in local knowledge of constraints and opportunities (Ashby 2009; Biggs 2008). Bottom-up participatory approaches started emerging to make research more responsive to distinct, complex environments and farmer demands (Scoones and Thompson 2009). However, the stakeholder focus has often been narrow, mainly involving farmers only (Cleaver 2001; Francis 2001). Yet there are other stakeholders committed to and with interests in rural development, including NGOs, the private sector, and government agencies. Over the last 30 years a distinct field of social science scholarship and practice has sought to rethink the idea of agricultural research supply and demand in systemic terms of multiple actors and sources of knowledge. Early work involved "Agricultural Knowledge and Information Systems" (Röling 1990), and "Rapid Appraisal of Agricultural Knowledge Systems" or RAAKS (Engel and Salomon 1997). Beginning around 2000 this work was consolidated in what became known as "Agricultural Innovation Systems" (World Bank 2012). Innovation systems thinking shifts the focus from *research* per se – the production of new knowledge, which might or might not be put into use – to *innovation* – the processes of change in the production and marketing of goods and services, which might or might not be driven by research (World Bank 2012). The developmental change occurs through the interactions between multiple actors – both individual and institutional – who have access to different knowledge and expertise (Biggs 2008; Engel and Salomon 1997; World Bank 2006).

CONTACT Jeffery W. Bentley jefferywbentley@hotmail.com

For innovation to occur, interactions among these diverse stakeholders need to be open and to draw upon available knowledge. Aside from a strong capacity in research and development (R&D), the ability to innovate is related to collective action, coordination, the exchange of knowledge among diverse actors, the incentives and resources available to form partnerships and develop businesses, and conditions that make it possible for farmers or entrepreneurs to use the innovations (World Bank 2012). For example, in Laos, dry direct seeding (DDS) of rice depended on researchers to develop the concept of machine seeding with fertiliser, machine shop owners to provide the new planting equipment, and innovative farmers (with some investment capacity) to test and adapt the innovations, which other farmers soon adopted (Clarke et al. 2018). Case studies from Nepal and India suggest that agricultural innovation depends as much on institutional innovations ("learning competence") as on technical change. For example, policy changes in Nepal allowed greater participation from farmers and other non-state actors in rice breeding. In Andhra Pradesh, India, mango exports were facilitated by creating links between farmer cooperatives and public-sector agencies that could help to meet stringent pest control standards for entering the US market (Pant 2014).

However, asymmetries among partners with respect to power, knowledge, resources, institutional strength, negotiation skills, and other assets may prevent a true partnership from developing (Rajalahti, Janssen, and Pehu 2008). An innovation culture requires trust, appreciation of other perspectives, shared values and stable relationships capable of evolving to meet new challenges. Projects that seek to collaborate on technical research with smallholders are further challenged because the innovation generated can be an "endogenous shock" that itself adds uncertainty to the value chain (Orr, Donovan, and Stoian 2018). These elements coupled with the need to proactively involve a large number of stakeholders make projects aiming at fostering agricultural innovation complex to manage, contributing to frequent failures (Ika 2012). One important reason for these failures is the tendency to manage these projects with a managerialist, technocratic, and instrumental style (Ika and Hodgson 2014). This reflects a limited understanding of the difference between complicated and complex problems (Katz 2016; Nason 2017).

Complicated problems can be hard to solve, but being reduceable to multiple, logically interrelated bio-physical processes, they are addressable with rules and recipes (Nason 2017). For example, sequencing the genome of sweetpotato is complicated, involving highly technical procedures, which however are all under the control of the researchers. On the other hand, complex problems involve too many unknown and interrelated factors to be reduceable to an underlying set of logical relations (Katz 2016).

Since agricultural innovation depends on the interaction of many self-organising actors operating in their environment, instead of aiming to fully plan and control the process, interventions aiming at stimulating innovation should be able to address complexity and foster the emergence of flexible support instruments that enable adaptive management (Klerkx, Aarts, and Leeuwis 2010).

Many international development projects fail to deliver impact because "when facing a problem, managers tend to automatically default to complicated thinking. Instead, they should be consciously managing complexity" (Nason 2017). The World Bank Sourcebook on Agricultural Innovation Systems (World Bank 2012) notes that agricultural innovation typically arises through dynamic interaction among the multiple actors involved in growing, processing, distributing and consuming agricultural products. However, participatory approaches may be ineffective unless researchers' attitudes and incentives are changed (World Bank 2006).

Even as managers of agricultural development projects have become aware of complexity in planning, for example, shifting from logical frameworks (logframe) to actor-based theories of change (Alvarez et al. 2010), project management still fails to take complexity fully on board. The logframe and similar planning tools (e.g. impact pathway) are largely based on linear thinking that, given certain assumptions, project activities lead to outputs, and hence to outcomes and impact (Couillard, Garon, and Riznic 2009). By the 2010s, the logframe had been enriched by the Theory (or Theories) of Change (ToC), a set of planning tools that call for continuous reflection and learning during the project (Valters 2015). Many major donors such as DFID and USAID now plan projects with theories of change – and similar tools – which look at the way outputs are translated into outcomes through the behavioural change of different actor groups, including changes in knowledge, attitudes and practice, and therefore impacts.

However, in practice, international agricultural development still tries to innovate in a project mode, with a defined timeframe, outputs and oversight procedures. As a result, most projects are still designed to address complicated rather than complex problems, and ToC may fall into the same traps as logframes, such as not taking into account local knowledge and culture (Valters 2015) while discouraging any activities other than those defined at the design stage, even as conditions change and actors refine their demands and reveal their preferences and limitations. Often, failure happens because donors require their projects to follow the same "one-size-fits-all" procedures, typically leading to top-down project management, limited flexibility in management, and excessive focus on external accountability (Ika 2012).

