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REVIEW

Why interventions in the seed systems of roots, tubers and bananas crops do not reach their full potential

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Abstract

Seed systems for roots, tuber, and banana (RTB) crops receive relatively little attention from development-oriented research and commercial seed sector actors, despite their importance for food security, nutrition and rural livelihoods. We review RTB seed systems—with particular reference to potato, sweetpotato, cassava, yam and banana —to reflect on current seed system development approaches and the unique nature of these systems. We refer to our own experiences, literature and 13 case studies of RTB seed system interventions to identify gaps in our knowledge on farmer practices in sourcing and multiplying seed, and processes affecting seed quality. Currently, most approaches to developing RTB seed systems favour decentralised multiplication models to make quality seed available to smallholder farmers. Nevertheless, arguments and experiences show that in many situations, the economic sustainability of these models cannot be guaranteed, among others because the effective demand of farmers for seed from vegetatively propagated crops is unclear. Despite the understudied nature of farmers' agronomic and social practices in relation to seed production and sourcing in RTB crops, there is sufficient evidence to show that local RTB seed systems are adaptive and dynamic. Our analysis suggests the paramount importance of understanding farmers' effective demand for seed and how this affects the sustainable supply of quality seed from specialized producer-entrepreneurs, regardless of the seed system paradigm. From the case studies we learnt that few interventions are designed with a rigorous understanding of these issues; in particular, what types of interventions work for which actors, where, and why, although this is a necessary condition for prioritizing investments to increase the use of improved seed by smallholder farmers.

Keywords Vegetative multiplication · Decentralized multipliers · Seed quality · Farmer demand

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1 Introduction

Seeds of agricultural crops have co-evolved with human activities. This places seeds at the nexus of many different biophysical and social relationships that make up seed systems. Seed systems involve genes, farmers, communities, breeders, researchers, politicians and governance regimes and operate at different scales. Seed systems have agro-ecological, socio-economic and political contexts; as such they are also affected by larger global developments such as climate change, globalization of economies and demographic developments. Projects to improve seed systems have long been an important component of agricultural development strategies. The different ways in which seed systems are understood have led to different types of project interventions, which are supported by different narratives that envisage different pathways into the future. Today, the agricultural and rural development landscape continues to sprout many seed system interventions: projects of different shapes and scales, aiming to increase seed security, food and nutritional security, agricultural productivity, or poverty reduction. Although the contexts and narratives of these interventions vary, the majority strive, regardless of the crop, to make quality seeds and traits more available and accessible to farmers. There is, however, a general notion that despite the tremendous investments, the outcomes of these interventions often have not met expectations and left the interests of many farmers still unattended. In the 1980s recognition of the importance of farmers' interests and the value of their knowledge led to the promotion of more bottom-up approaches to agricultural technology development. In the field of seed and varieties this stimulated interest in informal or farmer-based seed systems (e.g. Cromwell, 1990; Almekinders, Louwaars, & De Bruijn, 1994; Thiele, 1999; Tripp, 2001), and in-situ conservation and participatory plant breeding (Eyzaguirre & Iwanaga, 1996; Sperling, Ashby, Smith, Weltzien, & McGuire, 2001; Almekinders & Elings, 2001). Over the last two decades, much emphasis has been given to market solutions and public-private sector collaboration (Venkatesan, 1994; Scoones & Thompson, 2011).

In this paper we explore the status of practice in seed system development. We focus on cassava (*Manihot esculenta*), banana (*Musa spp.*), potato (*Solanum spp.*), sweetpotato (*Ipomea batata*) and yam (*Dioscorea spp.*), all of which are vegetatively propagated root, tuber and banana (RTB) crops that play major roles in the food security and well-being of people in developing countries. Except for potato and sweetpotato grown in temperate zones and export banana, they are tropical staple food crops with a historically low prestige and visibility: in most countries they have received little attention from agricultural research systems until after independence from colonial rule. A network of international agricultural research centers, the CGIAR, was established in the 1970s with some having programs on RTB.[1] The mission of these RTB programs, besides recognising and acting on their importance as food crops for the poor, centers on their distinctive multiplication characteristics: they are normally vegetatively reproduced through roots, tubers or stems with sexual propagation applied only for breeding. This way of propagation makes their 'seed' systems different from real 'true seed' systems[2] (see Section 3).

In the following sections, we first explore current approaches in seed system development, and specifically how these apply to the RTB crops. We look at seed systems in its broadest definition, including biophysical and social dimensions, formal and informal institutions operating at different levels and geographical scales. We use the literature, our own experiences and those of our collaborators, and a series of 13 case studies on seed system interventions (see Table 1) to underpin the lessons from the last 2–3 decades on the ways that farmers' acquire quality seed. With that information we discuss the rationale of commercially viable decentralised seed supply and the challenges of a cross-crop research agenda that will support the effectiveness of interventions in RTB seed systems.

Table 1. Case studies (Andrade-Piedra et al., 2016).

2 Current approaches to seed system development

2.1 The dominant approach

Up to the 1980s, the goal of seed system development in developing countries was a formal public-private sector seed system model, emulating the model which was so successful in north-western Europe and North America where it had emerged as a result of advances in agricultural technology and a strong agricultural sector. Although the actual stages of development and maturity of the seed systems vary among crops and countries (Douglas, 1980; Spielman & Smale, 2017), they are assumed to eventually reach the 'final' and 'mature' stage, characterized by a well-developed agricultural sector in which commercial seed companies and the market supply most of the seed and legislation and supporting

[1] CGIAR centers working on RTB crops and their date of entry into the CGIAR: International Center for Tropical Agriculture (CIAT) – 1971: cassava; International Institute for Tropical Agriculture (IITA) – 1971: cassava, yam and banana; International Potato Center (CIP) – 1973: potato, sweetpotato and Andean root and tuber crops; International Network for the Improvement of Banana and Plantain (INIBAP) 1985: banana, merged with IPGRI in 1994, which was renamed Bioversity in 2006.

[2] We will use the term seed throughout this article to refer to planting material for both sexual and asexual propagation. Where sexual propagation is referred to specifically, the term "true seed" is used, while reference to asexual propagation is denoted by the term "planting material".

Table 1 Summary of 13 case studies of root, tuber and banana seed system interventions (based on Andrade-Piedra et al., 2016)

Crop and Country	Short name	Funding sources	Scope	Scale	Duration	Main highlights from documents
Potato, Ecuador	CONPAPA (Consortium of Small Potato Producers)	Swiss Development Cooperation (SDC)	A local farmers' organization produces quality declared potato seed for accessing high-value markets	3 provinces, 500 farmers, 35 trained seed producers	2001-today	• CONPAPA is a farmer cooperative, which produces and markets potato seed and potato for local markets. It has shown itself to be able to control quality in the absence of functional formal regulations. A National Agricultural Research Institute (INIAP) supported training on seed multiplication, and farmer organization around seed production and marketing. • The initiative triggered the national regulators to accept the quality declared seed system.
Potato, Peru	Cajamarca	Yanacocha Mining Cooperation	Clean potato seed of local varieties with funding from a mining company	A farming community	2012-today	• A hydroponic-based seed production in a greenhouse was set up to provide these farmers with pre-basic seed of native potato varieties. An initiative implemented by an NGO funded by a corporate responsibility program of a mining company. Yields increased substantially, but the multiplication system is knowledge intensive and costly to set up. • Working together and in partnership turned out to be challenging for the farmers (due to mistrust). • The need for some kind of internal seed quality control is noted.
Yam, Nigeria	AYMT (Adapted Yam Minisett Technique)	Department For International Development (DFID), UK	Researchers improve an on-farm technique for planting more land with less seed yam	± 400 farmers in Abuja, Rivers, Oyo and Kwara Kogi and Ekati states of Nigeria	2003–2005	• The project promoted the use of adapted yam mini-sett technique (AYMT) to improve seed propagation ratio, reduce seed cost and improve seed quality. • On-farm training and demonstration plots to promote the technologies learnt that the best treatment was a combination of fungicide and insecticide • A major obstacle to farmers adopting the practice is thought to be the lack of awareness, reliability and (financial) accessibility of the chemicals needed. • This project laid the much needed foundation to propel the technology through subsequent projects.
Banana and plantain, Ghana	TARGET	USAID	Researchers shared new hybrids with farmers	800–900 farmers	2003–2005	• The goal was that farmers would disseminate planting materials of new hybrid-bananas within their own communities. Farmers received training in rapid macro-propagation techniques for clean seed multiplication, improved agronomic practices, marketing, and