In 2000, the International Potato Center (CIP) began experimenting with RAAKS, a participatory approach to stimulate agricultural innovation that brings together stakeholders in a flexible, participatory process (Devaux et al. 2009; Devaux et al. 2020; Engel and Salomon 1997). CIP first used RAAKS to foster pro-poor market chain innovation for native potatoes in Peru. While this approach proved useful for engaging value-chain actors, researchers, and service providers in the identification of market opportunities, it did not include steps for exploiting the identified opportunities by developing new products or processes. As steps and tools were added for developing commercial innovations, a new approach emerged, which became known as the Participatory Market Chain Approach (PMCA), a structured – yet flexible – method for learning about a value chain, from farmers, traders, processors, retailers and chefs, and stimulating commercial, technical and institutional innovations that benefit all actors in the chain (Bernet, Thiele, and Zschocke 2006; Devaux et al. 2009).

In Peru, the application of PMCA engaged value chain actors leading to multiple commercial innovations including blue, red or yellow chips made from native potato varieties and fresh, native potatoes packaged for supermarkets (Devaux et al. 2009). At least 20 more native potato products have recently appeared on the market in Peru, showing how PMCA can trigger a sustainable innovation process (Devaux et al. 2020).

The World Bank (World Bank 2012) notes that the application of PMCA in Peru has achieved higher prices for native potatoes, increased farmers' revenues, developed more stable markets for producers (partly through successful branding and marketing), enhanced farmer's self-esteem, and facilitated inclusion of women in value chains. Relevant to this paper, the sourcebook also points out that traditional evaluation approaches based on objectives and logical frameworks do not work for this type of innovation processes. The processes and tasks involved are too complex and results often take some time to be apparent.

The PMCA is based on three phases (Bernet, Thiele, and Zschocke 2006). In Phase 1, facilitators from an R&D organisation lead a rapid assessment of farmers and other value chain actors, using mapping, diagnostic and interview techniques (Horton et al. 2013). PMCA participants get to know the value chain actors, and their circumstances, while identifying bottlenecks and market opportunities. Value chain actors and stakeholders involved in PMCA form thematic groups around innovations that address the identified opportunities and constraints (Bernet, Thiele, and Zschocke 2006). In Phase 2, the thematic groups evaluate potential innovations, make a work plan and hold an event to close the phase where they present ideas for exploiting the new market opportunities, and receive feedback from new stakeholders. In Phase 3, the groups jointly refine and launch the innovation, usually a new market product (e.g. a new brand of coffee), in a final event. This phased approach is aligned to what Burns and Worsley (2015) proposed, that development projects should start with a "participatory systems inquiry" (similar to Phase 1 of PMCA) to allow participants to see and understand complexity and to identify leverage points within a system where action can be taken. This should be followed by engagement approaches which entail a more structured approach of "systemic action research" (similar to Phase 2 of PMCA) or a more organic process of "nurtured emergent development" (similar to Phase 3 of PMCA).

PMCA stimulates joint value chain innovations, based on shared ideas and trust, that translate into enhanced smallholders' participation that ensures they benefit directly.

> How the PMCA is implemented will vary from case to case, as different contexts will require different activities and tools to solve specific problems. In other words, the common denominator of PMCA is not so much 'what' is being done but rather 'how' it is done. (Bernet, Thiele, and Zschocke 2006, 17)

The World Bank Sourcebook repeatedly cites PMCA as best practice and PMCA is highlighted with an Innovation Activity Profile (World Bank 2012, 598).

In 2005, a group of Ugandan development specialists visited the Andes, with support from CIP, to see the outcomes of the PMCA, which generated enthusiasm and confidence to apply the method with Ugandan partners (Devaux et al. 2020). This stimulated several innovations with the private sector including potato crisps, a sweetpotato variety and pickled hot peppers (Horton et al. 2010). Some people who worked on this PMCA application would later support its use in the ENDURE Project – the focus of this paper.

Study aims, project design and management structure

This paper asks: "How can an agricultural R&D project adapt to complexity and uncertainty over the course of its three-year lifespan?" We describe the challenge of confronting complexity for innovation within a project structure that requires formal planning during the initial design. The paper aims to illustrate and discuss how complexity and uncertainty inherent in agricultural innovation can be addressed in project design, management and learning by using a combination of methods which included a participatory R&D approach (the PMCA), flexible project design and funding, and the ability to adapt to unforeseen events such as by dropping some of the original research topics, and modifying or adding others. It presents the experience of ENDURE (Expanding Utilization of RTB and Reducing Their Post-harvest Losses), a project that combined elements of the PMCA with flexibility in project design, budget, and in the management style that was attentive to change and adapted to it. ENDURE aimed to reduce post-harvest losses through innovation in post-harvest management in potato, sweetpotato, cassava and banana to improve food security and increase income for smallholders, especially women, in Uganda.

This study is a retrospective analysis, by project insiders, including managers and designers, who attempted to open the project management "black box" and learn how projects actually deal with the challenge of complexity and uncertainty (see Ika 2015). This paper presents the experience of a research project that fostered post-harvest innovations in agri-food value chains in Uganda to provide a rich description of the project, looking at actual practice and roles and responsibilities. Our analysis draws on innovation science and project management literature (Couillard, Garon, and Riznic 2009; Ika 2012; Ika and Hodgson 2014; Klerkx et al. 2012). For example, we analyse ENDURE as a classic example of complexity (e.g. Katz 2016; Nason 2017), which demanded constant adaptation of the project plans and structure.

ENDURE was richly documented during its three-year life (2014-2017). This paper is based on a review of that literature, including a business case (one each for potatoes, sweetpotatoes, cassava and bananas), a case study of a female banana trader, a report of the PMCA inception workshop for the banana sub-project, and a report on the PMCA final event for that same project, as well as a stakeholder workshop in 2017. We also looked at the completion report, the final technical report for each sub-project, and an external review sponsored by the project donors. The project was also highlighted in the 2015 and 2016 annual reports of the CGIAR Research Program on Roots, Tubers and Bananas (RTB).