Table 1 (continued)

Crop and Country	Short name	Funding sources	Scope	Scale	Duration	Main highlights from documents
						post-harvest handling (e.g. cooking duration) of the fruits. • The rapid multiplication nurseries that resulted were difficult to manage and were not economically viable.
Sweetpotato, Tanzania	Marando Bora ("better vine")	Bill & Melinda Gates Foundation	Delivering local and improved (orange flesh) varieties, producing clean seed off-farm, and managing vines on-farm for food security and nutrition	Reached 112,000 farmers in 16 districts through 88 decentralized vine multipliers	2009–2013	• The project used two approaches to get materials out: 1) decentralised vine multipliers (DVMs) and after this approach showed flaws 2) a mass multiplication approach. • The project set-up was designed to evaluate a number of aspects (the use of net tunnels to reduce degeneration, the use of vouchers, vine quality maintenance). However, the implementers reckon that the question of when farmers will commercially purchase vines remains unanswered.
Sweetpotato, Rwanda	SASHA Superfoods	Bill & Melinda Gates Foundation	Similar to the case above, with additional pull from a sweetpotato processor who requires a consistent supply of roots	20 farmer groups and 40 individual farmers	2013–2014 and 2014–2018	• With a value chain focus, the project facilitated linkages between sweetpotato farmers and a large scale bakery which offered a premium price for roots used in making processed products such as biscuits and mandazis (local donuts). • Two organizational models for the multiplication and dissemination of vines for planting were tested: 1) existing farmer groups, and 2) collaboration with individual farmers. Over half of the farmers were women. • Providing clean tissue cultured material to the farmers was problematic. • The demand for the vines was mostly from NGOs and farmers in non-intervention areas (who looked for the OFSP). The experience showed that farmers who had an assured market for their roots had interest in quality vines for planting.
Potato, Kenya	3 G (Three Generations)	USAID	Disseminate new varieties and clean seed with rationalized regulations permitting quality declared seed	The project ran in Kenya, Rwanda, Uganda, the case deals with Kenya only	2008–2013	• Stimulate public and private sector collaboration to link-in and increase investment from the private sector in seed potato production, raise and decentralize national production of basic seed potato, improve access to quality seed and the quality of farm saved seed and to enhance the adoption of diffused light stores. • More than 100,000 in-vitro plants produced, 1 million mini-tubers, with 52 ha under G2 seed

Table 1 (continued)

Crop and Country	Short name	Funding sources	Scope	Scale	Duration	Main highlights from documents
						and 921 tons of G3 seed harvested through a public and private sector network of more than 60 multipliers. • The fourth generation seed tubers (G4) were all sold, and in general at lower prices than third generation seed tubers (G3), and often at lower prices than seed in the informal sector. The ware yields of the first generation of potato were 150–200% higher.
Cassava, Nicaragua	CLAYUCA (Latin American & Caribbean Support for Cassava Research & Development)	Nicaraguan Government	New varieties for cassava awaken government and farmer interest after a lull of several years, in response to demand by agro-industry	National	Continuous	• The cassava processing companies are also considered to have a role to play in the cassava seed sector. • A seed multiplication system is now proposed in which INTA and private sector use in vitro multiplication technologies to provide farmer-groups with improved planting material that can be further multiplied to meet farmers' demand.
Potato, Malawi	Gender and seed	Irish Aid	Men have better access to land and seed, but a new project fails both genders equally	National, 4500 smallholder farmers	2007–2012 and 2012–2016	• Improved production training for more than 200 extension staff and 15,000 farmers (1/3 woman); 13,000 farmers were provided with access to small packets of promotion seed, and 86 diffuse light stores (DLS) were constructed. • The analysis showed that women had less access to improved potato technology than men.
Cassava, West, Central and South Africa	UPoCA (Unleashing the Power of Cassava in Africa)	USAID	Disseminating new, disease-resistant varieties in seven countries	DR Congo, Ghana, Malawi, Mozambique, Nigeria, Sierra Leone, and Tanzania	2008–2010	• Promoted improved cassava mosaic disease (CMD) resistant cultivars with the aim to close the yield gap and to encourage value-added processing by farmers and communities and better access to markets. • Project disseminated 59 elite cassava varieties through 290 community seed multiplication fields (710 ha in total) to 11,540 farmer households. • Eight new technologies were introduced to rural communities, including community seed production through contract growers as a Village-level Seed Enterprise, by training 354 men and 142 women farmers in 7 countries. • The project met dissemination targets, however, benefits due to improved varieties, processing and marketing were not established. CMD

Table 1 (continued)

Crop and Country	Short name	Funding sources	Scope	Scale	Duration	Main highlights from documents
						resistant varieties were recorded to improve yields by 30 to 60% in the recipient fields.
Banana, East Africa	Tissue culture banana	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)	Helping to establish nurseries where communities can harden tissue cultured bananas to sell to farmers	Kenya, Uganda, and Burundi	2008–2010	• The program supporting commercial nurseries at the community level that were linked to tissue culture laboratories. • The project had 6–7 intervention sites per country. The nursery technology and the use of the plantlets by farmers were capital and labour intensive and maintaining the quality standards within TC production and the nurseries was a challenge. The plantlets were predominantly bought by NGO projects to be handed out or sold to farmers.
Banana, East Africa	Emergency banana Crop Crisis Control Project (C3P)	USAID	Introduction of new varieties, new multiplication technology and training to help farmers manage a new crop disease	6 countries, 30 research and development partners	2006–2007	• To mitigate the effect of Banana Xanthomonas Wilt, the project trained more than 1000 extension staff and 65,000 farmers on disease identification and management (avoiding contamination via tools, the use of clean planting materials, uprooting infected plants and the removal of male buds). • Mobilizing collective action was an important objective (management of the disease, multiplication and distribution of new planting material). • The lack of clean source material and low multiplication rates hindered the availability of sufficient planting material.
Cassava, East Africa	GLCI (Great Lakes Cassava Initiative)	Bill & Melinda Gates Foundation	A cassava initiative in the Great Lakes Region of Africa	DR Congo, Burundi, Rwanda Tanzania Keny and Uganda (regions around the around the Great Lakes), 50 partner organisations, 1.9 million farmers	2007-mid 2012	• In response to cassava mosaic disease (CMD) and cassava brown streak disease (CBSD), the program used a decentralized farmer group approach for the multiplication and dissemination of farmer-selected, improved, disease-tolerant, cassava varieties. Thousands of minimally subsidized multiplication sites and hundreds of fully subsidized varietal demonstrations plots were established. • The project used PCR (Polymerase Chain Reaction) to supplement visual inspection and surveys of multiplication sites to prevent the multiplication and dissemination of diseased material. Vouchers gave farmers free access to 20–25 stems per household.

activities are functional and effective (Douglas, 1980). Seed systems of hybridized and industrial staple crops, together with horticultural crops, tend to be the most advanced. Following the four-stage scale of Douglas (1980), most RTB seed systems in developing countries are in 'stage 1', also termed 'nascent' (in contrast to 'mature', see Spielman & Smale, 2017). Their characteristics include a small ineffective formal and public R&D, a rudimentary (seed) value chain and the preponderance of farmer-saved planting material (Lynam, 2011; BMGF and USAID 2015).

This approach and existing policies and regulations for formal seed systems still dominate. They reflect the pursuit of a highly productive agriculture sector reliant on the use of intensive technology to close yield gaps in order to feed the world (Scoones & Thompson, 2011; iPES-Food, 2016). In this approach, farmers are perceived as choosing technologies, including varieties and seed sources, that maximize the expected economic benefits of farm production. In more advanced agriculture sectors, these choices are made in the context of private market exchanges for seeds, produce and traits, with the public sector's role relegated to market regulation and upstream or basic research. In other words, the market-logic organises and ensures effective production and technological development that is geared towards maximizing yields and profits. This view is also reflected in Africa's Green Revolution initiative and in which local private sector actors are given a prominent role (Scoones & Thompson, 2011; AGRA 2016).

2.2 Other approaches

A contrasting approach to seed system development is advocated by those who may be grouped under the banner of food sovereignty. The group is diverse in its history and philosophy, but there is a shared opposition to the current food system (Edelman, 2014). They advocate a food system model that strives for agro-ecological principles applied by smallholders. In this model, seed sovereignty stands for an open-access seed system with rights of farmers to multiply and maintain seeds that represent their cultural identity (Bezner Kerr, 2013; Edelman, 2014; Kloppenburg, 2014). Other seed system approaches can be positioned in between the two opposing extremes: they adopt a more pragmatic pluralist vision and are predicated on a blend of the diversity of varieties and crops, context specificity and variation in farmers' needs and aspirations. Staver, van den Berghe et al. (2010) propose that the challenge for seed system interventions is not to convert all farmers to commercial seed, but to identify and reach the sectors where improved seed quality will have the greatest contribution to agricultural productivity. Louwaars and de Boef (2012) emphasize the multi-actor character of seed systems and promote an integrated seed system development (ISSD) model. Thomas-Sharma et al. (2016) identify the need for a more integrated seed health strategy for potato seed systems to improve productivity; an approach that is also relevant for other RTB crops. These middle ground approaches recognize that formal and farmer-based seed systems each have their strengths and weaknesses, that they are potentially complementary and that no single model is suitable for all crops, conditions and farmers. Consequently, they advocate for optimizing mixed forms of seed supply, with varying practices of seed sourcing and saving and flexible regulations supported by coordinated R&D efforts.

In spite of decades of seed system projects, farmer-based sources and flows of seed continue to prevail in most crops in developing countries, (McGuire & Sperling, 2016) for multiple reasons (e.g. Almekinders et al., 1994; Jones, 2013; Coomes et al., 2015). This situation, and the different approaches discussed above, raise important questions about the optimal focus of R&D efforts since such efforts can put a nascent seed system on very different trajectories. Emphasizing the development of the formal sector supply side of the seed value chain through breeding and quality seed production is a strategy that represents tremendous challenges for countries where formal institutions are still weak (see Atilaw, Alemu, Bishaw, Kifle, & Kaske, 2016 for Ethiopia). Investing in the farmers' end of the seed value chain involves, for example, strengthened investment in farmers' capacity to control degeneration processes and maintain seed quality on-farm. This would reduce farmer incentives to replace planting material with cleaner, healthier or genetically purer material and make them less frequent buyers of seed, with implications for the financial viability of commercial seed multiplication and cultivar dissemination. In the following section we take a closer look at the way these issues and challenges play out in RTB seed supply and use.

Table 2 Key characteristics of common conventional propagation material of 4 RTB crops and maize (adapted from Andrade-Piedra et al., 2016).

3 RTB crops and seed system development

3.1 An overview

The propagation through the use of stems (cassava, sweetpotato), roots (yam), tubers (potato) or suckers (banana) of the RTB crops results in many differences (Table 2) which also affect the resulting seed systems. First, vegetative multiplication means that they can be multiplied 'true to type', i.e. their genotype is fixed. Secondly, vegetative propagation makes them vulnerable to the build-up of viruses and other pathogens. Third, their bulkiness, low multiplication rate and perishability have implications for their storability and transportation. The resulting seed systems are therefore

Table 2 Variation of key characteristics of common, conventional propagation material of five RTB crops and maize (adapted from Andrade-Piedra et al., 2016 and Staver et al., 2010)

	Maize	Banana	Cassava [b]	Potato	Sweetpotato [h]	Yam [i]
Consumed plant part	seeds	Fruits	Roots	Tubers	Roots	Tubers
Most common propagation material	seeds	Suckers (areal shoots)	Stem cuttings	Tubers	Vine cuttings	Tubers
Multiplication ratio	70–200	1:10 to 1:20 suckers	8–12	6:15 tubers [d]	3–15 (a vine may yield 2 or 3 cuttings 30-cm long)	1:8 tubers
Seed rate (bulkiness)	15–25 kg/ha [a]	1000 to 2500 kg/ha (500–2000 suckers per ha)	10,000 three-node stem cuttings (15 cm long) per ha	1000 to 2000 kg/ha	About 666 kg depending on variety & stage of wilting (33,300 cuttings of 25–30 cm)	10,000 tubers
Storability of harvested seed	Up to 1 year	2 to 3 weeks depending on the season	2 to 3 weeks maximum	Up to 6 months	A maximum of 2 to 3 days	3 to 4 months
Seed cost ($/ha)	$16 to $27[1]	$32 to $2240, but usually free as farmers would use their own	$60 to $120, but usually free as taken from own harvest	50–70% of the total production cost: $2527/ha (Chile, [e]); $818/ha (Idaho, [f]); $1090/ha (Peru, [g])	Highly variable. For Tanzania: $2 bundle of 300 vines (900 cuttings),circa $76/ha	About $500 to 800
Major pests and diseases carried over to next generation via the planting material		Banana bunchy top virus (BBTV), banana streak virus (BSV), Banana bract mosaic virus (BBrMV), Cucumber mosaic virus (CMV); bacterial wilts caused by *Ralstonia* spp., and *Xanthomonas* sp.; *Fusarium* wilt; nematodes (*Radopholus similis*, *Pratylenchus* spp., *Helicotylenchus* spp., *Meloidogyne* spp., *Hoplolaimus* spp. and weevils (*Cosmopolites sordidus*)	Cassava mosaic viruses (CMVs), cassava brown streak viruses (CBSVs), cassava frog skin-associated viruses (CFSVs); bacterial blights (*Xanthomonas campestris* pv *manihotis*); cassava green mite and mealy bugs	Potato virus X (PVX), Potato virus Y (PVY), Potato leafroll virus (PLRV), *Ralstonia, Rhizoctonia, Pectobacterium, Spongospora, Phytophthora infestans, Globodera, Meloidogyne, Tecia, Symmetrischema, Phthorimaea,* etc. [c]	Sweetpotato chlorotic stunt virus (SPCSV) and Sweetpotato feathery mottle virus (SPFMV)	Viruses: Yam mosaic virus (YMV), Yam mild mosaic virus (YMMV); nematodes: *Scutellonema bradys, Meloidogyne* spp.; fungi: *Botryodiplodia* sp., *Fusarium* sp.; insects: termites (*Amitermes* sp.), tuber moth (*Euzopherodes vapidella*), etc. [j]

(a) $0.80 to $1.00 per kg for open-pollinated subsidized maize in Nigeria, $1.33 per kg for private-sector hybrid (Bentley et al. 2011). Certified maize seed is sold for roughly the same price in Peru, according to the INIA website www.inia.gob.pe/prod-servicios/semillas

(b) IYA (2014)

(c) Thomas-Sharma et al. (2016)

(d) Struik and Wiersema (1999)

(e) Ministerio de Agricultura (2013). 1 USD = 554 Chilean pesos

(f) Patterson (2014)

(g) Victor Suárez, personal communication. Varieties Canchán and Yungay in Julcán province, La Libertad department in 2013. 1 USD = 2.75 Peruvian Sol

(h) Kwame Ogero, personal communication

(i) Ibana (2011)

(j) Emehute et al. 1998

quite distinct and characterised by being farmer and trader dominated, only partially commoditised, dependent on public sector R&D efforts and less formally regulated.