The project was led by CIP and implemented in collaboration with the other international research organisations which form part of RTB, along with local partners, including

Uganda's National Agricultural Research Organisation (NARO), universities, NGOs and private-sector actors.

ENDURE was planned with a flexible logframe developed during a planning workshop with stakeholders in 2012 (Table 1). The logframe left open the specific innovations that would be supported. In Year 1 (2014), multi-organisation teams were established, each focusing on one of the four target crops. The teams received funding to jointly conduct scoping studies (US$25,000 each) and write business cases for different potential innovations building on their findings and framing their own R&D agenda. The approach was competitive; after rigorous internal and external reviews, four of the seven submitted cases for innovations were selected for implementation as sub-projects, each implemented by its own team ("team" is defined as a loose group of partners from various organisations, who collaborated on a specific sub-project). Table 2 shows the team members and their main roles.

Selected project participants were trained to use the PMCA method. ENDURE was designed in two stages, meant to coincide with the three phases of the PMCA. The project's start-up stage dovetailed with Phase 1 of PMCA. A flexible project design allowed the project to progressively zoom in on the post-harvest and value chain innovations that were the most likely to succeed. Specific activities and outputs contributing to the project's overall goal were identified during the start-up stage in the first year and the most promising innovations were tested and disseminated in the implementation stage during following two years (corresponding to PMCA Phase 2 and Phase 3). The business case – which is not part of the conventional PMCA application – was one of the key elements of project flexibility; it entailed developing their R&D ideas. Preparing the business case for innovations provided opportunities for identifying and engaging with additional stakeholders to implement the R&D agenda. The scoping studies and writing the business cases were a key part of the flexible project structure; partners used this first stage to build collaborative skills and to learn how to work together while, upon their review, the project management could identify less promising research lines not to be further pursued.

Sub-project teams were each allocated part of the budget according to the products and the research agenda that had been identified in Year 1 and presented in the business case (sub-project teams received a similar level of funding, about US$350,000 each). Project management retained part of the budget to support cross-cutting activities to ensure consistency (e.g. comparing post-harvest losses of the four target crops) and relevance (e.g. analysing and addressing gender dynamics within households and value chains) and for annual project review meetings and other events where members of all teams shared ideas and lessons learnt. These activities enhanced cohesion and cross-learning across teams and helped the teams to switch from the initial competitive approach to a more collaborative one. Most importantly, these funds provided additional flexibility by allowing the project management to seize new opportunities not identified during the start-up stage (e.g. to facilitate linkages with additional private sector players, to access market price information, reinforce potato storage facilities, provide fellowships to MSc students and strengthen their research capacities). Sub-project teams, in consultation with project management, could also reallocate funds to new activities when they were appropriate responses to emerging findings and changing circumstances.

Results

Intervention as originally planned

During the first year, while writing the business cases, each crop team identified key innovations to reduce post-harvest losses and improve post-harvest management, and conducted preliminary market research on these options. During scoping, the different partners got to know each other, their capacities, interests, strengths and weaknesses and how these would have complemented one another. It also helped to identify and bring on board new partners and to drop others (who

Table 1. The project's logframe (summarised).

	Verifiable indicators	Means of verification	Assumptions
***Goal:* contribute to improved food security for RTB-producing communities in Eastern and Central Africa**	25% more consumption of RTB Improve nutritional quality 15% 20% higher incomes of RTB producers 3 new gender-equitable value chains	Household consumption surveys Rapid appraisal of producer associations	
Objectives: to improve food availability and income generation through better postharvest management and expanded use of RTB, based on: Postharvest and processing technologies Value chain assessment and development Capacity development	Decrease RTB storage losses by 15% in pilot sites 20% increased storage life of fresh RTB in pilot sites 10% increased processing of RTB in pilot sites 10% increased income from RTB and products, including livestock, in pilot sites More equitable distribution of benefits between men and women	Project baseline study and evaluation	Macro-economic situation conducive to scaling out Competitive position of RTB not undermined by subsidies to grains
Outputs			
1.1. RTB food availability situation assessed and priorities for improvement identified with value chain actors	4 crop and marketing assessments completed	Project reports	
1.2. RTB PHL reduction technologies inventoried and gaps for research identified	10 technologies per crop inventoried and product developed	Website	
1.3. RTB varieties with improved postharvest characteristics validated with target communities	6 RTB varieties selected for dissemination with stakeholder platform	Project reports M&E visits	Functioning extension organisations
1.4. RTB on-farm storage and processing systems trialled and validated	4 on-farm storing and processing technologies selected	Project reports M&E visits	
1.5. Other RTB technologies to reduce PHL and expand utilisation validated	4 other RTB technologies to reduce losses selected	Minutes of stakeholder meeting	
2.1. Current RTB value chains and food access situation assessed and priorities for improvement and enhanced gender equity identified with value chain actors	Priorities for improvement shared and agreed with stakeholders in 3 value chains	Minutes of stakeholder meeting	Policy environment favourable to expanding RTB
2.2. Assess new market opportunities to use RTB with stakeholders	1 new market opportunity identified per RTB crop	Project reports	
2.3. RTB producer/processor groups strengthened	2 producer/processor groups strengthened per pilot site	Project reports M&E visits	
2.4. Sustainable multi-stakeholder platforms for RTB value chain innovation created	4 platforms created and operational (1 per crop)	Project reports Stakeholder reports	Sufficient demand creation to sustain enlarged value chain
3.1. Online platform containing validated and documented methods, technologies, and knowledge products	1 platform established Project publications No. of website hits No. participants at project events	Website Series of project publications/ knowledge products	Adequate innovation absorption capacity
3.2. Capacity built in national partners for reducing PHL and increasing use of RTB	3 training events held per RTB crop	Project reports Reports of national partners	Stable partners committed to capacity development
3.3. Communication products developed so partners can disseminate outputs of research throughout agricultural knowledge and information systems	Communications plan 2 articles published 3–5 presentations and posters 5 technical manuals	Project communications plan Publications and dataset inventory	
Activities (sample of selected activities)			

(*Continued*)

Table 1. Continued.

	Verifiable indicators	Means of verification	Assumptions
Training of RTB producer and processor groups in innovation and market analysis	15 producer and processor groups trained	Participant scores in end of training test	
Organise stakeholder meetings for innovation in postharvest and value added	5 stakeholder meetings held per year in 3 stakeholder platforms	Minutes of meetings	
Set up online documentation platform	150 inventory items online	Website	
Organise training in PHL technologies and on assessing PHL at national level	3 national training activities in PHL conducted	Workshop reports	
Documenting project activities	1 synthesis document each year	Project reports	

Notes: acronyms are M&E (monitoring and evaluation); PHL (post-harvest losses); RTB (root, tuber and banana crops).

Table 2. Sub-projects' team members and their main role in the innovation process.

Sub-project	Action research	Capacity building and outreach	Private sector
Potato (led by CIP)	• CIP (varietal evaluation and storage systems) • NARO (agricultural practices, harvesting techniques) • Makerere University (market assessments, varietal evaluation, storage evaluation)	• NARO (pre- and post-harvest management) • NGO Self-Help Africa (store management, entrepreneurial skills, business plans)	• 3 farmers' associations • A traders' association
Sweetpotato (led by CIP)	• CIP (varietal evaluation) • ILRI (assessment feeding practices, feed evaluation) • NARO (bio-chemical analyses, feeding trials) • Makerere University (market assessment, bio-chemical analyses) • Uganda Martyrs University (varietal evaluation and agronomic practices)	• NARO (silage making and use) • NGO CHAIN Uganda (silage making and use, silage business centres, entrepreneurial skills, business plans) • NGO VEDCO (silage making and use, silage business centres, entrepreneurial skills, business plans) • Iowa State University – Uganda Programme (silage making and use)	• Pig Production and Marketing Ltd • Buvubuka Youth Group
Cassava (led by IITA)	• IITA (market assessment, business support) • NARO (varietal evaluation, bio-chemical analyses postharvest assessment) • IIRR (market assessment) • Makerere University (postharvest evaluation, economics) • Kyambogo University (post-harvest evaluation)	• IITA (market linkages) • CIAT (methods for postharvest assessment) • NARO (pre- and post-harvest management) • NGO IIRR (entrepreneurial skills, business plans)	• Brica Investments Ltd • A farmers' association
Banana (led by Bioversity Int.)	• Bioversity Int. (market assessment, seed system) • NARO (postharvest and storage evaluation) • CIRAD (optimum harvest time) • Makerere University (optimum harvest time)	• Bioversity Int. (seed system, postharvest management, market linkage, business plans) • Local Government Units (seed system)	• A farmers' association • KAIKA InvestCo • UFPEVA (producers and exporters association) • Ssemwanga Centre for Agriculture and Food Ltd

developed frictions with other partners). This probably avoided more serious problems within the team and made it easier to plan and identify responsibilities and workplans for each business case. At the end of Year 1, 60 people held a three-day meeting to launch the main project stage: the implementation of the selected business cases for innovation with their partners, thus defining the R&D agenda, summarised below for each sub-project (Table 3).

Potato. This crop is harvested twice a year in Uganda. Smallholders who sell their tubers to traders may receive low prices because of seasonal gluts of potatoes on the market. Being able to store potatoes for even a few weeks would allow farmers to earn higher prices. In its business case, the team proposed helping farmers store their potatoes on-farm until prices rebounded by improving storage facilities, mainly by using ideas from neighbouring Kenya. These included: small household-sized storage sheds, larger collective stores, and "coolbot" stores fitted with air conditioning run by solar power.

Sweetpotato. This root crop is more important in Uganda than in any other African country. Pig rearing is increasingly popular. Many smallholders who raise swine also grow sweetpotatoes, and feed the fresh leaves, vines and unmarketable roots to their pigs. But sweetpotato is a perishable, seasonal crop. Women livestock owners spend up to four hours a day acquiring food for their pigs, and if farmers had a way to preserve sweetpotato waste, women would save time and money. The sweetpotato team proposed to work on silage: chopped sweetpotato leaves, vines and roots, stored in an airtight container that could be kept for several months.

Cassava. The quality of cassava roots starts to deteriorate immediately after harvesting, with a shelf-life of two to three days. Rural households respond to this by gradually harvesting a field over several weeks, or by processing the roots soon after harvesting: by chipping and drying. Traders adapt to the short self-life by transporting fresh roots to market and selling them quickly. Nevertheless, much fresh cassava spoils along the chain or has to be sold off before going bad. In order to extend the shelf-life of cassava roots and building on experiences in Latin America, one proposal was to apply a food-grade fungicide and keep the harvested roots in plastic bags, ensuring high relative humidity. Another idea was to clean, wash and dry the roots, and dip them in hot, liquid paraffin which forms a protective coat (waxing) that keeps the roots fresh for weeks.

Banana. Cooking banana (shortened to "banana" here) is the main staple crop in Uganda. Most farmers have a banana garden to feed their families, selling the excess. However, the banana scoping study found that farmers were not always growing the varieties that the market demanded, especially those with a longer "green life". The project proposed macro-propagation (a village-level method for producing several viable suckers of market-preferred varieties from one plant), storage technologies and enhanced linkages with other value chain actors.

As agreed with the donors, the project logframe was not written in stone, but was updated to reflect the results of the scoping studies and business cases. A detailed workplan described the

Table 3. Main innovations originally proposed by ENDURE, by sub-project.