Because of the three differences, there is less attractiveness for the private sector to engage in RTB seed systems. The result in country after country is a small or virtually absent formal seed system managed by the public sector. For this reason, RTB crops are less present in investments and debates around genetically modified organisms (GMOs) and associated intellectual property rights (Tansey, 2011). Recent studies that do indicate a potential for public-private partnerships in RTB seed systems, in particular for the production of high-quality breeder and foundations seed (e.g. early generation seed, EGS planting material) of cassava and sweetpotato, also recognise some tensions in regulation and seed pricing (BMGF and USAID 2015; Lion, de Boef, Huisenga, & Atwood, 2015).

Potato has a special position among the RTBs in developing countries. While an important subsistence staple for poor smallholder farmers in its centre of origin and other highland regions of the (sub-) tropics (e.g. the Andean region, parts of Ethiopia, Nepal), it is a high value cash crop in many other developing countries. In many developing countries such as Pakistan, Cuba and Nicaragua, a substantial fraction of the seed potatoes are imported from the northern hemisphere. Extensive research has been conducted on potato in industrial countries, accompanied by public policies and regulations designed to advance formal commercial seed systems for the crop. Even though the potato seed system can hardly be said to be mature in most developing countries, there is an extensive body of knowledge globally that can be drawn on.

For most other root and tuber crops, the knowledge base is far more limited. R&D programs are incipient and the formulation and implementation of regulations has focused primarily on variety registration. In many countries, threshold values for seed quality are translations from sanitary health experiences in advanced seed systems and export-market situations. For certain countries, the presence of export banana production and/or commercial banana tissue culture laboratories provide a targeted knowledge base and regulations primarily in support of the export sector, although with potential leverage to domestic production (Staver et al., 2010). Countries with a growing cassava processing industry represent a similar case (Howeler, 2004).

In the five sections below we build a case for the importance of understanding how farmers currently ensure their seed and the role of variety and quality. We focus our analysis first on the adoption of new cultivars both for true seed and vegetative crops. We then examine the scant data from new cultivar informal dissemination and the nature and circumstances of seed flows. In the third and fourth sections we highlight circumstances in which seasonality of planting and seed-borne diseases in practical terms force farmers to seek sources of healthier seed. The final section addresses the complex nature of farmer demand for seed. A clearer assessment of current seed flows, seed quality and degeneration, as influenced by farmer practices, planting season and the motivations in farmer demand of improved seed, are highlighted in the five sections as relevant to identifying points of improvement that are needed to make RTB seed systems more effective.

3.2 Adoption of improved varieties

The adoption of improved varieties varies greatly among different RTB crops, countries, regions and continents (Walker & Alwang, 2015). As indicated, the formal seed systems for RTB crops are relatively undeveloped and small, even for potato. For example, in Kenya there is a public and private potato seed sector with regulations on varietal release and seed quality, but fewer than 1% of farmers buy seed from specialized seed sources (Gildemacher et al., 2012). Data on the adoption of improved varieties of different crops in sub-Saharan Africa, including grain staples presented by Walker and Alwing (2015), provide no evidence that farmers' access to improved varieties of RTB crops has been more limiting than in grain crops. They refer, for example, to the yam variety C18 in Côte d'Ivoire, which, 10 years after its introduction, is estimated to cover 18% of the area planted with yam. The same authors do, nevertheless, point out that adoption of improved varieties of all crops in Sub Sahara Africa (SSA) is low and show that access and diffusion of the improved varieties are a general concern. Spielman and Smale (2017) express a similar concern in their reflection on the low turnover from improved varieties in grain crops. Few data are available on variety turnover for RTB crops. The concept of turnover captures not just one-time adoption, but also the breeding pipeline. In Nigeria, a 60% adoption of improved cassava varieties in Nigeria over samples and regions (Wossen et al., 2017) therefore does not necessarily point to an effective cassava seed system considering that more than 40 improved varieties have been released in Nigeria since the late 1970s .

3.3 Diffusion of varieties and seed flows

A closer look at the successful adoption of improved RTB varieties suggests that farmer-to-farmer diffusion operates to generate broad-scale uptake. In spite of the bulkiness and low multiplication rate of RTB planting materials, vegetatively-multiplied improved cultivars maintain their improved traits. Once having obtained planting material of a desired RTB crop variety, the farmer multiplies the material with the improved traits and can easily exchange, give or sell planting material. Tadesse, Almekinders, Schulte, and Struik (2016) found that farmers in Ethiopia who had received quality potato seed of a new improved variety from an NGO shared on average with more than 6 other farmers, mostly relatives, neighbours and friends. Mowo er al. (2010) reported similar evidence in data from Tanzania with improved banana cultivars which were shared first with family. An ex-post evaluation of the GLCI program showed that 2/3 of the farmers who received a small number of stems of new cassava varieties had shared stems with others and more than a third of them did so with more than five farmers (CRS 2013). Anecdotal documentation suggests that improved varieties of RTBs have "escaped" from experimental stations and become popular. Shangi, now the most popular potato variety in Kenya and covering 70% of the area planted (GIZ, 2014), is one such example: the variety was little known in 2010 and is thought to be a clone from a CIP breeding program (E.O. Atieno, personal communication).

In farmer-based seed systems RTB planting material is transported over longer distances without any formal organisational involvement. Specialized seed potato producers in the highlands of Peru sell seed to farmers on the coast (Bentley, Tripp, & Delgado de la Flor, 2001), farmers from the tropical lowlands in Bolivia travel to the highlands to purchase quality potato seed (Almekinders, Cavatassi, Terceros, Pereira, & Salazar, 2009) and potato growers in Malawi sell seed tubers to farmers from Mozambique (Mudege & Demo, 2016). In East Africa, farmers who have some moist land may grow sweetpotato, which can then provide planting material to farmers in drier areas (Ogero, McEwan, & Ngabo, 2016). Gibson (2013) found farmers traveling from Sudan to find sweetpotato vines in Northern Uganda. In several instances these seed channels are facilitated by traders, resulting in the spread of new varieties over large areas and even crossing national borders. Chingovwa and NASPOT 1, white- and orange-fleshed sweetpotato varieties, respectively, from Zambia, are also spread before official release.