Sub-project	Original ideas identified in the first year
Potato	Test different varieties for storability. Design and test storage facilities where farmers could keep, either individually or collectively, tubers for a few weeks.
Sweetpotato	Silage: sweetpotato vines and unmarketable roots chopped and stored to feed pigs. Test different dual-purpose varieties for food (root) and feed (canopy). Business models for reaching pig farmers with silage.
Cassava	Test different varieties for postharvest physiological deterioration (PPD) and pruning to slow its progression after harvest. Plastic bags to keep high relative humidity (i.e. keep cassava moist). Dipping of roots in wax to slow PPD down.
Banana	Establish macro-propagation chambers at farmer level. Temperature-regulated storage options for different presentation forms of bananas (bunches, clusters, peeled and unpeeled fingers). Sale of sorted and graded bananas by weight and cushioning to minimise bruises during transportation.

revised activities and the outcomes the teams expected to achieve. Planned activities included building potato stores and setting up varietal trials, pig feeding trials and analysing nutritional profiles of different blends of sweetpotato silage, testing relative humidity bags and cassava waxing, and establishing mother gardens and macro-propagation chambers for bananas, as well as trainings, studies and other activities. Figure 1 shows project locations and on-station research sites. An action plan was developed to ensure that gender was systematically mainstreamed in the project (e.g. opening more space for women leaders in the management of potato stores) and to build team members' capacities.

Challenges and difficulties

Phase 2 of PMCA started in 2015, and although various difficulties emerged, teams were able to collaborate to adapt to the circumstances and modify activities, accordingly.

Potato. The first season of field and storage trials did not go as planned with several setbacks, including drought, unavailability of hay bales of similar consistency for building the large potato stores, and rodent attacks. The "coolbot" idea (air-conditioned storage) was dropped because the insulation material was too expensive and due to the unforeseen high risk of theft of the solar panels. Furthermore, the potato crop was affected by bacterial wilt (a disease that causes both field and storage losses). Even so, researchers tested eight CIP potato clones and 10 local potato varieties on-station. With farmer associations, the team built four collective stores, and designed the individual ones, while training 119 farmers to manage them. Collective potato stores were launched at a two-day event in October 2015.

Sweetpotato. The university lab was late providing the nutrition profile of the different types of silage, which delayed identifying the most suitable ones, setting back the on-station and on-farm pig feeding trials. Meanwhile, the piglets kept growing until they were no longer suitable for the original experimental design, but the team was able to adapt, by conducting the trials with pigs of different ages. Researchers started on-station trials of dual-purpose sweetpotato varieties (that could be used for silage and as people food) but a drought destroyed the first ones. Motorised choppers (to cut vines and roots in small pieces suitable for feeding pigs) were not available on the market and hammer mills had to be modified and used. Feeding trials were concluded with five treatments, with different inclusion rate of maize bran and cassava flour. The project trained 277 farmers to make and use silage.

Cassava. The proposed technologies, despite being commercially used in Latin America, were completely new in the country. Some friction emerged between two Ugandan research partners due to overlap of their national mandate. This was overcome by defining their roles more clearly: assigning responsibilities for post-harvest evaluation to one organisation and biochemical analyses to the other, with one MSc student assigned to each task. There was a lack of water for the cassava pack house (shed where cassava can be waxed and packed for market) to be managed by farmers. In spite of this, researchers collected 17 cassava varieties that were analysed for their biochemical properties and speed of post-harvest physiological deterioration (PPD). MSc students tested on-station waxing, high relative humidity bags and pruning (removing leaves six to seven days before harvest to extend shelf-life). In July 2015, six team members (mostly researchers) took a nine-day learning visit to CIAT headquarters in Colombia to be trained on how to assess PPD and extend the shelf life of cassava. Two pilot pack houses were established in project sites in Uganda.

Banana. Initial trials with two farmer groups for the sale of sorted and graded bananas by weight and cushioning to minimise bruises during transportation found that local traders were reluctant to pay more for graded and cushioned bananas, so this activity was largely dropped. Ten mother gardens were established with about 1,500 tissue culture plantlets of four market-preferred varieties, and four macro-propagation chambers were built jointly with local farmers organisations to further multiply clean planting material of preferred varieties. Each mother garden supplied two to three farmer groups. CIRAD started trials on optimal harvest time of banana bunches.

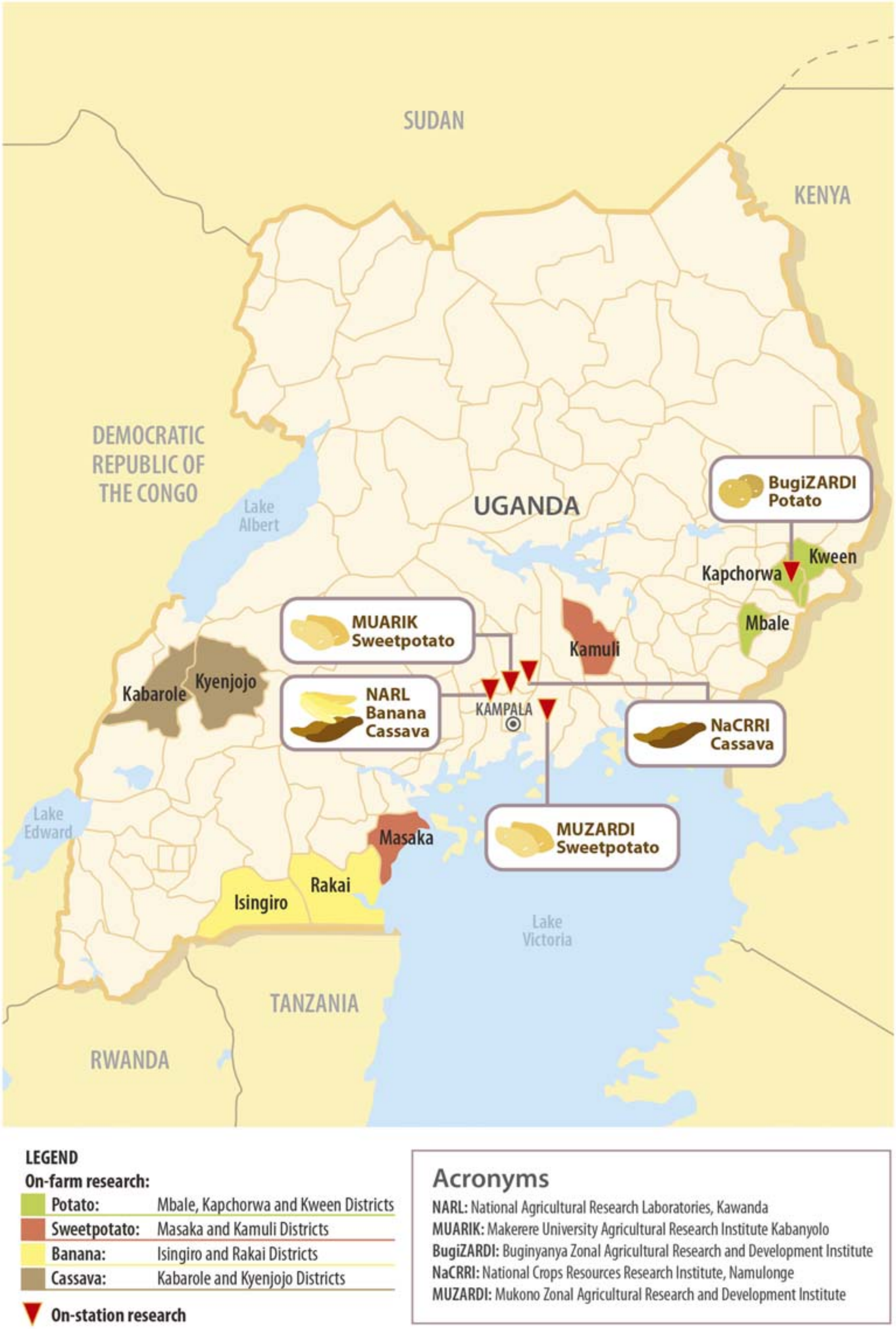

Figure 1. Map of ENDURE research sites, by crop and partner.

Adapting to surprise

Development planning should "plan on surprises", but it should also plan on human inventiveness (Scott 1998). Most project planning leaves little room for surprise. However, innovation processes with farmers and other value chain actors form part of a complex system and therefore cannot be tightly planned three years in advance (Ortiz et al. 2020).

Potato. One of the four large, collective stores collapsed under the weight of the cement plaster on the hay bales and because of termite damage to the timber poles. The team rebuilt the store based on an improved design and strengthened the others. It also developed guidelines for farmers on how to manage potato stores (both technically and institutionally), and tested 18 potato varieties, identifying one that was suitable for storage and met the demand of consumers and processors. Trials with farmers showed that potatoes could be stored for six weeks, and up to nine weeks at higher altitudes. Twelve small, eight-ton stores were built so farmers could store potatoes at household level. Based on farmers' feedback these small stores were larger than the individual stores originally proposed. Furthermore, based on emerging evidence of damage of potatoes at harvesting being a major cause of post-harvest losses, the team decided to trial ridge-planting and two types of potato lifter (mechanical harvester) on station (one ox-drawn and another attached to a tractor). Both lifters worked well, but farmers preferred the ox-drawn lifter for its ease of use.

Sweetpotato. There were problems finding safe, affordable and practical mechanical choppers on the local market. Trials found that silage produced in a plastic silo and mixed with maize bran was drier (i.e. less prone to spoilage), and farmers made over 77 tons of silage. An MSc student identified a dual-purpose variety which was suitable for both food and feed. The team reconfirmed the idea that silage needs to be supplemented with commercial feed (particularly maize bran) to ensure satisfactory growth rates of pigs. Three business centres were established to sell silage to pig farmers, and to provide fee-based chopping services, trainings and materials, including planting material of sweetpotato dual-purpose varieties, to farmers and entrepreneurs interested in making silage themselves. The team also came across and supported a youth group that made silage for sale to farmers.

Cassava. The farmer pack house had problems accessing water, but the one run by a trader had started selling waxed cassava roots commercially. Researchers realised that they needed to add sensory studies (taste tests) of the waxed roots that had been stored for 14 days. Waxed cassava was market tested in dozens of different outlets, including supermarkets. There was limited interest in the high relative humidity technology (the plastic bag) and it was dropped.

Banana. Mother gardens and macro-propagation chambers were fully operational and local government was further disseminating the technology. Two communities were starting to sell planting material as a business. Optimal harvest times for cooking banana were established. Two women began to sell bananas wholesale, including one who also exported. Optimum storage temperatures for bananas were established. The project began to promote an evaporation charcoal cooler (a cabinet with wire-mesh walls filled with charcoal) for peeled bananas in fresh produce markets in the capital city Kampala.

PMCA is a method that provides ample space for adaptation to emerging findings. While implementing the project, researchers were surprised with some of the innovations. For instance, there was low adoption of storing cassava in plastic bags, and the silage was too wet, contributing to early spoilage of the feed. The coolbot idea was impractical and was dropped. The sweetpotato trials had to be delayed because of the difficulties of coordinating the many actors. For bananas, the idea of selling fruit by weight was dropped because traders were reluctant to use it. Some of the surprises were about safety of the innovation, which no one had anticipated as a possible problem: women willing to make silage were concerned that motorised choppers could cause injuries, and the potato stores' structures were so heavy that one collapsed. Spotting such problems is a strength of participatory research, but responding to them requires flexible project management, as well as adaptable decision-making among partners who share a common goal. In other words, several ideas originally proposed were still too researcher-centric and had to be winnowed out.

This was possible because of the built-in flexibility of the PMCA that does not consider a discarded line of research as a failure. Other research ideas, such as forming small farmer groups to produce banana planting material, or making silage for pigs, were adapted and the prospered.