The importance of RTB crops for farmer households may contribute to the diffusion of improved RTB varieties both for food security reasons, especially as an emergency and hunger crop (Lynam, 2011), e.g. sweetpotato in Rwanda, Mozambique and potato in parts of Ethiopia, and more recently as a new source of income. Examples of the last include the industrialized processing of cassava in Thailand (Howeler, 2004; Kem, 2017) and more recently in Nigeria and Nicaragua and specialized smallholder production of banana production in Uganda for the Kampala market. The outbreak and rapid spread of diseases affecting RTB crops, such as virus pandemics affecting cassava in eastern Africa (Walsh, 2016) and banana bunchy top virus in the Congo basin (Carter et al., 2010) are aggravated by the vegetative character of the planting material (see next section). Spread of new diseases, including viruses, contribute to farmers' interest in accessing resistant varieties or clean planting material where resistance is unavailable. These pressures on important staple crops emphasize the relevance of farmer-based diffusion of new, improved varieties in the absence of a well-developed private or public seed supply. At the same time, it also shows that our knowledge of these farmer-based RTB seed systems is only anecdotal. Most information on seed flows and mechanisms of seed exchange among farmers are from grain seed systems (see Coomes et al., 2015). Of the vegetatively propagated crops, only farmer-based seed systems for potato have been relatively well studied, predominantly in the Andes (e.g. Scheidegger, Prain, Ezeta, & Vittorelli, 1989; Zimmerer, 1988; De Haan, 2009). Fewer studies deal with cassava and/or sweetpotato, e.g.Prain, Schneider, & Widiyastuti, 2000; Coomes, 2010; Adam, 2014, and banana, e.g. Mulumba, Nkwiine, Male-Kayiwa, Kalanzi, & Karamura, 2004; Lwandasa et al., 2014; Kilwinger, Rietveld, Groot, & Almekinders, 2018. We found no studies of farmer-based yam seed systems, despite the importance of the crop in West Africa and an almost complete absence of a formal seed system.

3.4 Farmers' need for planting material, seed quality and seed degeneration

So far we have focused on farmers' interest in off-farm seed sources to acquire new varieties, i.e. improved germplasm embodied in planting materials and their dissemination in seed flows. We distinguish three additional motivations for farmers to seek planting material off-farm. First, storage seasons and conditions may not allow farmers to save planting material until next harvest. Because sweetpotato vines and cassava stems are active living tissue, they are particularly sensitive to dehydration and resist poorly long periods of extreme temperatures and humidity. Yam and potato tubers are somewhat more storable (see Table 2). Banana suckers are not storable, but banana stands are maintained for multiple years, so suckers can be found in existing fields in almost any season of the year. Second, farmers simply may not have (enough) planting material from last years' harvest. This occurs under numerous circumstances: total or partial harvest failure (weather related, civil unrest, or other disasters that entire communities or individual households may experience), need to sell the harvest to cover cash expenses, bad storage season, expansion of the planted crop area because of attractive market opportunities, among others. Third, quality of seed from normal sources has declined too much to give a proper yield or new yield-threatening diseases have spread. The perishability of the planting material of RTB crops, i.e. roots, tubers and suckers, and the build-up of diseases over seasons make degeneration of quality a concern which is not commonly found in seed grain crops.

Seed quality has four dimensions: physiological (germination, vigour), genetic (varietal purity, adaptation), sanitary (absence of diseases) and physical seed batch characteristics (percentage of good seeds, free of stones and weed seed) (FAO, n.d.; Almekinders & Louwaars, 1999). The loss of quality of any of these four aspects from continuous propagation is called degeneration and can result in yield reduction. The relative importance of these factors varies for true seed and RTB. Seed for true seed crops is more easily storable from harvest to harvest and cases of disease spread through seeds in such crops is known, but less frequent. However, genetic degeneration is a greater concern, especially in improved varieties of cross-pollinating crops. Hybrid maize, sorghum and various horticultural crop varieties degenerate genetically and farmers using these varieties need to become repeated buyers of seed. Some farmers are known to reject improved varieties that are hybrids, even if these are economically more attractive, because it makes them dependant on the purchase of new seeds for each planting (Tripp, 2001; Jones, 2013). Vegetative multiplication minimizes problems of genetic quality of RTB planting material, except when planting material characteristics do not provide evidence of variety mixture. However, sanitary degeneration of seed due to vegetative multiplication is an extremely frequent issue: the daughter suckers, tubers and roots growing from a virus or bacteria contaminated mother plant will usually be contaminated as well. The physiological quality can also be an important concern in RTB crops when planting material needs to be stored for long periods from one harvest to the next. When storage conditions are unfavourable (warm, humid, no cooling facilities) and storage seasons are long, farmers may not be able to keep planting material from harvest to the next planting. The long-distance movements of seed potatoes and sweetpotato vines presented earlier occur in such situations. For potato seed tubers, physiological age is an important aspect of physiological quality for both storage time and conditions (Struik & Wiersema, 1999).

While degeneration of quality of planting material in RTB crops appears to impact, the effect on yield under farmers' conditions is poorly studied, even in potato (see Thomas-Sharma et al., 2016). The general rule of thumb is that with faster degeneration of the farmers' planting material and a larger effect on yield, farmers are more willing to invest in quality seed. Apart from work on potato in the Andes (Scheidegger et al., 1989), very little empirical information exists to confirm this statement.

3.5 Farmers' practices and degeneration of seed quality

Farmers' practices for reproducing and multiplying seed can accelerate or slow down the degeneration process, and thereby the need for replacing their own seed with other healthier material. For potato, among the traditional and better practices reported to improve quality are off-season planting or higher altitude planting for lower aphid pressure or lower growing temperatures, positive and negative selection of plants in the field, and partial replacement of planting material with higher quality seed (Zimmerer, 2003; Gildemacher et al., 2012; Tadesse et al., 2016; Bertschinger et al., 2017).

Farmers' seed management practices in other RTB crops are less well studied than for potatoes, although improved practices for quality declared seed have been compiled (FAO, 2010). As in potato, the practice of selecting small propagules for planting is also reported for yam, in which the tuber is both the propagule and the consumed plant part. In banana, replanting frequency and sucker selection and management practices are highly variable by cultivar and production system. For intensive, market-oriented dessert banana, high-quality tissue culture plants are used routinely. Smallholder farmers have varying practices: for example, in Uganda where banana stands are perennial, farmers often replace individual mats and fill gaps with suckers (Lwandasa et al., 2014; Kilwinger et al., 2018), whereas in Cameroon farmers harvest fields planted as part of a shifting cultivation regime for only 2–3 seasons before planting elsewhere (Kanmegne, 2004). Research in banana has shown that banana plants infected with bacterial wilt (*Xanthomonas*) do not necessarily transmit the disease to all the suckers that emerge from the same mat, creating opportunity to mitigate the incidence through collective action of farmers (Blomme et al., 2014), although other banana pests and diseases such as bunchy top disease and Fusarium wilt are transmitted in suckers with yield threatening consequences for the new field (Jacobsen et al., 2018). Recent work in eastern Africa shows that virus infection of clean sweetpotato vines can be reduced by placing net tunnels over nursery beds (Ogero et al. 2017). Improved practices require knowledge, labour, capital and collective action, which may put them beyond the reach of poorer and/or female farmers (Tadesse, Almekinders, Schulte, & Struik, 2017; Mudege & Demo, 2016) and which therefore seem more suited to farmers who specialize in seed production and have the potential to capitalize on their investments. Such research findings help us to identify improved practices that farmers can adopt in order to reduce the rate of degeneration in RTB seed systems. These farmer practices can be combined with contributions from formal R&D over such issues as resistance breeding and rapid multiplication techniques. Together they can form the components for an integrated seed health strategy for potato and other RTB crops (see Thomas-Sharma et al., 2016).

3.6 Farmers' demand for improved seed and technology: The overlooked social factors

Socio-economic research shows that in many situations farmers can invest profitably in quality seed to replace their farm-saved seed. In practice, many smallholders replace their seed with purchased quality seed only to acquire a new variety they do not yet have. Replacement of degenerated seed for higher quality seed of the same variety is much less common.

Explanations are given in terms of farmers lacking knowledge about a product or its attributes, not understanding or being reluctant to invest, etc. Data from adoption studies often show that greater age, less education and smaller farms are correlated with lower adoption. Non-adopters are, mostly implicitly, assumed to be delayed adopters. However, the majority of the studies do not unravel the causal relation to understand how cash constraints, labour and risk affect adoption of improved seeds and varieties. In Malawi, women buy cheaper potato seed, even when they know its quality is poor (Mudege & Demo, 2016). In Chencha, Ethiopia, improved potato varieties were not useful for farmers because they lacked the skills, cash and labour to adopt associated production practices successfully (Tadesse et al., 2017). Farmer-demand for improved seed and technology is thus in many situations a fictive demand, based on expert estimation, not an effective demand. The fictive demand serves a project planning to set targets, prepare multiplication schemes and calculate commercial viability of seed multiplication initiatives. In reality, the amount of seed purchased by farmers often falls short of the expectations. The reasons vary, depending on crop and context, but in-depth studies and ex-post analysis of effective farmer demand for seed are scarce (Walsh, Remington, Kugbei, & Ojiewo, 2015).

Better estimation of farmers' demand involves the need to better understand farmers' motivations for using seed from different sources. Urrea, Almekinders and van Dam (2016) found that smallholder potato farmers select among seed lots not by reading labels, but by looking at the soil in the eyes of the seed tubers: this tells them where the seed tubers were produced. From this information they infer seed quality and other seed attributes that they are looking for. These are not simply highest economic gains, but include objectives such as (human) 'health' and 'living well'. Studies on seed and variety choices in other crops show that farmers' motivations do not necessarily result in the technology choices that give highest yields or financial output per hectare. Low input and low risk, taste, colour and other culturally defined preferences, as well as diversity per se are among the important reasons for farmers to prefer particular varieties and seeds. Often, social character of relationships play an important role. For example the trust in client-trader relations strongly influences potato seed acquisition decisions in Bolivia (Almekinders et al., 2009). Farmers' trust in seed from formal sector sources is often low after having experienced variability in seed quality and variety performance. Farmer demand for seed is the result of an aggregation of agro-ecological and socio-economic considerations at the individual and household level, and interwoven with other land, technology, and market options (e.g. Jones, 2013; Pircher, Almekinders, & Kamanga, 2013; McEwan et al., 2015; Tadesse et al., 2017). Improved assessment of farmers' demand will contribute to improve seed system interventions (Spielman & Mekonnen, 2013).

4 Learning from case studies

4.1 Scope

In 2014, a group of CGIAR-affiliated researchers started a joint multiple-case study of RTB seed system interventions. The growing awareness of the importance of RTB crops for food security, nutrition and the income of rural households has led to an increase in the number of projects that introduce new RTB varieties and seed multiplication practices, especially in Africa (e.g. McEwan et al., 2015). Some of these interventions have 'seed' as a main focus, but often 'seed' figures as one among many components of a larger agricultural development project. In an effort to understand the landscape of interventions in RTB seed systems and draw lessons for research and development practice, 13 case studies were selected. The case studies were identified with the intention of covering the range of types, scale and context of interventions in banana, cassava, yam, sweetpotato and potato in Africa and Latin America. The case studies followed a common analytical outline and were carried out on the basis of available documentation and personal experiences of the researchers responsible for the case study. For a number of case studies, additional information was collected through short interviews with involved stakeholders (usually by phone or skype). These case studies are compiled and practical cross-case lessons have been drawn (Andrade-Piedra et al., 2016, see Table 1). Here we present some features of these case studies that we considered relevant in the context of this paper.

4.2 The landscape: The diversity of type of interventions, the actors and their goals

A first observation from the selection of the cases is the diversity of intervention types (Table 1). The studies show that many actors are involved in seed system interventions. In all the case studies, public sector researchers and breeders were present, either as advisors (3 cases: CONPAPA, the aeroponics for potato seed tuber production in northern Peru and the C3P in the Great Lake Region) or as project owners and hosts (all other cases). In addition, NGOs and donors are influential players and they come in all shapes and sizes, from multinational NGOs like the Catholic Relief Services and World Vision to small local ones like ADERS in Peru. Multi-country projects like UPoCA, C3P and GLCI involved a large number of international, national and local organisations. As such, the project approaches reflected the models of development-thinking in donor countries, be that of governments from industrialized countries or NGOs aligning to different seed system paradigms. Large philanthropic foundations have recently entered this landscape, adding to the diversity. This diversity of donors has led to different scales of interventions, with everything from micro-local scale initiatives involving a few dozen farmers stemming from cooperative responsibility of a mining company to national and macro multi-country scale interventions funded by the Bill and Melinda Gates Foundation. Related to these different scales, the purposes/goals of the interventions also varied. The 13 interventions were justified to: support seed system development; to mitigate a crop disease emergency (e.g. cassava and banana planting material); to improve food security and nutrition (e.g. orange-flesh sweetpotato and bio-fortified varieties); to meet the new opportunities of developing markets; or to promote the adoption of new varieties and technologies (see Table 1). While ambitious in their goals, most interventions were short-term (2–4 years) and clear linkages to national or regional seed system development strategies, policies and structures were for the most part absent.

4.3 Understanding the systems in which projects intervened

In none of the case studies could the authors report a systematic analysis of the target seed system within the context of the project, yet in in all cases farmer-based seed systems were predominant. Few of the case studies reported project activities oriented to build on the farmer-based seed system, e.g. by involving farmers who were known as local seed experts or by taking advantage of existing delivery channels. The Great Lakes Cassava Initiative (GLCI) was built on the assumption that farmer multiplication and dissemination would reach the goal of serving millions of farmers in six countries with disease resistant cassava varieties (CRS 2013). However, the knowledge base supporting the assumption was lacking. For emergency interventions the opportunities for a diagnosis prior to bringing in the seed is obviously time-constrained. Nevertheless, as McGuire and Sperling (2016) observe, such blind introduction often leads to introduction of unadapted varieties and the destruction of local seed markets.

Several interventions implicitly or explicitly assumed that smallholders would specialize and be able to function as suppliers of quality planting materials on an entrepreneurial basis. We found no evidence of efforts to assess seed demand, implying that most interventions were based on expert assumptions and expectations only. This suggests that most interventions were supply driven, dependent on seed delivery capacity, and lacked a good understanding of farmer demand for seed.

Other interventions, notably the promotion of vitamin-A rich orange flesh sweetpotato varieties in Rwanda, were more associated with the nutrition and health sector, and demonstrated a strong focus on supporting women and improving health. This can explain why tapping into the existing seed system was not a first priority. Nonetheless, in some cases such initiatives can achieve impressive adoption rates, as for example in the case of orange flesh sweetpotato (OFSP) varieties in Mozambique, which are now being grown by thousands of women in small parcels of land (Hotz et al., 2012). The case of sweetpotato in Rwanda also stands out as a project that made an effort to develop a value chain, from the supply of vines for planting by specialized farmer groups to processing and marketing.

Many of the interventions made use of rapid multiplication techniques — aeroponics for potato, mini-setts for yam, tissue culture and macropropagation for banana — to produce clean planting material that farmer groups would further multiply and commercialize. The case studies did not document how recipient farmers were identified and if they were potentially logical source-farmers. This is relevant because strategic distribution of small lots of high quality seed to effective source-farmers could make such materials available and accessible to a wide range of farmers, and upgrade the health status of planting materials in the entire local system. Moreover, for high quality ‘pre-basic’ seed production to be profitable, not only high multiplication rates are needed but also an economically profitable production pipeline of second, third and fourth generation seed (Mateus et al., 2013). The opportunity of selling the harvest in lucrative niche markets in the CONPAPA potato and Rwanda sweetpotato cases, created a concrete demand by farmers for quality seed, but involved only a relatively small group of farmers. We know little about the way farmer groups or local multipliers met farmer demand in other initiatives. Banana macropropagation chambers and nurseries were expected to meet the need of banana farmers who traditionally rely almost entirely on the farmer-based system and now face Banana Xanthomonas Wilt (BXW) or Banana Bunch Top Virus (BBTV) in various parts of Africa. Similarly, decentralised multipliers (DM) of sweetpotato vines in Eastern Africa were supported to make sure that farmers have access to quality planting materials when the rains start (McEwan et al., 2015): the technical and economic viability of these DMs without project support and subsidies is not yet clear.