Table 4 shows some of the creative responses to the surprises. Some of the required changes were institutional, such as adding a youth group to the sweetpotato team, or supporting the existing banana multi-stakeholder platform. Others were technical, such as adding evaluations of potato lifters and modifying the chopper design to make silage production safer. Some activities were dropped, such as the cushioning for bananas, while others were added, such as the charcoal coolers to keep bananas cool at the retail market.

Flexibility was built into ENDURE's two-stage design and supported by project management, budgeting and donors. PMCA's flexible nature made it an appropriate tool for encouraging teams to assume ownership, to influence outcomes, and to engage with other actors. For example, the banana team

Table 4. Project responses to surprise.

Sub-project	Surprise / unplanned event	Response
Potato	1. Harvesting with hoes damaged the tubers: the major cause of losses	1. A: In the third year, the team began to study ox-drawn and motorised potato lifters*
	2. One out of the four large potato stores collapsed due to poor design and termites (and it was too expensive)	2. M: Store rebuilt with a new design to be safer (e.g. sturdier, lighter) and also cheaper. Other stores strengthened with metal beams*
	3. There were no local suppliers of material required for coolbot (store at controlled temperature) and the solar panels were easily stolen	3. C: The coolbot component was dropped
Sweetpotato	1. The team loaned silage choppers to farmers. One farmer took the chopper home; while making silage her child was accidentally injured by the machine's belt. The lead farmer in Kamuli also lost a finger while chopping silage for women farmers (who feared using the chopper on their own)	1. M: The chopper design had to be modified, with a cover over the belt, to make it safer*
	2. The original silage design required a metal drum, with a bag in the drum, and a perforated plastic pipe in the bag to drain off moisture. The pipe and drum were expensive. Climbing into the drums forced the women to lift up their skirts, which they disapproved	2. M: The team replaced the originally planned supplement (molasses) with maize bran to the chopped sweetpotato to make a drier silage, without the need for the metal drum and the plastic tube
	3. Farmers were interested in silage, but found manual chopping too labour-intensive and the choppers were costly	3. M: The three original demo centres were restructured as silage business centres to provide training, and chopping services that farmers could access for a fee
	4. The team came across a dynamic youth group that, supported by a local researcher, had been involved in making and selling silage for a few years, primarily for cattle	4. A: the team was eventually supported by the project with a silage chopper to help disseminate the technology in an additional district*
Banana	1. The team envisioned cushions to protect banana bunches on route to market, but traders were unwilling to pay the added cost	1. C: Cushioning activity dropped
	2. Original ideas for extending banana shelf-life in markets were unsuitable	2. A: Charcoal cooler component added
	3. A regional banana multi-stakeholder platform was identified near project sites during the market study	3. M: The existing regional platform was supported, rather than creating one from scratch
	4. A women's seed group was established, but they found it difficult to sell banana plantlets	4. A: Participating in a trade fair created more demand and gave the women access to a wider market
Cassava	1. Roots often suffered mechanical damage during harvest, which accelerate spoilage	1. A: Farmers were trained to plant in ridges and to harvest more carefully
	2. Two enterprises (a trader and a farmer cooperative) started to sell waxed roots. The trader stopped waxing roots, but the farmer continued, with limited volumes. Both enterprises had limited business capacities	2. M: As waxed cassava was a high-end product; market testing was primarily done in supermarkets. Training was given to the management of both enterprises to increases their business capacities
	3. Limited initial interest of buyers in high relative humidity plastic bags discouraged the pilot enterprises from investing in them	3. C: Scaled down because of low adoption

Notes: A = Additional component; C = Cancelled or scaled-down component; M = Major modification of the component; * Totally or partially supported by centrally managed funds.

progressively built strong engagement with local governments. The group of women banana farmers mentioned in Table 4 established their own commercial macro-propagation chamber and received a grant of US$2,000 from the local government's gender fund to expand their seed business. After the project, the district government and a local NGO spread the macro-propagation technology to areas within and outside of the district. Near the end of the project, the business centres established in two districts by partner NGOs acquired funds to sell farmers silage choppers on credit and the youth group, another partner, experimented with making silage into pellets.

Some of the least promising activities were dropped or scaled down, freeing staff and money to implement others that had not been originally planned. Sometimes new partners were brought in (such as the youth group to make and sell silage). In other instances, a project partner was dropped due to limited engagement and unsatisfactory performances. Many of these adaptations would not have been possible with the typical rigid project design and without the flexibility that was granted to the project by the donor.

Case study: the banana sub-project

All four ENDURE teams used the PMCA, but the banana team followed the method most closely. In February 2015 (Year 2), the banana team held a five-day workshop to train sub-project partners and other stakeholders to use the PMCA. Following PMCA, the team established two thematic groups, which are "groups with a shared interest" in the innovations to be developed. Group 1 focused on marketing of differentiated forms of bananas (fingers, clusters, and peeled), protected bunches, and on weight-based pricing. Group 2 focused on identifying market-demanded varieties, introducing and multiplying their planting material, establishing demonstration sites, and facilitating the sale of the plantlets.

The PMCA is designed to stimulate different types of innovation: technical, institutional, and commercial (Devaux et al. 2009; Ortiz et al. 2020). The greatest technical innovation was the split corm method (cutting the banana corm into sections) that was found the most suitable and cost-effective technique for multiplying the planting material of the market-preferred varieties (identified during the scoping study in Year 1). Other important technical innovations included the identification of the optimal harvesting time (with good trade-off between ripening and shelf-life) and the introduction of the staggered removal of suckers.