4.4 The need to learn from experiences

The case study documents did not show us evidence of much effort to understand the target seed system. Identification of challenges and the way they were addressed – in cases where the objective of intervention was to contribute to seed system development - seemed to lack underpinning by studies, rural appraisals or consultations of local technicians or development practitioners. Most of the case studies identified a plethora of data and reports during the grant reporting period, but post-intervention evaluations and reflections were for the most part not found. We saw no examples where a theory of change was rigorously assessed in the form of an ex-post evaluation. This suggests that monitoring and evaluation in seed systems interventions should emphasize and focus more on learning. Without more explicit learning, and the willingness to use lessons learnt to adapt project strategies mid-term, it makes little sense to advocate long-duration projects.

5 A reflection on farmers' demand for seed and a research agenda

A crucial assumption shows up repeatedly in the literature and the case studies i.e. an existing demand from farmers for quality seed, which could form the basis for specialized local seed production and commercialization that is economically viable. The model of improving seed availability and access through local, decentralized multipliers (DMs) is widely explored within the context of different seed system approaches. It is seen as a solution for situations where the public sector does not have the capacity or the reach and large-scale private sector companies are not interested or present (e.g. Alemu, Tesfaye, Ayana, & Borman, 2013; Mubangizi, Mesigwe, & Thijssen, 2013; FAO and ICRISAT, 2015; AGRA 2016, Van Mele, Bentley, & Guéi, 2011; De Roo, 2016), or not serving farmers' interest (Bezner Kerr, 2013). DMs are mostly thought of as farmer groups, cooperatives or individual local entrepreneurs - actors who are seen as potential bridge builders between the formal and farmer systems. Moreover, such local seed production is expected to generate local employment and income, especially for women's groups or young people. We reflect on the assumptions for RTB crops.

Proximity of DM is considered to improve availability and access of farmers to quality planting material. More specifically, DMs are thought to cater for the local demand more effectively because of lower transportation costs, which is particularly relevant for RTB crops that have bulky and perishable propagation material. But what does the local demand for RTB seed look like and how does it fit with a commercial seed business model? As mentioned earlier, the vegetative nature of the planting material of RTB crops poses huge challenges for a commercial company involved in seed sector development. The ease of multiplying stems, roots, tubers and suckers suggests that the use of farm-saved seed dominates. Nevertheless, the research done so far shows that each season a substantial portion of the smallholder farmers makes use of off-farm seed sources. McGuire and Sperling (2016) found that, over RTB crops and research sites, 47% of the farmers had used off-farm seed in the last planting season. Kansiime and Mastenbroek (2016) reported that 30% of the Ugandan farmers in their study sourced off-farm cassava stems for planting in normal years. We found in our study sites in Nigeria and Vietnam/Cambodia that respectively 10–20% and 13–70% of the farmers used off-farm planting material in the last season (Pircher et al. in preparation, Delaquis et al. 2018). Different agro-ecological conditions, such as length of storage season explain part of the variation. However, practically no information is available which explains farmers' motivation and the role of seed replacement in this use of off-farm sourced RTB planting material.

In section 3 we distinguished four categories of demand for planting material: 1) acquisition of a new variety, 2) insufficient planting material from own farm, 3) lack of adequate seasonal storage, 4) replacement of health-degenerated material with higher quality "clean" seed. Will DMs be able to cater for these different demands profitably both for the DM and the farmer?

In the first case, farmers may be willing to pay for seed from a DM for a variety that is not otherwise locally available, even if this means a cash transaction with a friend or family (e.g. Tadesse et al., 2016). However, because RTBs are vegetative propagated, once a new cultivar has been acquired, it can be multiplied. How often and for what reason will the farmers return to a DM and pay for new planting material of RTB varieties? And, what is the character of that seed demand for a DM?

In the second case, farmers may buy planting material when they cannot keep the vines, stems or tubers in good condition until next planting because storage temperatures are too high or conditions are otherwise too unfavourable for too long a period. Sweetpotato and cassava farmers may keep their stems and vines in shady conditions where there is water available. If not, the stems and vines easily dry out. Such a situation may generate a demand for planting material that is to some extent predictable. It may explain the situations in which there is a yearly high percentage of farmers who source off-farm seed, such as we found in Tanzania and Uganda for sweetpotato and in Vietnam and Nigeria for cassava. Obviously these farmers are acquiring seed from some source. These situations are potentially interesting opportunities for specialised seed production by working with the informal seed suppliers but are often overlooked by researchers or project staff. Local producers may have a market opportunity for selling seed when they have access to water for off-season production or can invest in cooled storage facilities such as in the case of commercially cooled storage for potato seed tubers in lowland tropical regions, such as Bangladesh.

A third type of demand for seed originates from "not having been able to save seed". This can happen at random to farmer households, e.g. because of sickness or other unfortunate events, but is more generally the case after an unfavourable production season. In particular the last represents a variable and rather unpredictable and anti-cyclical demand for local seed producers. That is, the demand tends to be high after an unfavourable growing season: all farmers experience unfavourable conditions and many may not have been able to save seed or have surpluses to share. However, these same unfavourable conditions are likely to also affect the yields of the local seed producers (see Janssen, 1989), unless these specialized producers have irrigation, have applied crop protection chemicals or have otherwise been able to off-set unfavourable conditions.

Finally, farmers will consider buying new planting material when their own seed has lost quality because of the build-up of yield-debilitating diseases in their seed stock over the seasons or other conditions that favour degeneration. However, the local DMs will also have to cope with such conditions: they may do so by keeping the seed disease-free using specialized technologies such as net tunnels, pesticides and fungicides, roguing and fewer or no multiplication cycles. This, however, increases the production costs of the seed. Without a seed quality difference, the economic profitability as a motivation for farmers to buy seed from a DM falls away. As some forms of seed degeneration are relatively predictable, this can result in a relatively stable demand for healthy planting material. Nevertheless, we found hardly any information on farmers' decision making around replacing their degenerated seed with cleaner higher yielding material except for situations in which there was a secure high-paying market for their harvest as in the cases of CONPAPA in Ecuador and SASHA SuperFoods in Rwanda (see Table 1, Kromann, Montesdeoca, & Andrade-Piedra, 2016; Nshimiyimana et al., 2016).

In addition to coping with the same production conditions as their customers, local specialized seed producers also face an important social challenge. Their customers are usually neighbours, friends or relatives from the same community. This complication for a business-approach to the seed transactions is important in Africa and especially in vegetatively propagated crops that are essential for local food security. For these crops it is often considered inappropriate to pay, or ask for cash for planting material (Ngabo, 2015; Kilwinger et al., 2018; Kansiime & Mastenbroek, 2016), although experiences show that this may be partly overcome when dealing with a new variety that is not yet commonly available.

Group and community-based forms of seed multiplication have been promoted since the 1980s (Camargo, Bragantini, & Monares, 1989; Friis-Hansen, 1989; Rohrbach et al., 2002; David, 2004), but so far they have been unable to become a prominent form of decentralized seed supply (Walsh et al., 2015) and the economic sustainability is unclear (Tripp & Rohrbach, 2001; Lynam, 2011; Tripp, 2012). From this it follows that we need a better understanding of the underlying issues when setting up DMs in RTBs that involve local farmer groups (see also FAO and ICRISAT, 2015). Regular renewal with clean seed and a high variety turn-over in the DMs' portfolio seems to be a basic condition in the case of RTB crops along with a better understanding of farmers' demand for variety and other quality traits of planting material.