In terms of institutional innovation, the team supported the farmers groups to develop two business models for selling and distributing plantlets outside and within their communities, respectively, in order to ensure a balance between economic viability and fair access to seed by other farmers not involved in the project, thus avoiding their resentment. Moreover, following an analysis of gender norms and roles in the value chain and intra-household dynamics, specific responsibilities were identified through a facilitated process to ensure that both men and women benefitted from the initiative. For instance, women were mainly in charge of the management of the macro-propagation chambers and of distribution within the community, while men provided primarily supporting roles, offering labour for construction work, and utilising their knowledge, experiences and networks to facilitate the sale of plantlets outside their village. While ENDURE was intended to establish multi-stakeholder innovation platforms for each target crop, the team learnt that a banana platform already functioned (Western Region Banana Platform) and decided to strengthen it rather than building a new one. New partners were brought on board: the Uganda Fruits and Vegetable Exporters and Producers Association (UFVEPA) – key for accessing export market and enhancing compliance to quality standards – and two district governments which would prove crucial for scaling the macro-propagation technique to non-target villages. However, one private actor underperformed, and some of its responsibilities and budget were reduced and transferred to NARO.

As for commercial innovation, Thematic Group 2 identified seed as a business opportunity for women. Men and women farmers started selling quality planting material of market-preferred varieties with improved packaging and labelling and were linked with the Western Region Banana

Platform to find customers beyond their community, including traders, input dealers and other farmers. One of these groups, Bakyala Kwekulakulanya (Women in Development) used members' resources to build an additional large multiplication chamber, and at the PMCA's final event, the group was awarded a grant by the district to build a water tank. ENDURE formally ended in early 2017, but by the end of the year this group had sold US$3,000 worth of plantlets and began to offer training to other farmers.

Discussion and conclusions

Promoting innovation in agricultural value chains is inherently complex. Innovations unfold in uncertain ways, so they cannot be entirely planned or predicted in advance. It is advisable to first facilitate joint understanding of the problem by many stakeholders and then together generate ideas, prototypes and interventions that include mechanisms to learn and adapt from feedback arising from engagement with the problem. This paper discussed how complexity and uncertainty have been addressed in the design, management and learning of a specific project, ENDURE.

ENDURE was **designed** around a participatory approach for fostering innovation in value chains, the PMCA, which recognises that innovation cannot be fully anticipated, especially when the project's innovations cause changes in a system that is constantly evolving (Orr, Donovan, and Stoian 2018). Accordingly, PMCA starts with a diagnostic phase to identify a potential core innovation and the actors to engage in a facilitated innovation process. In order to enhance the fit between PMCA and a quite large – although still resource-limited – R&D project like ENDURE, the project was designed with a two-stage approach and funding which could allocate funds to sub-projects as opportunities emerged, allowing for the flexibility to accommodate innovation. The start-up stage entailed scoping studies, the development of seven business cases, of which four were selected for funding. This first stage identified (and in some cases revised) the core innovations most likely to succeed while improving the theory of change and partnerships before starting full implementation. In the second stage, implementation, more rigorous assessments were conducted and those innovations that had proven technically feasible, economically viable and socially acceptable were promoted and disseminated.

The project **management** was attentive to surprises: unexpected or unplanned changes or events, linked to the complexity of innovation processes. In consultation with project management, each implementation team could add, drop or change activities. Well into the project's life, implementing teams could still reallocate funds from disappointing activities to more successful ones. Project management could provide additional funds to teams to support promising activities that had not been anticipated at time of developing the business cases.

Feedback and cross-**learning** were systematically promoted by ENDURE. Surprise was fed back creatively into project management. The project encouraged an approach from the beginning that surprise was not failure. For instance, if a potato store collapses, while it is disappointing and dangerous, it is also a learning experience and can lead to jointly designing a new improved store based on users' feedback. After selecting the business cases, ENDURE switched from a competitive to a more collaborative approach among implementing teams. Reflection meetings were held with all partners to compare results and experiences across teams. This helped teams to identify areas that had to be added, strengthened, scaled down or dropped based on emerging findings.

ENDURE recognised that innovation is complex and project management needs to have the flexibility to adapt. Project management systematically tried to avoid rigid planning and some of the most promising innovations emerged unplanned, toward the end of the project, for example, making pellets from sweetpotato silage and linking banana seed producers to local governments. The lessons learnt should be valuable for other development projects which support innovation in complex systems. The three-year project lifecycle was too short to fully validate the proposed innovations or to take them to scale. Hence, an additional recommendation for donors is to sequence investments across a portfolio through phased projects for nurturing promising innovations to full potential.

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Notes on contributors

Jeffery W. Bentley is an agricultural anthropologist, and the regional coordinator for Latin America for Access Agriculture.

Diego Naziri is a value chain and post-harvest specialist at the International Potato Center (CIP) and Senior Research Fellow at the Natural Resources Institute of the University of Greenwich. He coordinated the ENDURE project in Uganda.

Gordon Prain was the leader of the Social and Nutrition Sciences Division at the International Potato Center (CIP) when the ENDURE project was launched and has been a member of the ENDURE advisory group since its inception.

Enoch Kikulwe is an agricultural economist at Alliance of Bioversity International and International Center for Tropical Agriculture (CIAT). He headed the banana sub-project of ENDURE.

Sarah Mayanja is a Research Associate at the International Potato Center (CIP), and a PhD Fellow at the Uganda Martyrs University. She was the Deputy Project Leader of ENDURE.

André Devaux is an agronomist at the International Potato Center (CIP), where he is Regional Director for Latin America and the Caribbean. He helped to guide the PMCA focus for ENDURE.

Graham Thiele is the Director of the CGIAR Research Program on Roots, Tubers and Bananas (RTB). He led the development of ENDURE.

ORCID

Jeffery W. Bentley http://orcid.org/0000-0002-4101-8843
Diego Naziri http://orcid.org/0000-0002-8078-5033
Gordon Prain http://orcid.org/0000-0002-3275-681X
Enoch Kikulwe http://orcid.org/0000-0003-2433-1704
Sarah Mayanja http://orcid.org/0000-0002-9698-0036
André Devaux http://orcid.org/0000-0002-2340-197X
Graham Thiele http://orcid.org/0000-0002-3739-0431

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