Finally, we need to better understand how and what kind of regulations and supporting policies can enhance the availability and access to quality planting material by farmers. Each seed system intervention, irrespective of its scale, scope and duration, touches on existing policy regimes and highlights desirable changes. Certification requirements for seed potato increase the costs of planting material for farmers to prohibitive levels, but the absence of enforcement of such schemes leaves ample space for selling low quality or contaminated planting material. Quality Declared Seed (QDS) is believed to be a more appropriate regime for the conditions in developing countries (FAO, 2010), but field evidence is scarce (Tadesse et al. in preparation). Different forms of subsidies, such as the use of vouchers (Walsh, Odero-Onyango, & Obiero, 2006) can make seed of new varieties more accessible to farmers, but questions remain about how this affects the recurrent purchasing of seed to replace degenerated planting material or what happens when the subsidies are removed.

What emerges from this study is the very real need for seed system interventions to be more aware of the existing system and context in which they are operating and to assess the potential of using traditional channels and actors for seed distribution. Surveying has been the main general method for generating data on the existing systems. A wide range of qualitative and quantitative tools and methods are available and these could help to generate more incisive reflection among actors, allowing them to reorient their interventions as appropriate. Expert consultation employing e.g. reflection frameworks (RTB 2016) or network analysis approaches (Garrett, 2018; Buddenhagen et al., 2017) offer opportunities for generating timely, socio-technically and biophysically integrated information that gives a central place to understanding famers' motivations and preferences in relation to use of planting material. Such data collection can be integrated into the monitoring and evaluation systems. Monitoring and evaluation should move away from being an obligatory filling in of log frames and be oriented to a critical reflection and learning in order to contribute to a better understanding of effects of interventions in complex systems (Jones, 2011; Arkesteijn, van Mierlo, & Leeuwis, 2015).

6 Conclusions

Two decades ago Thiele (1999) reported that none of the potato projects he had studied had published systematic information about the workings of farmer-based seed systems or the costs and benefits associated with interventions. These features are essential for any meaningful evaluation. He also wrote that, under these circumstances, adherence to one or other of the strategies had more to do with beliefs about the nature of development than with scientifically grounded theory or data. Not much seems to have changed since. Our examination of 13 distinct development interventions, involving farmer-based RTB seed systems, indicates that there were almost no systematic efforts to understand the seed system ex-ante and to use this knowledge to inform project design. The resulting interventions seemed, as a whole, not well integrated within existing seed systems and made limited use of the experiences to learn, reflect and improve their efforts to strengthen them.

We conclude as well that the use of understanding of farmer-based seed systems to re-orient ongoing, and to design future seed system interventions must be dynamic and adaptive. Some may feel strongly that supporting on-farm seed production does not contribute to highly productive agriculture, whereas others may consider that the 'advanced' mature seed system model has proved to be unfit for many farmers in developing countries. Both views can make their case, but in the meantime the world is rapidly changing. Markets and information provision are rapidly changing the lives of the poor in many different ways. Climate change, migration and urbanization will radically change smallholder farming in the future (Zimmerer, Haan, & Lupp, 2019). This suggests that seed system interventions, which did not work yesterday, may work today or tomorrow (and vice-versa). Key to progress in the improvement of the quality of planting material used by farmers is to pay attention to what works where, and for whom, and how to scale up good practices. The continued investments in seed system interventions and their relative lack of success can be traced back to our limited understanding of them, suggesting the need for a deeper knowledge of how they work in order to make such interventions more effective and to up-scale the successes. An improved understanding of farmers' motivations to use (or not use) planting material from formal sector sources is one step towards better designed interventions for the improvement of RTB crops and seed systems.

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Compliance with ethical standards

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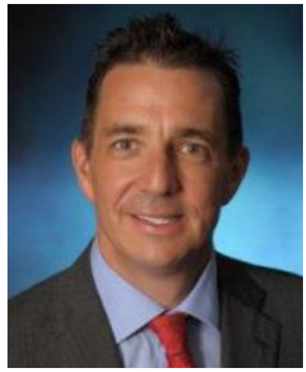

Stephen Walsh is a seed system consultant with over 20 years experience in sub-Saharan Africa, which began with designing and promoting voucher-based seed fairs as an alternative to direct seed relief distribution in South Sudan, Burundi, and the Democratic Republic of Congo. He later worked as a manager and technical advisor on Root, Tuber & Banana seed programs on several multi-country, multi-partner seed programs involving various CGIAR research centers and numerous development partners. More recently he coordinated the ISSD Ethiopia seed program focused on grain crops. He has both participated and led several seed system security assessments including those for Zambia, Mali, and Burkina Faso. He believes that to develop seed systems, which respond to the diverse needs of farmers and farming systems, we must bring together economics, physical science, and social dynamics. Stephen holds a Master’s Degree in Law and Diplomacy from the Fletcher School at Tufts University.

Kim Jacobsen holds a PhD in bio-engineering from the Catholic University (KU) Leuven. She has a background in tropical agronomy, nematology and marine biology. From 2001 to 2006, she worked for the International Institute for Tropical Agriculture (IITA), Bioversity International and the Centre African de Recherches sur Banananiers et Plantains (CARBAP) in Cameroon, where she studied small-scale banana farming systems. For the past 10 years, she has worked at the Royal Museum for Central Africa, on research archives from the Belgian Congo colonial period, with the aim of establishing baseline measurements necessary for long-term ecological and climatological research through valorization of unexplored historical data. She is also active as a freelance consultant for the CGIAR Research Program on Roots, Tubers and Bananas, contributing to the seed systems working group.

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Margaret McEwan works as a social scientist at the International Potato Center's regional office for sub-Saharan Africa based in Kenya. She has over 30 years' experience working in multi-disciplinary teams focused on rural development, farming systems research, household food security and nutrition in Kenya, Uganda, Somalia, North Sudan, Zambia and Mozambique. In research for development contexts she is concerned with how to engage multi-stakeholder partnerships in ensuring improved livelihood and nutrition outcomes, and in understanding the conditions required to up-scale technologies for greater impact. She has an MSc in Human Nutrition and is currently pursuing a PhD at Wageningen University and Research, in the Netherlands, focusing on the social-technical interactions, which influence the institutional arrangements for sustainable sweetpotato seed systems.

Stef de Haan works as a researcher with the International Centre for Tropical Agriculture (CIAT) in Vietnam. He has a particular interest in contemporary on-farm management and use of crop genetic resources with a geographical focus on the Andes and Southeast Asia. His main research focus has been on understanding the conservation and use of genetic resources under farmer management, including ongoing evolution, seed systems, geospatial patterning and nutrition. Stef currently works on cassava and also coordinates CIAT's Sustainable Food System's research in Asia. Previously he worked for the International Potato Centre (CIP) in Peru. Stef is also a member of Grupo Yanapai, a grassroots organization working on agrobiodiversity and nutrition in the central Peruvian Andes.

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Charles Staver is a cropping systems agroecologist and has been working in the banana group at Bioversity International since 2004. Previously, he worked as a weed ecologist in an IPM team based in Nicaragua through CATIE working on coffee agroforestry, food grains, plantains and vegetables. He did his Masters and Ph.D. studies at Cornell University focusing on integrated cropping systems from ecological, production and socio-economic perspectives. In recent years, he has led research projects which combine formal biological and production research with participatory technology generation. Projects include multi-strata coffee with bananas, ecological intensification of smallholder export banana in Latin America, integrated banana agroforestry with livestock in Uganda and recovery of banana production in regions affected by banana bunchy top virus in East and Central Africa. He was a founding member of the seed system working group in RTB and has conducted research and prepared training materials on farmer access to clean, low cost planting material in these and other projects.